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# VISUAL PATTERN RECOGNITION IN THE CEREBRAL HEMISPHERES: THE ROLE OF SPATIAL FILTERING

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# VISUAL PATTERN RECOGNITION IN THE CEREBRAL HEMISPHERES: THE ROLE OF SPATIAL FILTERING

by

Fred H. Previc

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the Faculty of the Graduate School at
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Approved by

M. Russell Harter
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# APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at the University of North Carolina at Greensboro.

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The differences between the left and right cerebral hemispheres in terms of visual pattern recognition were examined in the context of the spatial filtering model of visual perception. On the basis of a wide range of evidence, it was hypothesized that the right hemisphere is superior in the processing of low spatial frequency and/or high contrast information, and that this superiority may underlie its predominant role in "gestalt" perception. The left hemisphere, on the other hand, was hypothesized to be more highly involved in an analysis of high frequency and/or low contrast information contained in the visual environment.

The spatial filtering capabilities of the two hemispheres were assessed by presenting square-wave gratings to the left and right visual fields, which project almost exclusively to the primary visual cortical areas of the contralateral hemispheres. Twenty-four right-handed adult male subjects were required to discriminate two different orientations of each of six gratings varying in fundamental spatial frequency and level of contrast.

Analyses of variance revealed that discrimination performance (both in terms of latency and accuracy) was superior: a) when low as compared to high frequency gratings were presented; b) when the contrast of the gratings was in the moderate to high range; and c) during the second of two experimental replications. In addition, discrimination performance proved superior overall in the right visual field (RVF). The magnitude of the RVF latency advantage was greater in the case of the high frequency gratings, as predicted, although this trend only approached significance. The results were discussed in relation to the predictions made by the spatial filtering model, as well as those of other theories of hemispheric specialization in visual pattern recognition.

# ACKNOWLEDGMENTS

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I would like to dedicate this dissertation to my parents, whose continued support throughout my graduate years ultimately made possible its completion.

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# CHAPTER I

# INTRODUCTION

In recent decades, an enormous expansion of research aimed at achieving a better understanding of the respective functions of the left and right cerebral hemispheres in man has occurred. Based upon an extensive set of findings, several general views of hemispheric functioning have emerged. Perhaps the most widely held among these is that which maintains that the functional differences between the hemispheres may be placed along a verbal/nonverbal dimension (Kimura, 1966; Milner, 1971). According to this view, the left hemisphere in the vast majority of right-handed adults is specialized for the perception and production of language, whereas the right hemisphere is specialized for such nonverbal functions as musical perception (Kimura, 1964) and spatial manipulations (Hecaen and Albert, 1978). In support of this view, neuroanatomical differences between the hemispheres have been demonstrated in brain regions believed to be critically involved in receptive language functions (Geschwind and Levitsky, 1968).

Based upon evidence of extensive right-hemispheric linguistic capabilities (see Zaidel, 1978a), a major alternative to the above view has recently emerged. Largely promulgated by split-brain researchers such as Levy (1974), Nebes (1974) and Sperry (1974), this view maintains that the respective functions of the left and right hemispheres in normal, right-handed adults may be more adequately characterized along the analytic/gestalt dimension. Processing of sequential and highly detailed information (such as rapid phonemic transients, the internal features of the human face, etc.) is considered to be a function primarily of the left hemisphere, whereas a more global and parallel processing mode is attributed to the right hemisphere. This view suggests that functional differences between the hemispheres are both widespread and fundamental. Neuroanatomical findings which indicate that the left and right hemispheres may differ in their basic neural organizations (see Semmes, 1968) are consistent with this view.

Research in the area of visual pattern recognition has both contributed toward and been influenced by these overall views of hemispheric functioning. For example, the repeatedly demonstrated superiority exhibited by the right visual field in the discrimination of English block letters has been interpreted within the context of the general linguistic superiority of the left hemisphere (Kimura, 1966), whose primary visual cortex is the almost exclusive recipient of the right visual field's neural projections. On the other hand, the superiority of the right hemisphere in the discrimination of fragmented letters has been cited in support of the view that this hemisphere is specialized for global, or gestalt processing (Martin, 1979).

In an attempt to understand further the nature of visual pattern recognition in the cerebral hemispheres, the present dissertation study was designed to investigate an alternative to the more general views outlined above. This alternative view proposes that hemispheric differences in such visual perceptual functions as pattern and facial recognition may be accounted for by the lateralization of basic mechanisms involved in the spatial filtering of the visual environment. Before proceeding to examine the rationale for such a view, however, it is first necessary to examine critically the major paradigms which have been utilized in hemispheric specialization research, and which have contributed to current views of hemispheric functioning. A particular emphasis will be placed upon the procedures associated with tachistoscopic discrimination experiments, given the nature of the experiment included as part of this dissertation.

## The Principal Methodologies Utilized in Investigations of Hemispheric Differences in Visual Pattern Recognition

Four basic types of studies have contributed to the present understanding of the specializations of the left and right hemispheres for various aspects of visual pattern recognition: a) neuropsychological, in which clinical patients with damage to either the left or right hemispheres are employed as subjects; b) electrophysiological, in which electroencephalogram (EEG) and event-related potential (ERP) measures of left- and right-hemispheric functioning are compared; c) split-brain, in which various types of visual stimuli are presented to patients whose corpus callosums are severed; and d) tachistoscopic, in which the discrimination and detection of tachistoscopically presented visual information is measured for normal individuals. A discussion of the above approaches will follow, with an emphasis upon the special challenges which each of them faces. A methodological concern of all of these approaches -- namely, the determination of the language hemisphere -- is discussed in the METHOD chapter.

The principal advantage of the neuropsychological approach is that hemispheric differences in visual processing may be examined under conditions of prolonged viewing. As noted by Goldstein (1974), the major difficulty inherent in this approach is achieving a precise description of both the site and nature of the lesion. However, the effectiveness of traditional assessment techniques in obtaining clearly demarcated and focalized lesion sites has been substantially increased by recent advances in radiological assessment. An additional requirement of the neuropsychological approach is the avoidance of either an overt or covert verbal response on the part of the patient, since the requirement of such responses could implicate the left hemisphere even when the perceptual function in question is mediated by the right hemisphere. An alternative procedure is to employ a verbal response, but only after all patients in the left- and right-damaged populations have been shown to be capable of producing that response.

Electrophysiological measures such as the EEG and ERP represent perhaps the two most direct measures of neural functioning which have been employed in hemispheric specialization research. These measures have been employed extensively in attempting to determine the hemispheric localization of speech production and other such higher-order linguistic functions (see reviews by Donchin, Kutas and McCarthy, 1977; Marsh, 1978). To a lesser extent, the EEG and the ERP have also been employed in studies which have investigated hemispheric differences in basic visual perceptual functions. Perhaps the two most important requirements of this methodological approach are a) the choice of an appropriate electrode location, and b) the use of bilateral or at least counterbalanced visual field presentations, under conditions of controlled binocular fixation. As regards the electrode location, a site should be chosen which is capable of recording neural activity associated with the processing of a visual stimulus, such as the scalp regions overlying occipital cortex, and to a lesser extent, parietal and temporal cortex. Care must be taken in interpreting occipital recordings, however, due to the fact that the geometrical arrangement of the left and right occipital cortical surfaces may, in some instances, result in the prominent recording of volume-conducted neural activity generated by the contralateral hemisphere (Halliday, 1978). The second requirement of bilateral and/or counterbalanced visual field presentations is a consequence of the fact that ERP's generated by a particular hemisphere are greater in amplitude in response to contralateral visual field stimulation (Halliday, 1978; Jeffreys, 1977). This relationship is a result of the nearly complete decussation of the primate visual pathways, such that the left visual field projects almost exclusively to the right hemisphere, and vice versa (see Polyak, 1957).

The decussation of the primate visual pathways serves as the cornerstone of the split-brain and tachistoscopic approaches. Both of these rely upon the presumption that the presentation of stimuli to one side of the subject's fixation point insures that at least the initial processing of a stimulus will be confined to the contralateral hemisphere. In the split-brain patient, of course, the processing of all but the most basic, subcortically mediated information remains lateralized, due to the severance of the corpus callosum. In normal subjects, however, interhemispheric transmission of information occurs very early in the sequence of visual information processing. These interactions are initially confined to the central few degrees of the visual field representations in areas 17 and 18 of visual cortex, but are not believed to be of any great consequence during the course of pattern recognition (Berlucchi, 1978). It appears that the first major contribution of the ipsilateral hemisphere in the processing of patterned visual information in normals occurs in such higher-order visual association areas as inferotemporal cortex (Gross and Mishkin, 1977), which receives a substantial ipsilateral input via the splenium of the corpus callosum.

In order for any performance differences between the left and right visual fields to be validly ascribed to functional differences between the hemispheres, the use of the <u>split-brain</u> and <u>tachistoscopic</u> paradigms requires that the following methodological criteria be met: a) sufficiently lateralized visual presentations; b) controlled ocular fixation; c) binocular viewing; and d) counterbalanced responses.

The first requirement must be met because of the incomplete decussation of the visual pathways. Anatomical studies of the monkey (Stone, Leicester and Sherman, 1973) and human (Kupfer, 1963) have revealed that the overlap of retinal projections from the left and right hemifields is on the order of one or two degrees at most (i.e., one degree into each visual field). Thus, it may be presumed with considerable confidence that the presentation of visual stimuli one degree laterally into each visual field should result in virtually complete functional decussation.

Even if lateralization of a degree or more should insure initial segregation of visual input to the left and right hemispheres, however, the interhemispheric transfer of information may occur so rapidly as to prevent any hemispheric processing differences from being manifested. This problem may be reduced by the choice of an appropriate, temporally constrained discrimination task which taps into primary visual cortical processing.

Lateralized stimulus presentations cannot be guaranteed for any of the above approaches, of course, unless the second requirement of controlled ocular fixation is met. Controlled ocular fixation requires that the subject′s fixation prior to the presentation of a stimulus is centered directly on the vertical meridian, and that no deviation occurs subsequent to the stimulus presentation. In most studies, control over the subject′s fixation during visual discrimination and detection tasks is achieved by means of a) brief, tachistoscopic stimulus durations (150 msec or less), and b) randomized presentation of stimuli across the left and right visual fields. The use of a brief stimulus duration insures that a saccade initiated by the onset of a stimulus will not bias the processing of that stimulus, since approximately 150-200 msec are required for the initiation of a saccade (Saslow, 1967). The purpose of randomizing stimulus presentations across visual fields is to discourage subjects from fixating upon an area in one visual field or the other prior to the presentation of the stimulus. It is conceivable that the subject may desire to bias his or her fixation in the direction of the visual field in which performance is poorest -- presumably, that field which projects to the hemisphere less specialized for the processing of the relevant information. The ultimate result of such a tendency, however, would be to reduce the probability of finding significant differences between performance levels in the two visual fields.

The requirement of binocular viewing insures that any visual field performance differences may not be attributed to differential processing by the nasal and temporal portions of the retina. During monocular viewing, for instance, the contralateral hemisphere receives virtually all of its information from the nasal retina, whereas the temporal retina projects almost exclusively to the ipsilateral hemisphere. Recent studies which have revealed differences between the nasal and temporal retinae in terms of Landolt-C acuity (Markowitz and Weitzman, 1969) and contrast sensitivity (Rovamu and Virsu, 1979) demonstrate the seriousness of this confound. Even under binocular viewing conditions, the naso-temporal differences could conceivably represent a confound if only one eye is instrumental in contolling fixation. Little, if any, relationship between eye dominance (i.e., which eye controls fixation) and hemispheric differences in visual perception has heretofore been demonstrated, however (Bryden, 1965; Kimura, 1966).

The final requirement of a counterbalanced response is necessary in tachistoscopic discrimination experiments because of the superiority (in terms of response latency) of the ipsilateral stimulus-response pathway. While estimates of the ipsilateral advantage vary to some extent (see Swanson, Ledlow and Kinsbourne, 1978), most research suggests a three or four millisecond advantage for the ipsilateral pathway. The ipsilateral superiority is a direct consequence of the predominance of the contralateral hemisphere in the control of pyramidal motor responses. This control, in conjunction with the contralateral projections of the visual system, results in a situation wherein information presented to one visual field is projected to the same hemisphere as exercises predominant control over the ipsilateral hand, so as to avoid the callosal transmission delay. It should be emphasized that the use of a verbal response, which is mediated exclusively by the left hemisphere, does not meet the counterbalanced response requirement.

Fulfillment of the above methodological requirements eliminates or reduces most of the serious challenges to the view that differences in left and right visual field discrimination performance validly reflect differences between the cerebral hemispheres. It must be noted, however, that at least two challenges to the above view are not related to controllable methodological parameters. The first of these dissident views argues that reading tendencies across various cultures constitute an important influence upon visual field differences in tachistoscopic discrimination performance. The second view suggests that lateralized asymmetries in attention or activation, as opposed to processing per se, may account for performance differences between the left and right visual fields.

The view that differences between the discrimination performances of the left and right visual fields might be related to reading tendencies across cultures developed from early research by Mishkin and Forgays (1952). These researchers demonstrated that subjects who were bilingual in Hebrew and English exhibited a right visual field (RVF) superiority in the recognition of English words, but a left visual field (LVF) advantage in the recognition of Hebrew words. Mishkin and Forgays (1952) attributed this difference to the opposite reading directions (left/right for English, right/left for Hebrew) for the two languages.

Subsequent research has challenged this view, however. First, the slight LVF superiority shown by Mishkin and Forgays′ subjects for the recognition of Hebrew words has been replicated in studies by Orbach (1952,1967) only for left-handed subjects who had learned Hebrew first. In addition, Barton, Goodglass and Shai (1965) demonstrated that a vertical (as opposed to horizontal) alignment of Hebrew words reversed the LVF recognition advantage. Secondly, RVF superiorities in recognizing and discriminating verbal materials have been demonstrated for both Chinese (Kershner and Jeng, 1972) and Japanese (Hirata and Osaka, 1967) subjects, whose reading directions differ from that of English readers. It may be concluded, therefore, that the influence of reading tendency upon word recognition in the two visual fields is slight at best. As regards the perception of letters and various geometric forms, there is virtually no evidence linking reading tendencies with visual field performance differences.

The second major alternative to the view that visual field performance differences reflect hemispheric processing differences has been put forth by Kinsbourne (1970,1973). Kinsbourne suggests that lateralized cerebral activation, rather than hemispheric processing differences per se, is responsible for visual field performance differences. According to Kinsbourne, activation of the left hemisphere occurs whenever a subject is required to perform a linguistic processing task. The activation of the left hemisphere, in turn, serves to direct eye movements toward, and/or decrease reaction-time latencies in, the right visual field. Thus, RVF superiorities would be expected whenever the subject is engaged in tasks requiring the discrimination of verbal materials.

While most researchers concede the existence of lateralized cerebral activation, it remains doubtful whether such patterns may account for the majority of demonstrated visual field differences in tachistoscopic research. First, the behavioral effects of lateralized activation are slight (Moscovitch, 1979), even when a highly demanding verbal reasoning task is required on the part of the subject. Second, even when subjects are required to perform verbal and nonverbal discrimination tasks concurrently (so as to activate both hemispheres, presumably), the visual field performance differences still occur as a function of the type of information presented to the subject (Berlucchi, Brizzolara, Marzi, Rizzolatti and Umilta, 1974). Third, visual field superiorities have repeatedly been shown to reverse direction when only a subtle change in the nature of the stimulus, such as fragmentation, is made. It is difficult to conceive of shifts in cerebral activation accompanying such a subtle stimulus change. A more fundamental concern, finally, involves the logical sufficiency of this hypothesis, given that the existence of lateralized activation must inevitably depend upon the specialization of the left and right hemispheres for different types of processing (see Kimura and Durnford, 1974).

In conclusion, then, it would appear that neither the reading tendency nor the cerebral activation hypotheses represent serious challenges to the view that visual field performance differences in the discrimination and detection of tachistoscopically presented stimuli such as letters, faces and geometric designs reflect the differential capabilities of the left and right hemispheres for the processing of such stimuli. This conclusion is further buttressed by the important influence of cerebral dominance upon visual field performance differences (Bryden, 1965; Zurif and Bryden, 1969).

In the remainder of this chapter, representative findings from the four literatures concerning hemispheric differences in the processing of various visual patterns will be presented. Except as noted, only the findings of those studies which have attempted to meet the above methodological requirements will be cited. The differences between the left and right hemispheres in various aspects of pattern recognition will then be discussed in relationship to the spatial filtering model of visual perception (Ginsburg, 1978). This discussion will serve to establish the rationale for investigating the possibility of hemispheric specialization in basic processing mechanisms.

## Hemispheric Differences in the Processing of Visual Patterns

In an influential review, White (1972) summarized much of the previous tachistoscopic and neuropsychological literatures dealing with the issue of hemispheric differences in the processing of various types of visual forms. This review will extend beyond that of White (1972) so as to include a treatment of hemispheric differences in facial perception, and a review and discussion of findings which indicate that figural fragmentation may be a crucial variable in distinguishing between the processing modes of the left and right hemispheres.

In the case of letter recognition and discrimination, the finding of the vast majority of tachistoscopic studies both prior and subsequent to White's 1972 review is that these processes are carried out more proficiently in the right visual field. Included within the voluminous set of studies which has demonstrated an RVF reaction-time (RT) or detection advantage are those by Arndt and Berger (1978), Berlucchi, Brizzolara, Marzi, Rizzolatti and Umilta (1974), Broman (1979), Bryden (1965,1966), Bryden and Rainey (1963)[Note 1], Heron (1957)[Note 1], Kimura (1966), Rizzolatti, Umilta and Berlucchi (1971), Simion, Bagnara, Bisiacchi, Roncato and Umilta (1980), and Zurif and Bryden (1969). An RVF advantage has also been reported for digits (Geffen, Bradshaw and Wallace, 1971) and inverted letters (Bryden, 1966). A few studies, however, have failed to replicate the general finding of an RVF superiority in letter recognition. These include instances of both name-matching (Davis and Schmit, 1973; Hellige and Webster, 1981; Wilkens and Stewart, 1974) and physical-matching (Davis and Schmit, 1973; Geffen, Bradshaw and Nettleton, 1972; Ledlow, Swanson and Kinsbourne, 1978) of letter pairs.

An examination of the few studies within the other paradigms which have investigated hemispheric differences in letter processing reveals a less clearcut situation, however. Although split-brain studies which have employed chimeric words (in which half of one word is presented to the left visual field, and half of a different word is presented to the right) have indicated that the left hemisphere may be superior in the processing of individual letters in a word (see Levy, 1974[Note 2]), Kimura (1963)[Note 1] failed to disclose any differences in the letter recognition capabilities of patients with either left or right temporal lobe damage. Thatcher (1977) and Poon, Thompson and Marsh (1976) have revealed differences between left and right temporal lobe ERP′s to English letter presentations, but the amplitude of left-hemispheric responses was not always greater than that of right-hemispheric responses. Similarly, Ledlow, Swanson and Kinsbourne (1978) demonstrated that the amplitude of a late positive component of the ERP (P300) was greater over the occipital-parietal region of the right hemisphere during both name-matching and physical-matching of letter pairs. Shelburne (1972), meanwhile, found no differences between left and right parietal ERP′s in response to English letter presentations.

All of the stimuli employed in the above investigations were comprised of <u>unbroken line segments</u>. By contrast, the few studies which have investigated the processing of fragmented letters (i.e., letters comprised of broken contours) have demonstrated that the right hemisphere may be superior in this function. Martin (1979)[Note 3], for instance, showed that the discrimination of fragmented letters whose individual fragments are also letter forms is more rapidly achieved in the left visual field. Similarly, a greater impairment in the recognition of fragmented letters following right, as opposed to left, posterior damage was demonstrated by Warrington and James (1967a).

Subsequent to White's 1972 review, a right-hemispheric superiority has also been convincingly demonstrated in the area of facial perception. Included among the tachistoscopic studies in which an LVF advantage has been evidenced are those by Berlucchi, Brizzolara, Marzi, Rizzolatti and Umilta (1974), Broman (1979), Ellis and Shepherd (1975), Geffen, Bradshaw and Wallace (1971), Klein, Moscovitch and Vigna (1976), McQReynolds and Jeeves (1978), Moscovitch, Scullion and Christie (1976)[Note 4], Rizzolatti and Buchtel (1977), and Rizzolatti, Umilta and Berlucchi (1971). A comparable number of neuropsychological studies have likewise revealed greater impairments in facial recognition following right, as opposed to left, posterior cortical damage (Benton and Van Allen, 1968[Note 1]; DeRenzi, Faglioni and Spinnler, 1968[Note 1]; Milner, 1968; Warrington and James, 1967b; Yin, 1970[Note 1]). Finally, a study which investigated facial perception in split-brain patients who were presented with chimeric faces revealed that faces presented in the left visual field are more frequently recognized in competition with those presented in the right visual field (Levy, Trevarthen and Sperry, 1972)[Note 2].

The right hemisphere may not be superior in all aspects of facial perception, however. The findings of studies involving normals (Patterson and Bradshaw, 1975), split-brain patients (Levy et al., 1972)[Note 2], and other types of clinical patients (DeRenzi and Spinnler, 1966a) suggest that the left hemisphere may be more prominently engaged in a serial processing of the internal features of the face, such as the eyes, nose and mouth. This finding could serve to explain why the left hemisphere is more highly involved in the processing of familiar, as opposed to unfamiliar faces (Marzi, Brizzolara, Rizzolatti, Umilta and Berlucchi, 1974; Umilta, Brizzolara, Tabossi and Fairweather, 1978), since the recognition of familiar faces is more dependent upon the processing of the internal facial features (Ellis, Shepherd and Davies, 1979).

The final types of forms which will be examined in this section may be broadly categorized as nonverbal in nature. Included among these are a) dot patterns; b) various random, geometric, and block designs; and c) fragmented and completed pictures of common objects. White (1972) pointed out a number of conflicts in the literature prior to his review which precluded any general statement from being made concerning hemispheric differences in the processing of such forms. The evidence to be reviewed below will contradict the position taken by White in 1972, at least as regards the processing of fragmented forms.

Research during the past decade has revealed that one of the functions which may most definitively be linked to the right hemisphere is the processing of fragmented forms, dot patterns, and other forms requiring perceptual "closure" (Zaidel, 1978b). In the case of fragmented forms, the neuropsychological evidence appears particularly convincing. For a wide variety of fragmented forms, right-hemispheric lesions have resulted in greater recognition deficits than their left-hemispheric counterparts (DeRenzi and Spinnler, 1966b[Note 1]; Lansdell, 1968,1970; Meier and French, 1965[Note 1]; Newcombe, 1974[Note 1]; Warrington and James, 1967a). The evidence from numerous split-brain studies, as reviewed by Nebes (1974), also provides strong support for a predominant right-hemispheric role in the perception of fragmented figures. Unfortunately, little or no evidence from the other literatures bearing upon this issue has heretofore been obtained. However, the ability to perceive tachistoscopically presented Julesz random-dot stereograms (which, when fused, form an image comprised of broken contours), is superior in the left visual field (Kimura and Durnford, 1974).

A limited amount of evidence also suggests a predominant right-hemispheric role in the perceptual grouping of dots. Normal subjects, for instance, exhibit an LVF superiority in the reproduction of forms comprised of dots (McKeever and Huling, 1970), while a similar LVF superiority has been demonstrated for split-brain patients in the perception of oriented rows of dots in the classic Wertheimer figure (Nebes, 1971). These findings are consistent with the well-established finding of a left-hand (right-hemispheric) superiority in the reading of braille letters (Harris, Wagner and Wilkinson, 1976; Hermelin and O'Connor, 1971).

Although the evidence cited above suggests a greater degree of cerebral lateralization in nonverbal form recognition than acknowledged by White (1972), his position may still hold true for the processing of forms comprised of unbroken line segments. Of the six tachistoscopic investigations of nonfragmented form perception in normals which White reviewed (Bryden, 1960,1964[Note 5]; Bryden and Rainey, 1963[Note 1]; Heron, 1957[Note 1]; Kimura, 1966; Terrace, 1959[Note 1]), none revealed a visual field advantage in either direction. Since then, an additional number of tachistoscopic studies have yielded either no visual field differences, or conflicting ones. These include studies by Fontenot (1973), Hannay, Rogers and Durant (1976), Kimura and Durnford (1974), and Umilta, Bagnara and Simion (1978). Two sets of findings are particularly noteworthy, since they were generated by the same group of researchers. Umilta, Bagnara and Simion (1978) demonstrated an RVF RT advantage for the processing of simple geometric forms such as circles, squares and triangles, whereas Simion, Bagnara and Umilta (1980) subsequently demonstrated an LVF RT advantage for virtually identical figures. Even more perplexing is the finding of Umilta, Bagnara and Simion (1978) of two virtually identical sets of complex polygons which yielded opposite visual field advantages, even when the same group of subjects was employed.

The neuropsychological literature likewise suggests that the processing of nonfragmented forms may not be highly lateralized. The majority of such studies (DeRenzi and Spinnler, 1966b[Note 1]; Warrington and James, 1967a; Yin, 1970[Note 1]) have reported no significant differences between left- and right-damaged patients in the processing of these forms, although Kimura (1963) did report greater deficits in the recognition of certain nonfragmented forms following damage to the right temporal lobe. The conclusion that nonfragmented form perception is not highly lateralized is further buttressed by the findings of split-brain researchers (see Levy, 1974[Note 1]; Nebes, 1974).

Based upon the evidence cited above, the vast literatures regarding hemispheric differences in visual form perception may be summarized in the following manner. The left hemisphere may be viewed as more important in the perception of nonfragmented letters and the internal features of the face. By contrast, the right hemisphere appears to be more heavily implicated in the perception of the overall facial form, as well as figures comprised of broken contours or dots. As regards the processing of nonfragmented, nonlinguistic forms, no consistent lateralization has been demonstrated.

Various explanations have been put forth to account for the findings outlined above. The three which will be considered here relate to a) the verbal/nonverbal processing distinction; b) the analytic/gestalt processing distinction; and c) the concept of perceptual complexity.

The view that differences between the left and right hemispheres in visual form perception may be best understood in terms of a verbal/nonverbal distinction has been outlined most forcefully by Kimura (1966) and Milner (1971). This view rather easily accounts for the left-hemispheric superiority in letter perception and the right-hemispheric involvement in facial perception. The inconsistent findings regarding the lateralization of various forms which are not directly linguistic in nature pose more of a problem, although proponents of the verbal distinction have put forth the following explanation. Nonlinguistic forms whose processing is subject to verbal mediation (such as familiar faces, simple geometric forms, and pictures of common objects) will to a greater extent involve the left hemisphere than will those forms which do not lend themselves as readily to verbal mediation (Kimura, 1966).

There are several difficulties associated with the above view, however. First, the evidence concerning fragmented form perception suggests that forms both directly and indirectly linguistic in nature will, when fragmented, be processed more effectively by the right hemisphere. Conversely, the processing of various types of clearly nonlinguistic information, such as nonfragmented nonsense forms, appears to be mediated in part by the left hemisphere. Second, the extent to which the process of verbal mediation could influence tachistoscopic discrimination performance is probably slight (see Umilta et al., 1978a), in part because of the rapidity with which the subject's discriminative response is usually made.

These and other difficulties associated with the <u>verbal/nonverbal</u> hypothesis have led other researchers to the view that hemispheric differences in visual form perception may be best characterized in terms of analytic versus gestalt processing (Levy, 1974; Martin, 1979; Nebes, 1974; Sperry, 1974). According to this view, the details of a form are processed more effectively by the left hemisphere, whereas the global aspect is perceived more easily by the right hemisphere. This alternative explanation can account more readily for the fact that fragmented figures, dot patterns, the overall facial configuration, and other forms requiring gestalt perceptual capabilities exhibit greater right-hemispheric involvement. It may also account for the left-hemispheric superiority in the processing of stimuli requiring a detailed feature analysis, such as letters, digits, internal facial features, and other such highly angulated forms.

Perhaps the most serious reservation which may be held against the analytic/gestalt hypothesis is that no specific processing mechanisms or operations are implied. A number of different perceptual operations may, for example, underlie what is traditonally referred to as gestalt perception. Included among these are such functions as spatial memory, extended visual scanning, figure-ground separation, etc., most of which have been localized to the right hemisphere (see Hecaen and Albert, 1978). An attempt to specify more clearly the processing differences between the left and right hemispheres in this regard has recently been made by Zaidel (1978b), who argues that the left hemisphere may be superior in the processing of "embedded" figures (such as the internal facial features), whereas the right hemisphere is more proficient at perceiving figures which require "closure" (i.e., fragmented forms). Unfortunately, this distinction has received virtually no empirical test, and is of uncertain relevance to figures which do not fit into one of these categories (e.g., nonfragmented letters).

A final explanation put forth to account for hemispheric differences in visual form perception focuses upon the role of perceptual complexity (Fontenot, 1973; Warrington and James, 1967a). According to this account, stimuli of greater complexity (such as faces and fragmented forms) will be processed to a larger extent by the right hemisphere than will forms of lesser complexity, such as digits, letters, and other simple, nonfragmented forms. Unfortunately, this hypothesis suffers from some of the same reservations associated with the others, particularly in translating the concept of "perceptual complexity" into more specific terms. If defined in terms of the number of contours, for instance, then it cannot account for the inconsistent findings concerning the lateralization of both simple and complex polygons (Umilta et al., 1978). If, on the other hand, it is defined as "perceptual difficulty", then it is unable to account for those instances in which a decreased LVF advantage has been associated with the more difficult of two tasks (Martin, 1979).

In conclusion, all of the above explanations of hemispheric differences in visual form perception may be regarded as somewhat unsatisfactory, if only for their failure to postulate specific processing differences between the hemispheres. In contrast to these accounts, it is the view of this author that the most fruitful approach to the understanding of hemispheric differences in visual form perception involves the investigation of basic mechanisms involved in the spatial filtering of the visual environment. The rationale for this view will be provided in the remaining sections of this chapter.

## Spatial Filtering and Visual Perception

The view that hemispheric differences in form perception may be a consequence of the lateralization of basic visual mechanisms is not a novel one (see Davidoff, 1977; White, 1971). The uniqueness of the view espoused here, however, lies in the specific visual process which is proposed to account directly for the hemispheric differences in visual form perception outlined in the preceding pages. In this section, the basic tenets of the spatial filtering, or Fourier model of pattern recognition will be outlined, with an emphasis placed upon the role of spatial frequency and contrast in the perception of those forms for which a clear cerebral lateralization has been demonstrated. This discussion will provide the basis for a set of specific predictions concerning the lateralization of spatial frequency and contrast perception.

The role of spatial frequency. Just as the propagation of a soundwave through the air occurs at a characteristic temporal frequency (expressed in cycles per second, or Hz), so does a sine-wave grating periodically varying in intensity have a characteristic spatial frequency (expressed in cycles per degree of visual arc, or c/d). This is illustrated in Figure 1. As with most types of auditory information, the information contained in a visual image is typically comprised of multiple periodicities, or spatial frequencies. A square-wave grating, for instance, can be constructed from a series of sine-wave gratings bearing a particular harmonic relationship to one another (Figure 2), as first demonstrated by the mathematician Fourier. As is clearly evident, the presence of the higher harmonic frequencies (especially the third) is critical for the perception of the edges of the individual bars comprising the grating.

Although Helmholtz (1954) and others suggested over one hundred years ago that the human auditory system performs a Fourier analysis of incoming auditory information, it was not until 1968 that the first clear suggestion arose that the human visual system may perform a similar form of spatial analysis. From a seminal proposal of Campbell and Robson (1968) emerged the belief that independent spatial frequency "channels", comprised of neurons and/or aggregates of neurons selectively responsive to particular spatial frequencies, operate in conjunction with one another to filter the visual environment into various frequency domains. Numerous experimental studies have since demonstrated the existence of spatial frequency channels in the visual systems of humans and other species (Blakemore and Campbell, 1969;

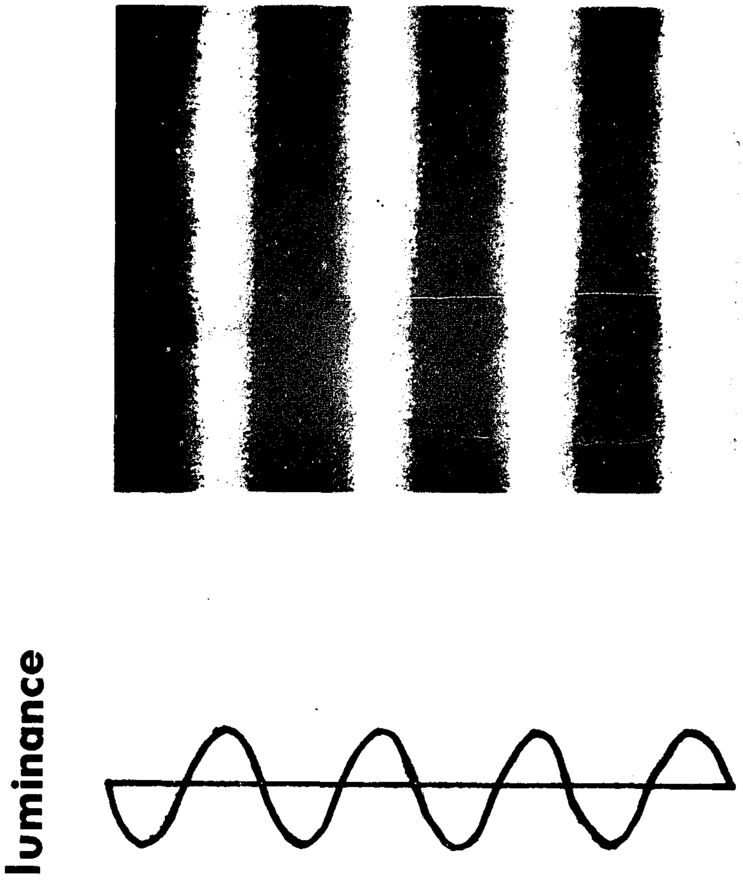

Figure 1. An illustration of a sine-wave grating and its corresponding luminance distribution.

Assuming a viewing distance such that one degree of visual arc is portrayed, then the above sine-wave grating would have a fundamental of 4 c/d. (From Campbell and Maffei, 1976, with permission from F.W. Campbell).

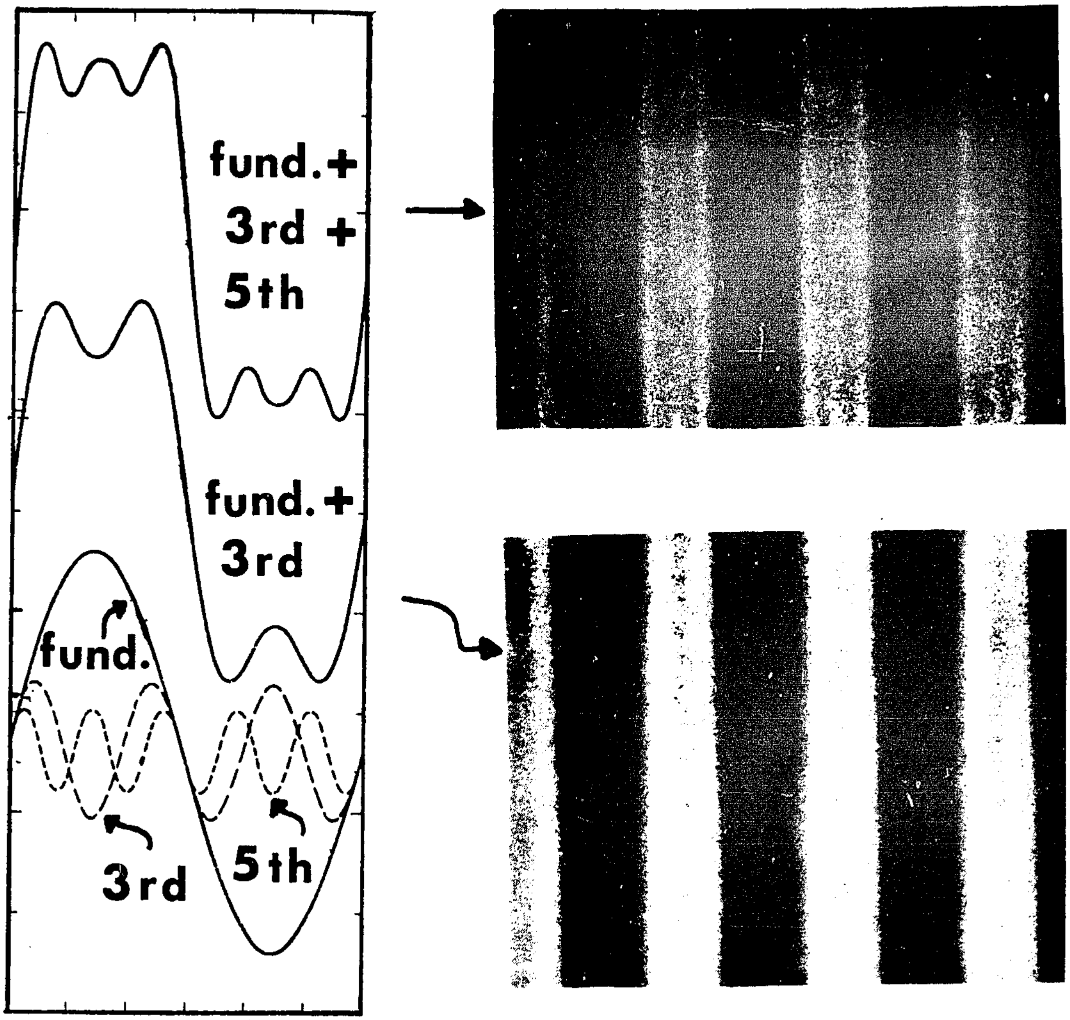

Figure 2. The transformation of a sine-wave grating into a square-wave grating.

The sine-wave grating portrayed in Figure 1 gradually becomes transformed with the addition of its third and fifth harmonics. (From Campbell and Maffei, 1976, with permission from F.W. Campbell).

Blakemore, Nachmias and Sutton, 1970; Braddick, Campbell and Atkinson, 1978; Campbell and Maffei, 1970; Harter, Towle and Musso, 1976), and the best characterization of neurons in primary visual cortical areas in the cat and primate appears to be that of "spatial frequency detectors" (Albrecht, DeValois and Thorell, 1979). Needless to say, many prominent vision researchers have recently found it extremely useful to describe the recognition of visual patterns within the framework of the spatial filtering concept (see reviews by Braddick et al., 1978; Campbell, 1974; DeValois and DeValois, 1980; Weisstein and Harris, 1980).

Before proceeding to a discussion of the role of spatial frequency in visual pattern recognition, it is first necessary to discuss the two-dimensional Fourier transform. Unlike a sine-wave grating, whose luminance variations have a periodicity lying along a single axis, most visual patterns are comprised of luminance variations along both the vertical and horizontal axes. The two-dimensional Fourier transform permits one, therefore, to establish the Fourier spectral characteristics of more complex patterns. Since researchers may subject these transforms to a variety of experimental manipulations by reducing the amplitude of selected spatial frequency components to zero, the importance of individual frequency components to the recognition of the overall visual pattern may be assessed (see Ginsburg, 1978). One relatively easy procedure for reducing the amplitude of high frequency components to zero is the progressive blurring of a stimulus, which impairs the ability of the human visual system to resolve high frequency information (Loomis, 1981).

Using such techniques, researchers have generally concluded that it is the low frequency information which is critical to the perception of most visual forms (see DeValois and DeValois, 1978; Ginsburg, 1978). It appears that whereas the details of a form are mediated by the high spatial frequency channels, low frequency information is critical to the perception of the overall form. In the case of faces, for example (see Figure 3), the loss of moderate to high frequency (i.e., greater than 4.0 c/d) components renders the internal facial features barely discernible, while perception of the overall form remains good (Harmon, 1976; Ginsburg, 1979; Tieger and Ganz, 1979).

In the case of fragmented forms, including letters, the importance of low spatial frequency information is perhaps even greater, since the high frequency edge information actually disrupts the perception of the overall form. Thus, fragmented English letters (Kabrisky, Tallman, Day and Radoy, 1970) and braille letters (Loomis, 1981) are recognized with considerable accuracy when subjected to low-pass optical filtering. Similarly, the perception of fragmented forms such as the Kanizsa triangle is largely dependent upon the information contained in the low spatial frequencies (Ginsburg, 1975). Finally, the perceptual grouping of rows of dots in the Wertheimer figure is easily accounted for by the fact that the low spatial frequency information is actually oriented in the direction of the perceived rows (Ginsburg, 1978).

The perception of certain types of forms, however, has been shown to be more dependent upon information contained in the higher spatial frequencies. The role of the higher periodicities in the perception of the internal facial features has already been noted. In addition, Coffin (1978) demonstrated that the inclusion of progressively higher frequency components into a low-passed Fourier spectrum considerably improves the discriminability of nonfragmented letters, although the

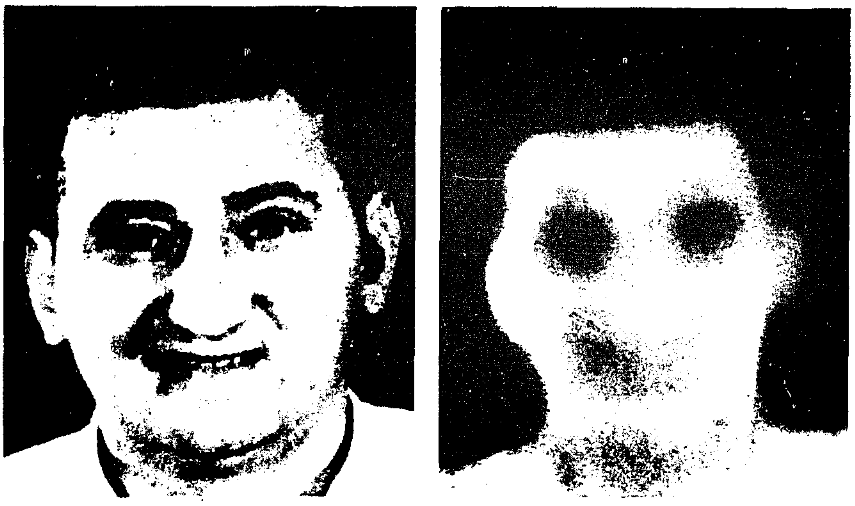

Figure 3. A comparison of the high and low frequency information in the human face.

Following the removal of high frequency components via computer averaging (right), the internal facial features are no longer discernible. (From Harmon, 1976, with the author's permission).

importance of high frequency information has been shown to vary depending upon the type of letter employed (Howland, Ginsburg and Campbell, 1978). A similar high frequency contribution may be presumed in the processing of other types of highly contoured forms, such as digits.

On the basis of the evidence presented in this section, then, it may be concluded that a) the perception of English letters, internal facial features, and similar types of highly detailed forms benefits from the presence of high spatial frequency information, whereas b) the perception of fragmented figures, dot patterns, and the overall facial form is more dependent upon the contribution of information contained in the low spatial frequencies. As may be noted, the above categorization almost precisely parallels that drawn earlier as to the respective functions of the left and right hemispheres. One logical hypothesis based upon the above evidence, then, is that the left hemisphere is superior in the processing of high spatial frequency information, whereas the right hemisphere is specialized for the processing of low frequency information.

It may be noted that the human visual system appears to possess a greater high spatial frequency sensitivity than not only such species as the cat, but other primates as well (see Towle, 1976). It is tempting to speculate, therefore, that the evolutionary pressures which promoted the increased high frequency resolution capabilities of the human visual system may have also led to their isolation in a single hemisphere.

_The role of contrast_. Another critical variable which influences the perception of a visual pattern is its contrast. "Contrast" refers to the percentage luminance difference between the light and dark regions of a form, and the reciprocal of the threshold for perceiving contrast is referred to as "contrast sensitivity". As illustrated in Figure 4, the contrast sensitivity of the human visual system is greatest for a medium range of spatial frequencies (approximately 2.0 - 6.0 c/d).

Just as a form may be associated with an overall level of contrast, so may each of its component frequencies be assigned a contrast value. However, the interaction between spatial frequency and contrast is complex, and varies depending upon the form in question. Clearly, the contrast of a fragmented form against its background is less than that of its individual fragments, given that the former averages across both fragments and neighboring spaces. In this case, then, the low frequency components which contribute to the perception of the overall form are of a lower contrast value than certain higher frequency components. This is not true in facial and object perception, however, as shown in Figure 5. In these instances, maximum contrast is present for spatial frequencies in the low to moderate range. A similar relationship may be presumed for block letters (see Howland et al., 1978).

In general, then, the high frequency information components of various forms are of lower contrast than are the low frequency components. A second hypothesis based upon the spatial filtering model of visual perception, therefore, would hold that a) the left hemisphere is superior in processing low contrast information, due perhaps to an overall greater contrast sensitivity, whereas b) the right hemisphere is superior in processing high contrast information. This hypothesis would have difficulty in explaining only one finding -- the right-hemispheric superiority in the perception of fragmented forms, whose critical low

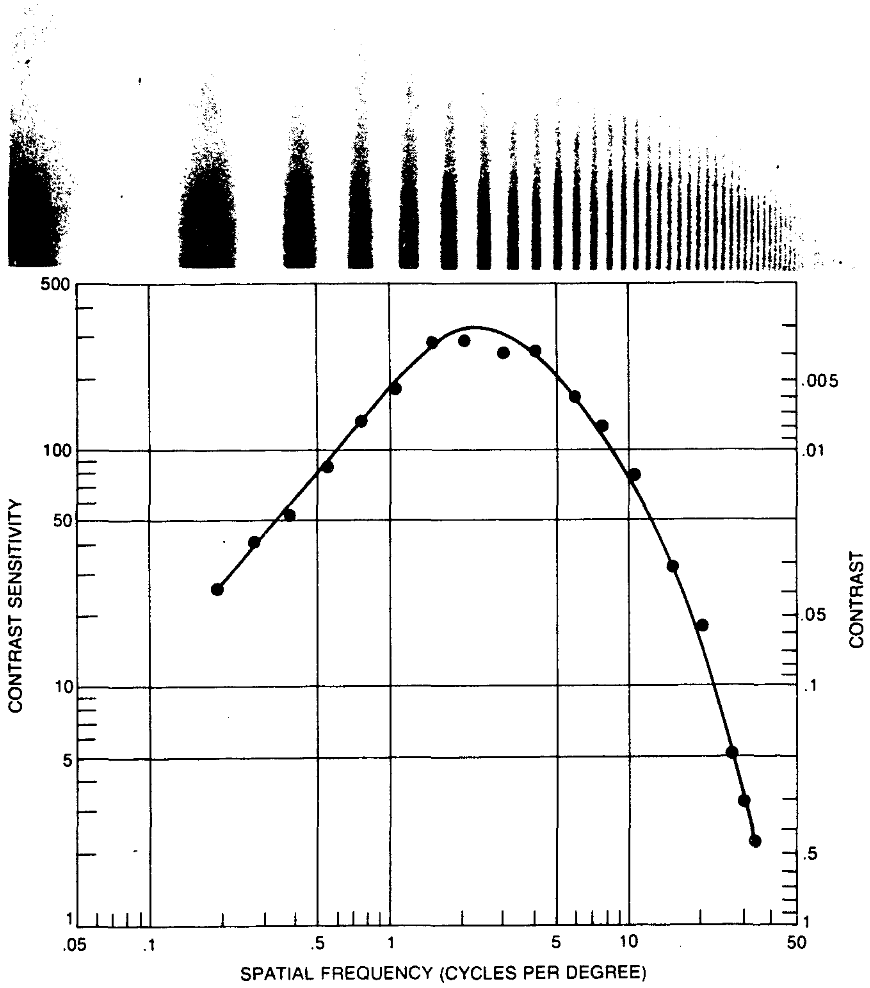

Figure 4. Human contrast sensitivity as a function of spatial frequency.

Contrast sensitivity across various spatial frequencies is illustrated above (from Ratliff, 1976, with permission from J.M. Enoch) and graphed below (from "Contrast and Spatial Frequency" by Fergus W. Campbell and Lamberto Maffei. Copyright @ 1974 by Scientific American, Inc. All rights reserved).

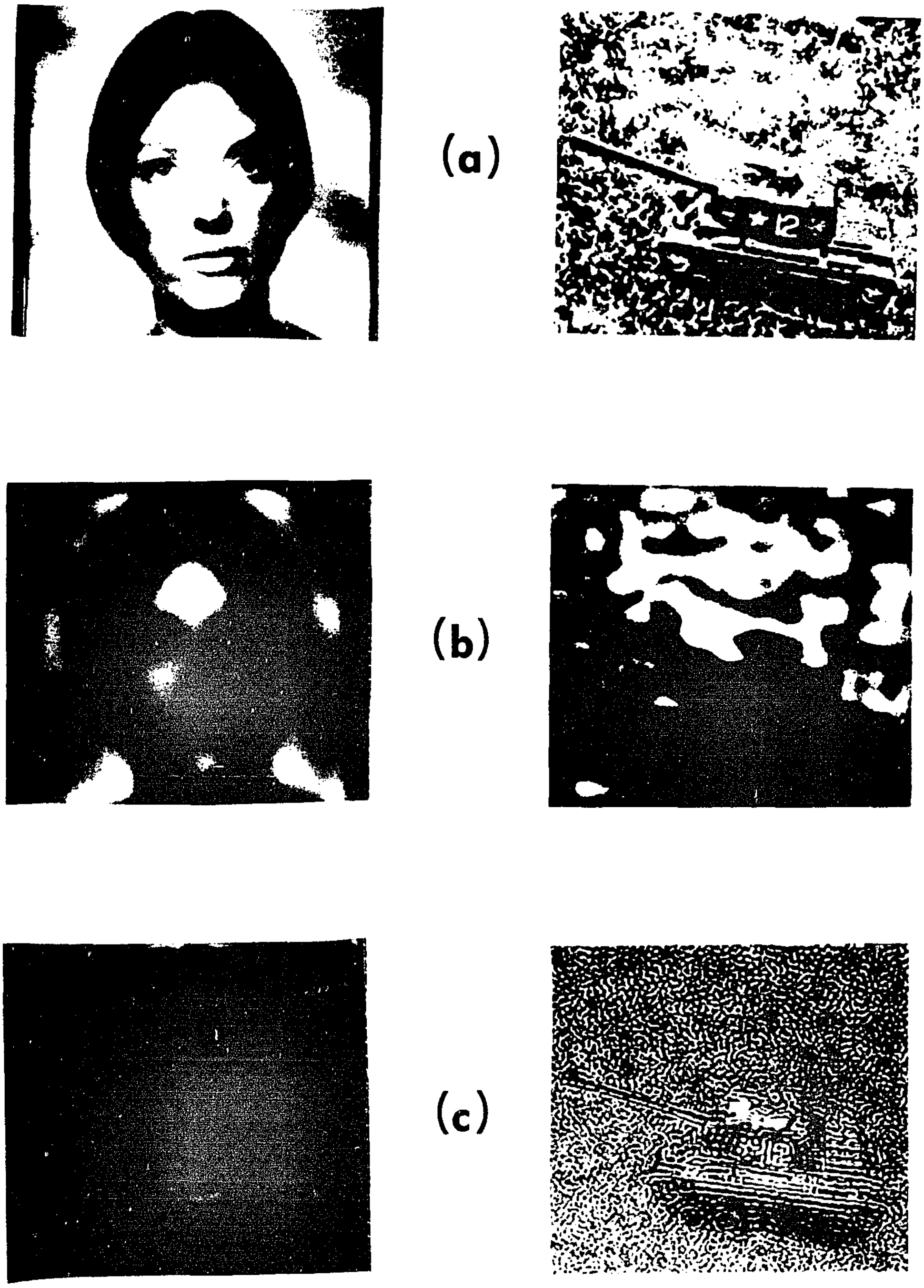

Figure 5. Spatial filtered images of a human face and a common object.

The original images (a) are either low-frequency passed (b) or high-frequency passed (c). (Left portion from Ginsburg, 1978, with author's permission; right portion from Braddick et al., 1978, with permission from Springer-Verlag Publishing Company).

frequency components are not only of a low to moderate contrast, but are lower in contrast than certain of its high frequency components.

Conclusions. Based upon a spatial filtering model of visual perception, then, the following hypotheses may logically be derived in order to explain the specialization of the left and right hemispheres in the perception of visual forms. The first states that the left hemisphere is a high frequency filter responsible for processing the detailed contour information contained in a figure, whereas the right hemisphere may serve as a low frequency analyzer more prominently involved in the perception of the overall aspects of a form. This hypothesis, which will be termed the spatial frequency hypothesis, makes no reference to contrast, and is the only one consistent with all of the data cited in the preceding section. The second hypothesis states that the left and right hemispheres are specialized, respectively, for the processing of low and high contrast information, regardless of spatial frequency. This hypothesis will be termed the contrast hypothesis, and has difficulty explaining only the right-hemispheric superiority in fragmented form perception. Based upon an interaction of the proposed influences of spatial frequency and contrast, a final set of hypotheses would be that a) the left hemisphere is specialized for processing a unique combination of high frequency and low contrast information, and b) the right hemisphere is specialized for processing a unique combination of low frequency and high contrast information. These hypotheses will be termed the interactional hypotheses. Collectively, they would have difficulty only in accounting for the LVF advantage in the processing of fragmented forms, whose low frequency components are of low contrast.

## Evidence Concerning the Lateralization of Spatial Frequency and Contrast Perception

In this section, the limited amount of direct evidence bearing upon the three hypotheses presented in the preceding section will be examined. Only two studies are clearly relevant in this regard: a study by Rao, Rourke and Whitman (1981) which examined contrast sensitivity differences between the left and right visual fields, and a study by Davidoff (1977) which examined the effects of changes in supra-threshold contrast level upon visual field differences in tachistoscopic dot detection.

In measuring contrast sensitivity for spatial frequencies in the low to moderate range (4.0 c/d or less), Rao, Rourke and Whitman required subjects to detect the presence or absence of a nonuniform field. Contrast sensitivity proved greater in the left visual field at the lowest temporal modulation rates, whereas the reverse occurred at modulation rates above 2 Hz, a finding which Rao and colleagues attributed to the greater temporal resolution capabilities of the left hemisphere. The results of this study must be interpreted with caution, however, given two serious flaws in the design of the experiment: a) the use of monocular (right eye) viewing; and b) the failure to present stimuli tachistoscopically.

In Davidoff′s experiment, the contrast between the tachistoscopically presented dots and their white backgrounds varied between .18 and .52. For male subjects, an LVF detection advantage was demonstrated only for contrast values below .30, although the overall _visual field x contrast_ interaction effect did not achieve statistical significance. Davidoff′s results must also be interpreted with caution, however, given that the stimulus displays in his experiment differed not only in contrast but in overall luminance as well. Furthermore, his results do not shed light upon the issue of hemispheric differences in contrast sensitivity for particular spatial frequencies, given the broad Fourier spectrum associated with dots (see Weisstein and Harris, 1979).

Contrary to the contrast hypothesis, then, a limited amount of evidence tentatively suggests that the right hemisphere may be superior in processing certain types of low contrast information. No direct evidence exists which indicates that the left and right hemispheres differ as regards spatial frequency processing. In order, therefore, to examine more definitively the role of spatial frequency and contrast in the differential processing of visual information by the left and right hemispheres, the following experiment was designed.

## An Experiment Investigating Spatial Frequency and Contrast Perception in the Left and Right Hemispheres

In this experiment, an attempt was made to isolate and compare the speed and accuracy of the processing of information of a particular spatial frequency and contrast in the left and right visual fields. As in a typical tachistoscopic discrimination experiment, subjects were required to discriminate the contour orientations of stimuli equivalent in terms of spatial frequency content and overall level of contrast. In previous experiments, however, the facial, letter, and other types of stimuli have been comprised of multiple periodicities of varying contrast and frequency. Subjects in the present experiment, on the other hand, were required to discriminate the orientation of contour periodicities contained in square-wave gratings of a particular fundamental spatial frequency and level of contrast.

The square-wave gratings presented to subjects were either of a low or high fundamental spatial frequency, and of a low, medium, or high level of contrast. Based upon the hypotheses presented earlier, the following interaction effects were predicted: a) _visual field_ x _spatial frequency_ (according to the _spatial frequency_ hypothesis); b) _visual field_ x _contrast_ (according to the _contrast_ hypothesis); and/or c) _visual field_ x _spatial frequency_ x _contrast_ (according to the _interactional_ hypotheses).

# CHAPTER II

# METHOD

## Subjects

Twenty-four adult males, presumed to be neurologically normal, served as subjects in the experiment. These subjects were selected, for the most part, from an introductory psychology course at the University of North Carolina at Greensboro, and were naive as to the purposes of the experiment. In return for participating, each subject received a specified number of extra-credit hours, and/or a sum of money not greater than 21 dollars. Prior permission for the use of these subjects was obtained from the Human Subjects Committee of the Department of Psychology at UNC-Greensboro. The purpose in restricting the subject population to adult males was based upon the purported age- and sex-related influences upon the degree of cerebral lateralization (see Lennenberg, 1967; Levy, 1972).

In addition, all subjects exhibited right-hand dominance. The standard use of right-handedness in determining the locus of the "dominant" hemisphere in studies similar to the present one is based upon the results of the sodium amytal preparation (Wada and Rasmussen, 1960). By means of this technique, it has been revealed that 90% of all right-handers exercise the predominant control of speech via their left hemisphere (Branch, Milner and Rasmussen, 1964). In the present study, handedness was judged on the basis of a series of six test items selected from the Edinburgh Inventory (Oldfield, 1971), the Harris Tests of Lateral Dominance (Harris, 1974), and handedness tests conceived by Studdert-Kennedy and Shankweiler (1972). This composite test (Appendix A) required approximately twenty minutes to administer. In order for a subject to be categorized as right-handed, right-hand dominance was required on all individual test items. In addition, all members of his immediate family were required to be right-handed.

A final requirement of all subjects was the possession of either normal or corrected-to-normal binocular and monocular visual acuities. Screening for these functions was accomplished by means of a Bausch and Lomb orthorater.

### Procedure

Stimulus presentation. The stimuli employed in the present experiment (Appendix B) were square-wave gratings whose fundamental spatial frequencies were .9 and 5.5 c/d. These frequencies were selected because they a) are symmetrically situated below and above the peak of the contrast sensitivity function shown in Figure 6, and b) bear no harmonic relationship to one another. The contrast of the gratings was set at either .1, .4 or .6 [Note 6]. These particular contrast values were selected because they a) fall within a range of values which has been shown to influence visual field differences in dot detection performance (Davidoff, 1977), and b) range from the contrast level characteristic of such high frequency information as the letters of this text to that of selected spatial frequency information contained in the human face (see Figure 5). The individual bars of the gratings were oriented obliquely, at angles of either 45 or 135 degrees [Note 7].

All gratings and their background fields were presented tachistoscopically by means of a four-channel Gerbrands T-4a Harvard tachistoscope. The duration of each stimulus interval was set at 100 msec, with an interstimulus interval of 1.9 sec. The 100 msec exposure duration prevented a rapid change in fixation following the illumination of the grating from influencing subsequent processing of it. The square-wave images were viewed at a distance of 94 cm, and subtended 2.0 deg(2) of visual arc. They were centered 2.5 degrees from the vertical meridian in either the left or right visual field, at a point lying along the horizontal axis. As discussed in the preceding chapter, such an eccentricity effectively restricted the processing of the left and right posterior cortices to input received from the contralateral visual fields. Each grating was superimposed upon a background field subtending approximately 6 x 9 degrees. The average luminance of the gratings was 1.5 cd/m(2), a value equal to 50% of the background luminance.

A phosphorescent, diamond-shaped area subtending .75(2) degrees of visual arc and centered at the juncture of the vertical and horizontal meridians served as the central fixation area. Viewing was binocular, in order to avoid the confound associated with differences between the nasal and temporal retinae.

The tachistoscope was situated in the center of a 3.0 x 2.4 m room, whose illumination was dim. Extraneous sounds were masked by the presence of low-amplitude Gaussian noise.

In a given experimental condition, square-wave gratings identical in fundamental frequency and contrast but differing in field of presentation and orientation were presented on a random basis. The only constraint was that each of the four stimuli was presented a minimum of thirty-two times. The random stimulus generation was intended to discourage subjects from deviating from the central fixation area prior to the onset of the stimulus display.

Discrimination task. The subject was required to perform a reaction-time orientation discrimination task. Such a discrimination is mediated largely by primary visual cortical regions (Blake, Jarvis and Mishkin, 1977) and would, therefore, primarily involve precallosal visual mechanisms. In a given experimental condition, square-wave gratings of a particular fundamental spatial frequency and contrast were deemed relevant or irrelevant depending upon their orientation. The subject was required to respond to relevant gratings in both visual fields within 600 msec, and to avoid responding to all other, irrelevant gratings. The 600 msec criterion was established on the basis of previously obtained pilot data. Responses were categorized according to the terminology of signal detection theory (Green and Swets, 1966), such that all responses to relevant gratings occurring within 600 msec were considered "Hits", all responses to relevant gratings occurring beyond this latency were termed "Misses", and all responses to irrelevant gratings were categorized as "False Alarms". If the average of the "Miss" and "False Alarm" percentages exceeded 25%, a given series of trials was repeated.

In making his response, the subject was required to place his index finger upon a Gerbrands G1355 response lever positioned directly in front of him. This was achieved in a counterbalanced sequence with the index fingers of his left and right hands, in order to remove any bias due to the "uncrossed" stimulus-response advantage. Reaction-time responses were recorded by means of a Coulbourn Instruments R21-01 serial printout counter. All responses occurring in excess of 1000 msec following the onset of either a relevant or irrelevant grating were discarded.

Overall design and counterbalancing procedure. The design of this experiment was a repeated-measures factorial, involving the following within-subject factors: visual field of presentation (left vs right), fundamental spatial frequency (.9 vs 5.5 c/d), level of contrast (.1,.4 or .6), hand of response (left vs right), and replication (one and two).

All combinations of spatial frequency, level of contrast, and hand of response resulted in a total of twelve experimental conditions. Within each condition, four blocks of 36 trials each were run, with the 45 and 135 degree gratings deemed relevant in a counterbalanced sequence. Each subject was presented with the twelve conditions and a replication of each during the course of four sessions extending over a period of two weeks. Each session was run on a separate day, required approximately one and one-half hours to complete, and contained a total of six experimental conditions. In most cases, the replication condition was run on corresponding days and times during the second week. The presentation order of the twelve experimental conditions was counterbalanced across subjects by means of a modified Latin Square procedure (Campbell and Stanley, 1963), with the spatial frequency and contrast conditions completely counterbalanced, and hand of response alternated in a counterbalanced sequence within each of the six stimulus conditions. For all subjects, the order of presentation of the latter conditions was reversed during the second replication.

At the completion of the initial screening session, subjects were given the opportunity to practice the orientation discrimination task which they would later be required to perform. A few additional practice trials were accorded the subject at the beginning of each experimental session. During the session, subjects received a five-minute break at the completion of each stimulus condition. A full debriefing as to the purposes of the experiment followed the completion of the final session.

# CHAPTER III

# RESULTS

Repeated-measures analyses of variance (Keppel, 1973) were performed upon two sets of dependent variables, pertaining to the speed and accuracy of the reaction-time (RT) response. The former consisted of the mean and median RT latencies [Note 8]; the latter consisted of the percentages of "Hits" and "False Alarms", and an overall measure of discrimination accuracy (d′) based upon signal detection theory (Green and Swets, 1966) [Note 9].

## Latency Measures

Table 1 contains a summary of the analyses of variance performed upon the mean and median measures. All significant main and interaction effects are listed.

The following four main effects proved highly significant for both the mean and median measures: Replication, Visual Field of Presentation, Spatial Frequency, and Contrast. No interaction effects proved significant in the case of the median, and only a single fourth-order interaction effect (Replication x Spatial Frequency x Contrast x Hand of Response) proved significant in the case of the mean.

The four highly significant main effects are shown in Figures 6 and 7 for the mean and median measures, respectively. As illustrated, RT responses were significantly faster: a) in the second, as compared to first, replication; b) to gratings presented in the right, as opposed to left, visual field; and c) to the .9 as compared to 5.5 c/d grating.

Table 1

Analysis of Variance Summary (Latency Measures)

| | Mean | | |
|---|---|---|---|
| Source | df | MSe | F |
| Replication | 1 and 23 | 2155.86 | 41.01*** |
| Visual Field of Presentation | 1 and 23 | 1624.86 | 14.76*** |
| Spatial Frequency | 1 and 23 | 4528.11 | 68.81*** |
| Contrast | 2 and 46 | 970.14 | 75.96*** |
| .1 vs. (.4+.6) | 1 and 46 | 970.14 | 75.22*** |
| .4 vs. .6 | 1 and 46 | 970.14 | .86 |
| Replication x Spatial Frequency x Hand of Response x Contrast | 2 and 46 | 218.90 | 3.63* |

| | Median | | |
|---|---|---|---|
| Source | df | MSe | F |
| Replication | 1 and 23 | 2376.32 | 33.18*** |
| Visual Field of Presentation | 1 and 23 | 1856.14 | 14.22*** |
| Spatial Frequency | 1 and 23 | 4947.20 | 59.68*** |
| Contrast | 2 and 46 | 1088.40 | 68.65*** |
| .1 vs. (.4+.6) | 1 and 46 | 1088.40 | 68.16*** |
| .4 vs. .6 | 1 and 46 | 1088.40 | .54 |

_Note_. Only statistically significant effects are listed

* $p<.05$
*** $p<.001$

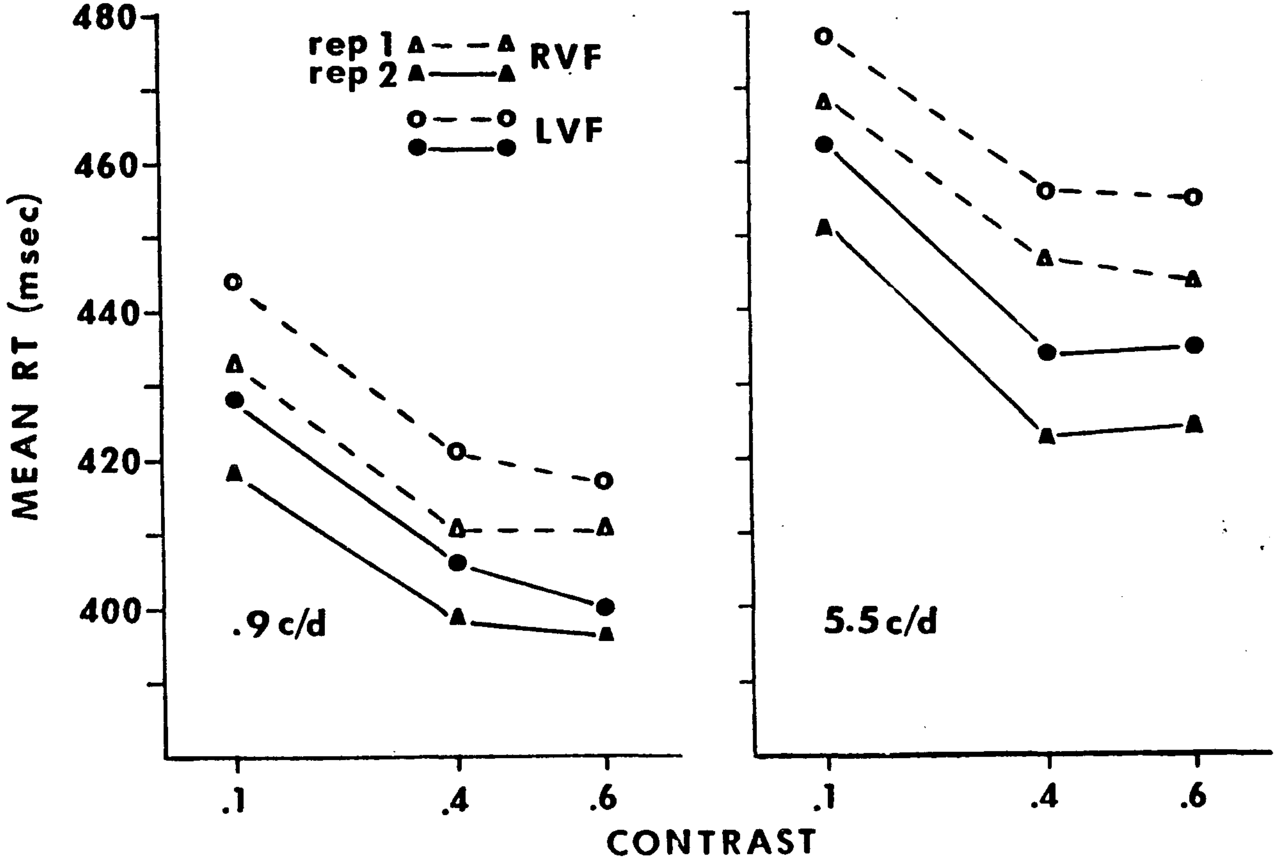

Figure 6. Mean reaction-time latency as a function of Replication (rep 1 vs. rep 2), Visual Field of Presentation (RVF vs. LVF), Spatial Frequency (.9 vs. 5.5 c/d) and Contrast (.1, .4 or .6).

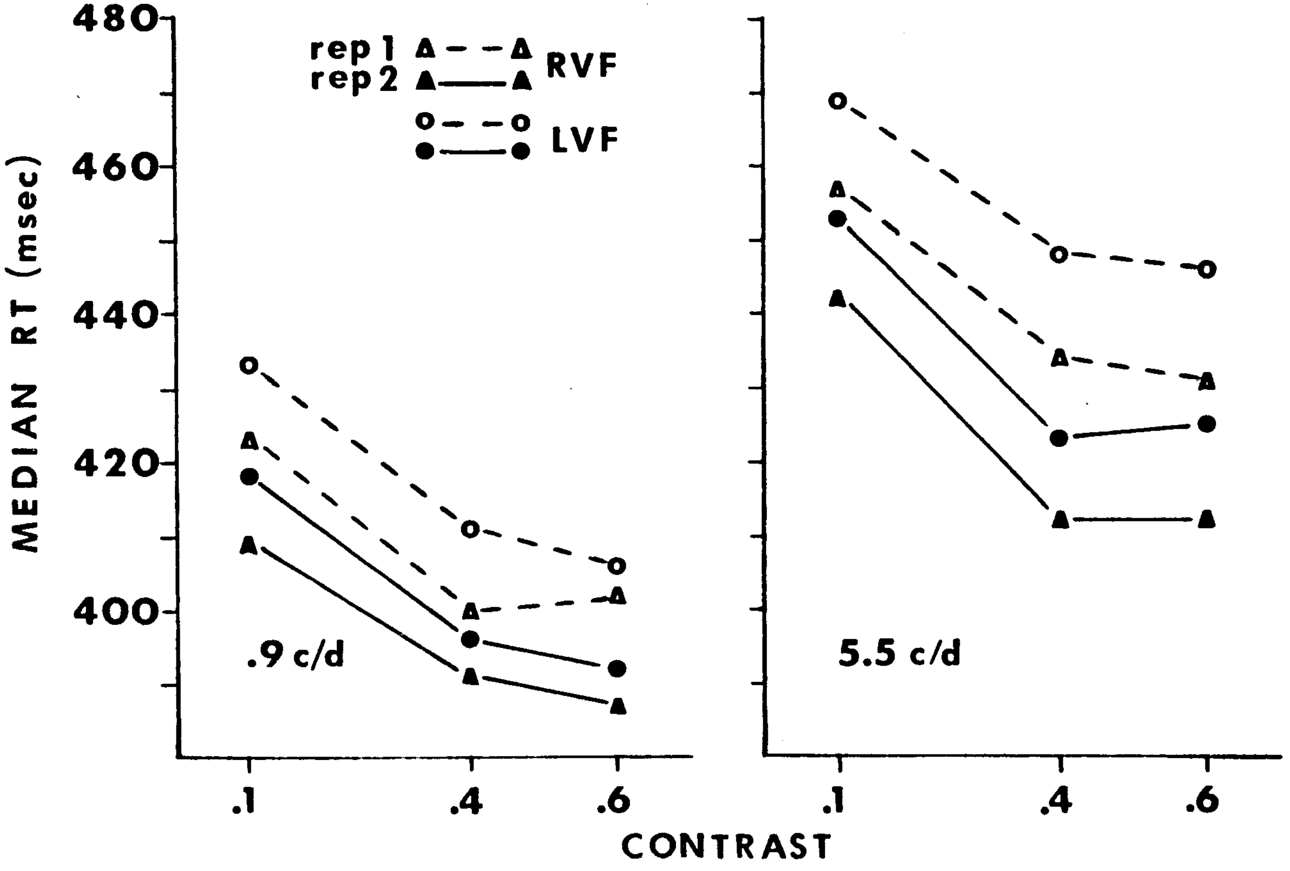

Figure 7. Median reaction-time latency as a function of Replication (rep 1 vs. rep 2), Visual Field of Presentation (RVF vs. LVF), Spatial Frequency (.9 vs. 5.5 c/d) and Contrast (.1,.4 or .6).

Orthogonal analyses further revealed a significant increase in the mean and median RT latency from the two highest contrast levels (.4 and .6) to the lowest (.1), but no significant difference between RT latencies in the .4 and .6 conditions.

The predicted interactions involving visual field of presentation and the stimulus variables of spatial frequency and contrast only approached statistical significance ($p<.15$, for the Spatial Frequency x Visual Field of Presentation interaction effect, in the case of the median, and the Spatial Frequency x Contrast x Visual Field of Presentation interaction, in the case of the mean). As predicted, the right visual field's RT advantage was slightly greater for the 5.5 as compared to .9 c/d grating. This was especially true in the medium and high contrast conditions, wherein eighteen of the twenty-four subjects exhibited this trend.

### Accuracy Measures

Due in part to the fact that response accuracy in the present experiment was required to attain a minimum criterion of 75%, the scores associated with the three accuracy measures could not be assumed to be normally distributed. In order to correct for this violation, arcsin transformations (Winer, 1971) were performed upon the three sets of accuracy scores. Table 2 contains a summary of the analyses of variance performed upon the transformed "Hit" percentages, "False Alarm" percentages, and d′ scores. Once again, all significant main and interaction effects are listed.

The following main effects proved highly significant for all three accuracy measures: Replication, Spatial Frequency, and Contrast. In addition, the effect of Visual Field of Presentation proved significant

Table 2

Analysis of Variance Summary (Accuracy Measures)

Hits

| Source | df | MSe | F |
|---|---|---|---|
| Replication | 1 and 23 | .05 | 52.05*** |
| Spatial Frequency | 1 and 23 | .10 | 27.38*** |
| Contrast | 2 and 46 | .05 | 19.65*** |
| .1 vs. (.4+.6) | 1 and 46 | .05 | 39.15*** |
| .4 vs. .6 | 1 and 46 | .05 | .02 |
| Replication x Spatial Frequency | 1 and 23 | .07 | 7.21* |
| Spatial Frequency x Contrast | 2 and 46 | .02 | 5.13* |

False Alarms

| Source | df | MSe | F |
|---|---|---|---|
| Replication | 1 and 23 | .10 | 8.23** |
| Visual Field of Presentation | 1 and 23 | .06 | 11.46** |
| Spatial Frequency | 1 and 23 | .11 | 35.63*** |
| Contrast | 2 and 46 | .05 | 9.09*** |
| .1 vs. (.4+.6) | 1 and 46 | .05 | 18.08*** |
| .4 vs. .6 | 1 and 46 | .05 | .02 |
| Visual Field of Presentation x Hand of Response | 1 and 23 | .02 | 6.59* |
| Spatial Frequency x Hand of Response | 1 and 23 | .01 | 11.33** |

Table 2 (con't.)

| d' | | | |
|---|---|---|---|
| Source | df | MSe | F |
| Replication | 1 and 23 | .33 | 31.14*** |
| Visual Field of Presentation | 1 and 23 | .36 | 9.42** |
| Spatial Frequency | 1 and 23 | .41 | 63.39*** |
| Contrast | 2 and 46 | .22 | 14.41*** |
| .1 vs. (.4+.6) | 1 and 46 | .22 | 28.80*** |
| .4 vs. .6 | 1 and 46 | .22 | .06 |
| Spatial Frequency x Hand of Response | 1 and 23 | .06 | 6.77* |

_Note_. Only statistically significant effects are listed

* $p<.05$
** $p<.01$
*** $p<.001$

for the False Alarm and d′ measures. An illustration of all of the above effects is provided in Figures 8, 9 and 10 for the Hit, False Alarm and d′ measures, respectively.

As shown in these figures, the percentage of Hits and the d′ scores were significantly higher: a) in the second, as compared to first, replication; b) in response to the .9 c/d as compared to 5.5 c/d grating; c) in the .4 and .6 contrast conditions, relative to the .1 condition; and d) when stimuli were presented in the right, as compared to left, visual field (for the d′ scores only). Similarly, the percentage of False Alarms was significantly lower in the second replication, in response to the .9 c/d grating, in the two highest contrast conditions, and in response to right visual field stimulation.

The interaction effects obtained for the three accuracy measures are depicted in the remaining figures of this section. Two interaction effects involving the percentage of Hits proved significant. Figure 11 illustrates the Spatial Frequency x Replication interaction effect, in which a greater advantage for the .9 c/d grating was evident in the first relative to the second replication. In the Spatial Frequency x Contrast interaction (Figure 12), the effect of contrast was more pronounced when 5.5 c/d as compared to .9 c/d gratings were presented.

The significant interactions obtained for the False Alarm measure are illustrated in Figures 13 and 14. In the Visual Field of Presentation x Hand of Response interaction (Figure 13), more False Alarms were made to gratings presented in the left visual field when the left hand as compared to right was responding, whereas no effect of hand of response was observed for right visual field stimuli. In the Spatial Frequency x Hand of Response interaction (Figure 14), the discrepancy

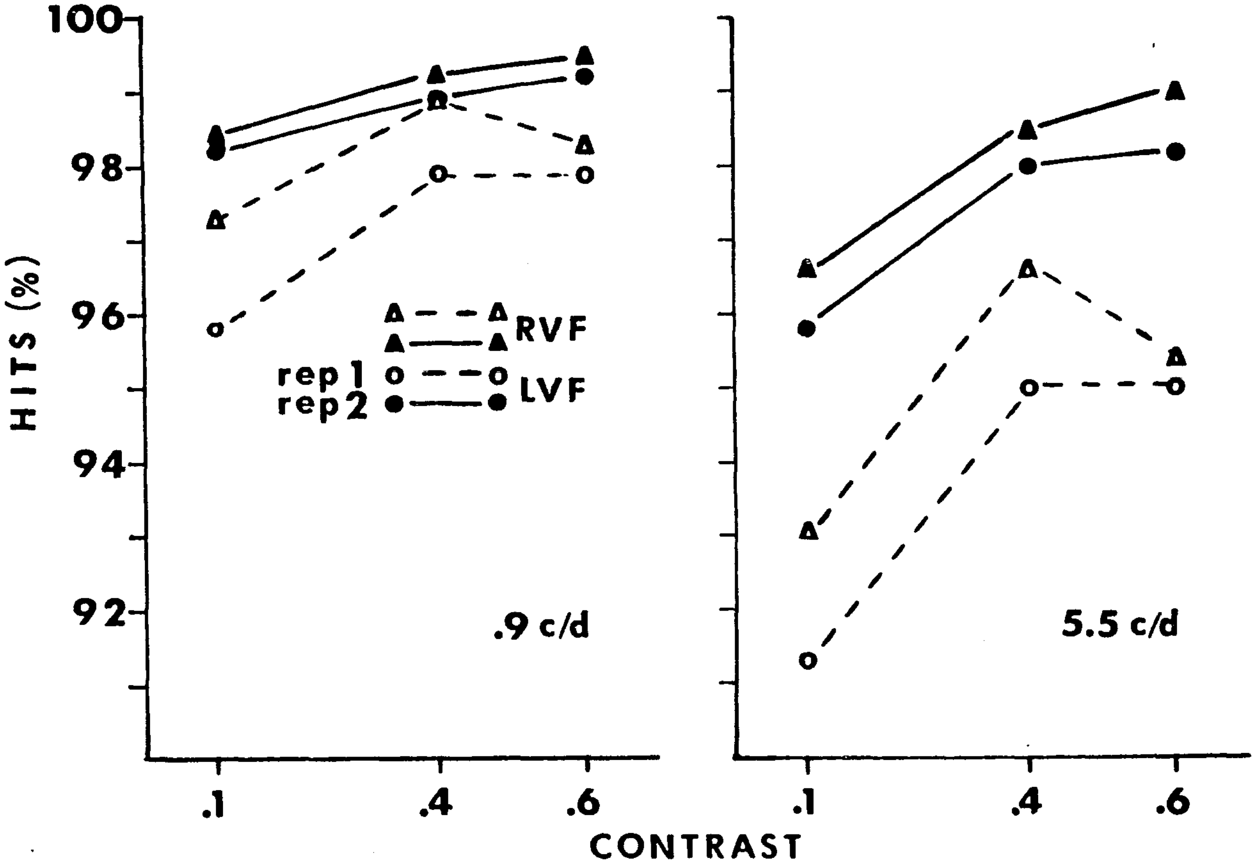

Figure 8. The percentage of "Hits" as a function of <u>Replication</u> (rep 1 vs. rep 2), <u>Visual Field of Presentation</u> (RVF vs. LVF), <u>Spatial Frequency</u> (.9 vs. 5.5 c/d) and <u>Contrast</u> (.1, .4 or .6).

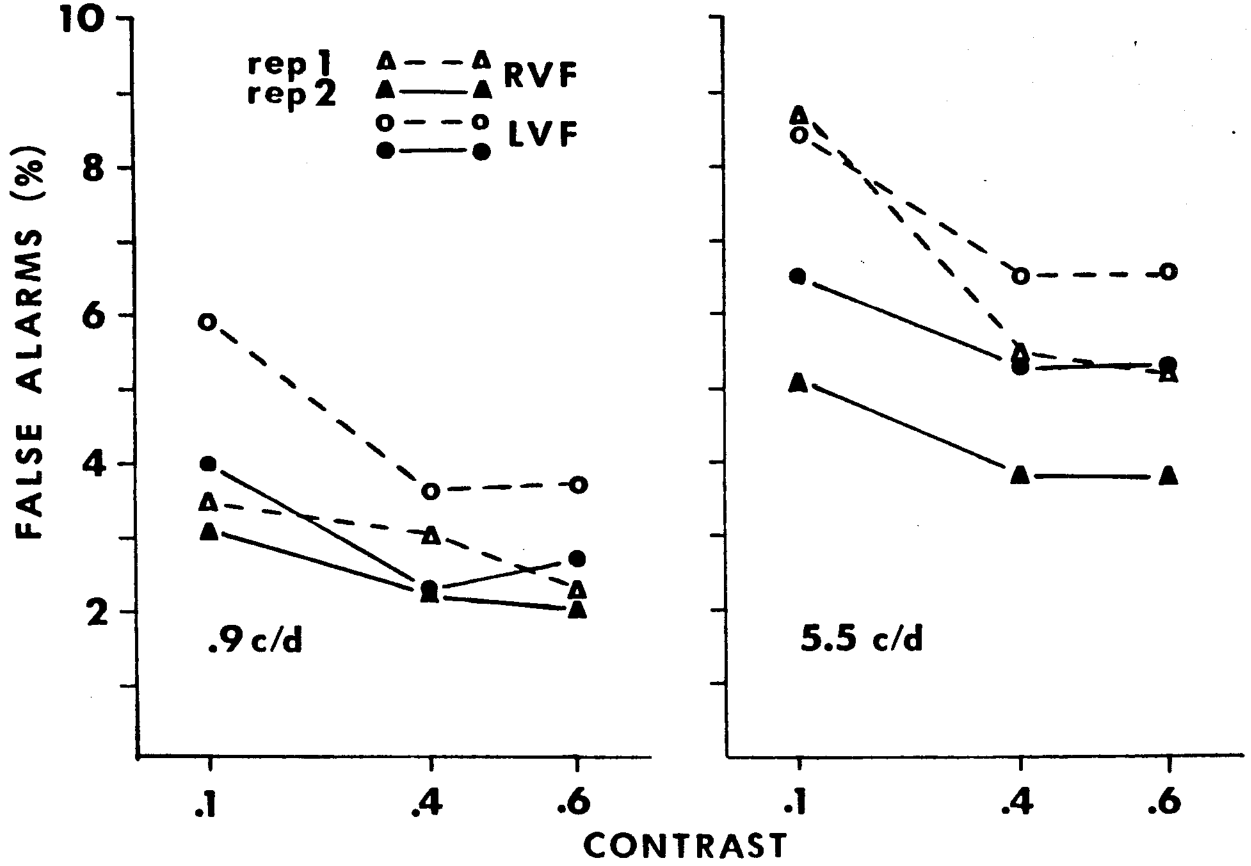

Figure 9. The percentage of "False Alarms" as a function of <u>Replication</u> (rep 1 vs. rep 2), <u>Visual Field of Presentation</u> (RVF vs. LVF), <u>Spatial Frequency</u> (.9 vs. 5.5 c/d) and <u>Contrast</u> (.1, .4 or .6).

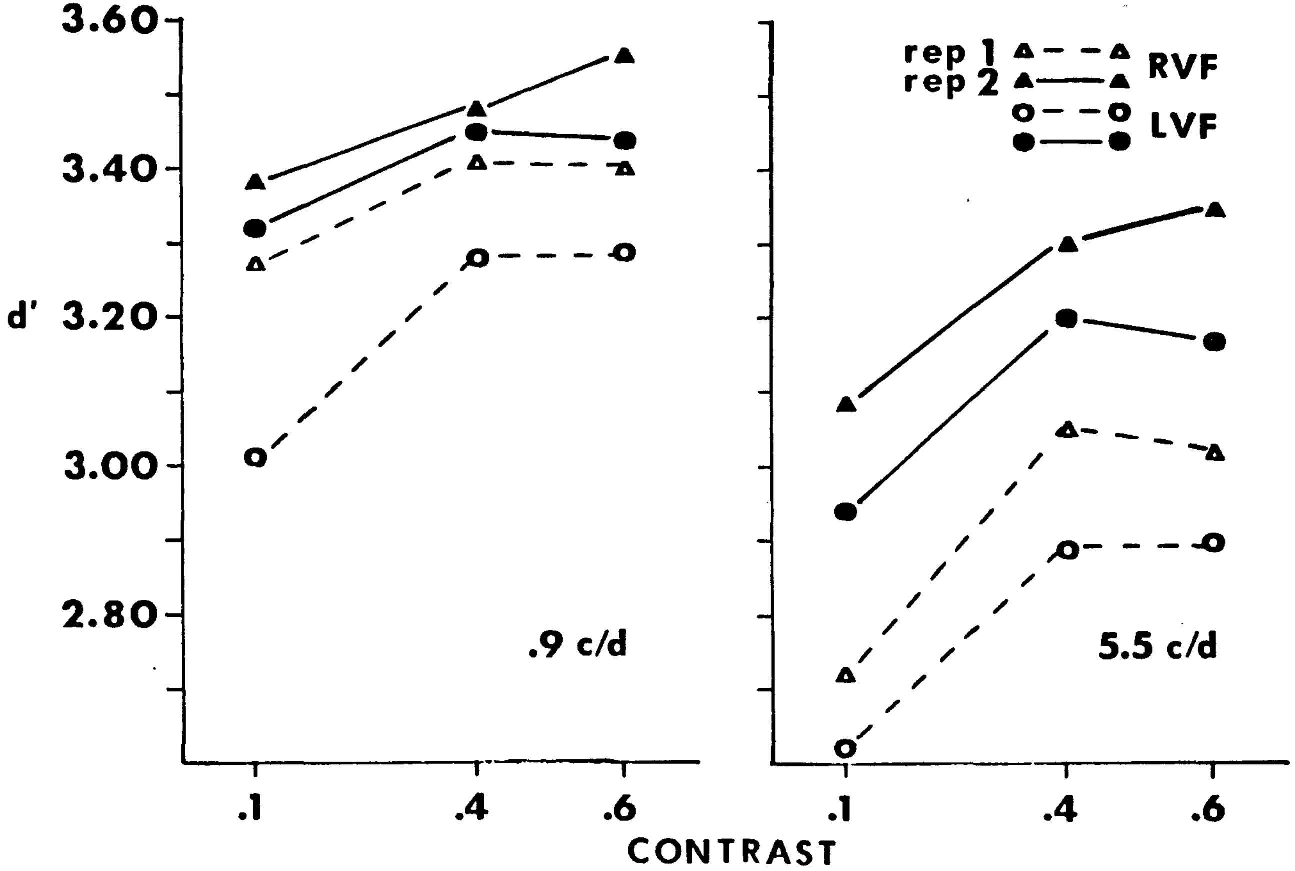

Figure 10. d´ scores as a function of Replication (rep 1 vs. rep 2), Visual Field of Presentation (RVF vs. LVF), Spatial Frequency (.9 vs. 5.5 c/d) and Contrast (.1, .4 or .6).

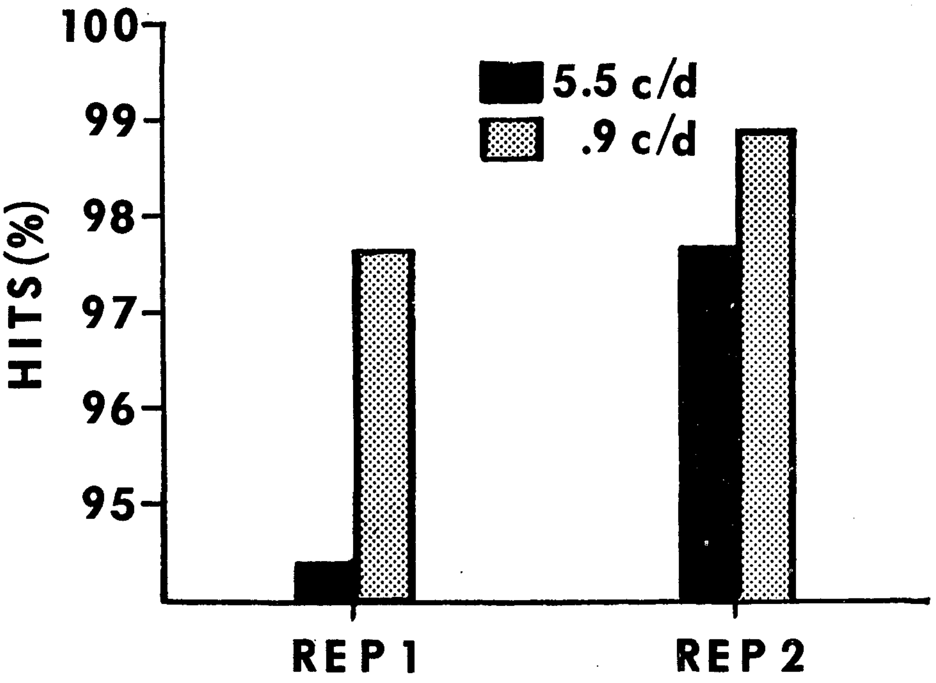

Figure 11. The percentage of "Hits" as a function of <u>Spatial Frequency</u> (.9 vs. 5.5 c/d) and <u>Replication</u> (rep 1 vs. rep 2).

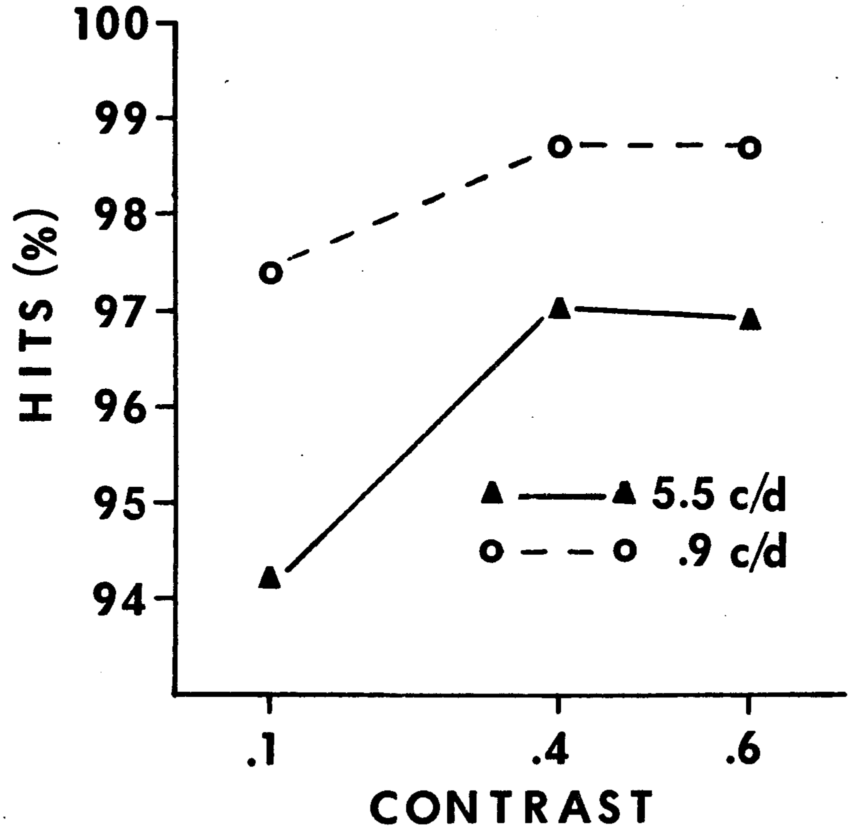

Figure 12. The percentage of "Hits" as a function of Spatial Frequency (.9 vs. 5.5 c/d) and Contrast (.1, .4 or .6).

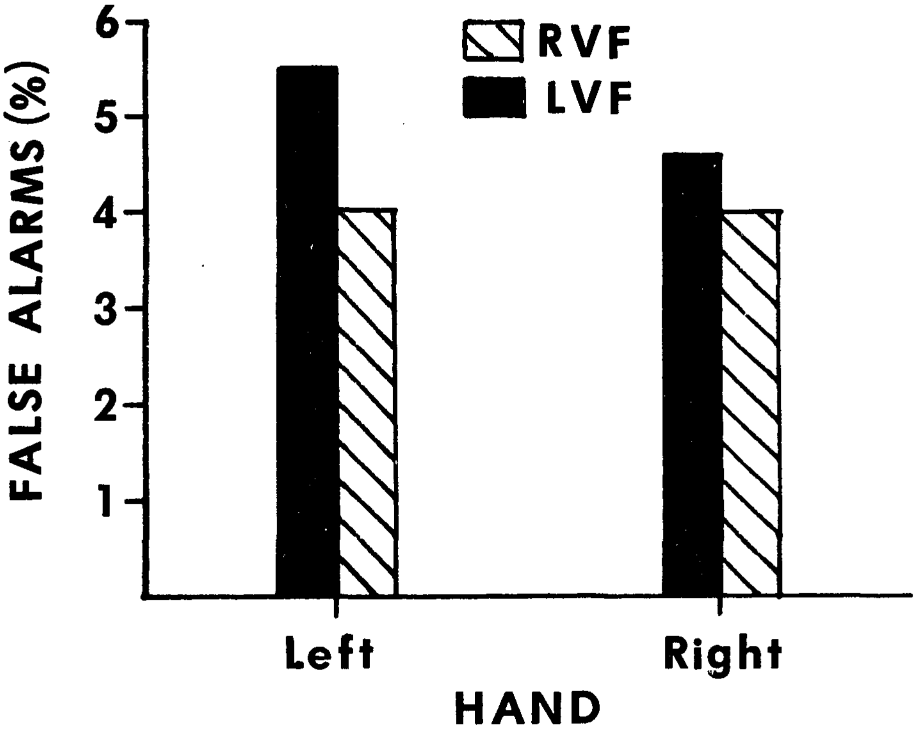

Figure 13. The percentage of "False Alarms" as a function of <u>Visual Field of Presentation</u> (RVF vs. LVF) and <u>Hand of Response</u> (right vs. left).

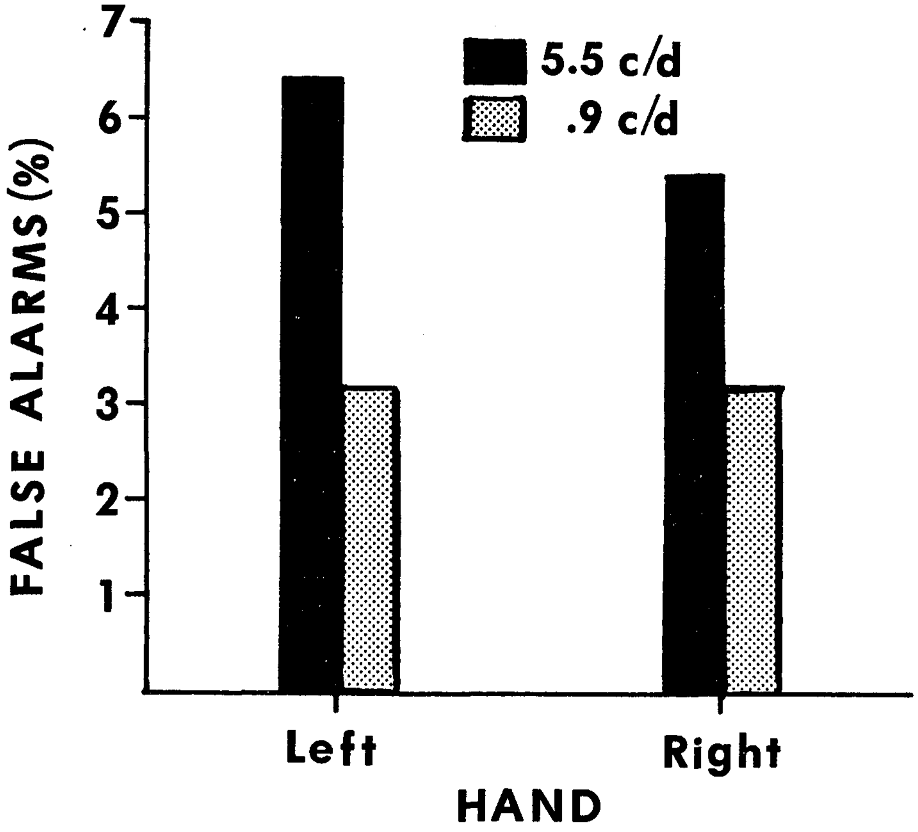

Figure 14. The percentage of "False Alarms" as a function of <u>Spatial Frequency</u> (.9 vs. 5.5 c/d) and <u>Hand of Response</u> (right vs. left)

between the number of False Alarms made to the .9 and 5.5 c/d gratings was greater when responses were executed by the left hand.

Finally, the Spatial Frequency x Hand of Response interaction effect obtained for the d′ measure is shown in Figure 15. As in the case of the False Alarm measure, the discrepancy between d′ values in the .9 and 5.5 c/d discrimination conditions was greater for left-hand responses.

None of the above interaction effects were specifically predicted. In all of them, the effect of one interacting variable was greater at the level of the second variable associated with the poorer discrimination performance (i.e., replication one, the 5.5 c/d grating condition, etc.). With the exception of these interaction effects, the results obtained for the speed and accuracy measures were highly similar.

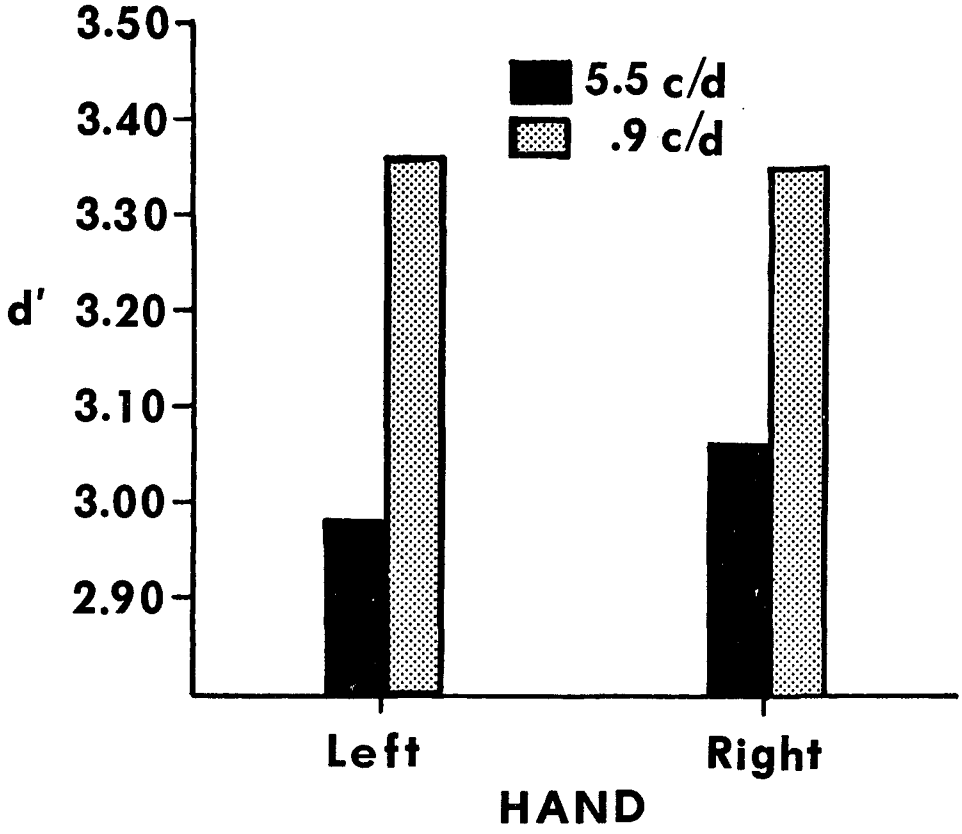

Figure 15. d′ scores as a function of <u>Spatial Frequency</u> (.9 vs. 5.5 c/d) and <u>Hand of Response</u> (right vs. left).

# CHAPTER IV

# DISCUSSION

The major findings of this study as regards cerebral specialization in visual pattern recognition were that a) the left hemisphere proved superior in the processing of low and high frequency square-wave gratings over a wide range of contrast levels, and b) no significant differences were exhibited between the hemispheres as a function of the spatial frequency and contrast of the gratings. In this final chapter, these findings will initially be discussed in relation to the predictions made by the spatial filtering hypotheses. Implications for the *verbal/nonverbal*, *analytic/gestalt*, and *perceptual complexity* hypotheses will subsequently be presented. The highly significant main effects of *spatial frequency*, *contrast*, and *replication* which were obtained will be briefly alluded to during the course of these discussions. No further mention will be made of the various interaction effects involving the three accuracy measures, which were neither predicted nor considered relevant to the specific hypotheses examined in this dissertation.

## *Implications of the Present Findings for the Spatial Filtering Hypotheses*

The three hypotheses based upon the concept of spatial filtering -- the *spatial frequency*, *contrast*, and *interactional* -- predicted *spatial frequency* x *visual field*, *contrast* x *visual field*, and *spatial frequency* x *contrast* x *visual field* interaction effects, respectively. Since none of these interactions attained statistical significance, the findings of the present study do not provide convincing support for the view that the left and right hemipsheres differ in the characteristics of their visual filtering mechanisms. Given that none of the above hypotheses predicted an overall left-hemispheric advantage in the processing of the gratings employed in the present study, it is clear that the spatial filtering concept is at least insufficient in accounting for hemispheric differences in grating perception. It should also be noted that the absence of a significant visual field x contrast interaction effect is inconsistent with those findings which have indicated a right-hemispheric superiority in the processing of low contrast information (Davidoff, 1977; Rao et al., 1981).

While the absence of all interaction effects involving spatial frequency, contrast and visual field of presentation prevents the acceptance of any of the spatial filtering hypotheses, the null findings of this study do not permit their outright rejection, either. It is possible, for instance, that the left and right cerebral hemispheres do differ in their spatial filtering capabilities, but that these capabilities were not adequately assessed in the present instance. Such a possibility will be explored in the remainder of this section, as explanations as to why the predicted interaction effects did not achieve statistical significance will be presented and evaluated. These will focus upon the following: a) subject variables; b) stimulus variables; c) inadequate segregation of processing in the hemispheres; and d) the nature of the discrimination task.

Given the percentage of right-handers with reversed hemispheric asymmetries, two to three subjects in the present study should have failed to exhibit the predicted interactions involving visual field, spatial frequency and contrast. Despite the stringent handedness criteria employed, it is possible that the six subjects who actually failed to discriminate low frequency, high contrast gratings relatively better in the left visual field did not possess the typical left-hemispheric control of speech. Alternatively, differences in monocular resolution capabilities, visual field attentional biases, etc., may have prevented some subjects from reflecting the overall trend. Presumably, these factors would have also influenced visual field performance differences in tasks such as letter and facial recognition, which have consistently yielded RVF and LVF superiorities, respectively. Since the major purpose of the present study was to account for the opposite visual field superiorities in such tasks, one possible solution might be to employ only subjects who have been shown previously to exhibit these well-established tendencies.

A second issue pertains to the role of stimulus variables in preventing significant interactions among spatial frequency, contrast, and visual field. Given the highly significant main effects of spatial frequency and contrast, which are consistent with those reported by other researchers (Breitmeyer, 1975; Harwerth and Levi, 1978; Lupp, Hauske and Wolfe, 1976; Tolhurst, 1975; Vassilev and Mitov, 1976), it is clear that these two stimulus variables were validly manipulated (see Note 7, however). Nevertheless, the stimuli chosen may have been inappropriate in two important respects: a) the use of square-wave as opposed to sine-wave gratings; and b) the choice of spatial frequencies.

Two pieces of evidence argue against the view that the use of sine-wave gratings would have substantially altered the results of the present study. First, RT's to suprathreshold square- and sine-wave gratings have been shown to vary in an almost identical fashion as a function of spatial frequency and contrast (see Lupp et al., 1976; Vassilev and Mitov, 1976), as predicted by findings that the perceived contrast of suprathreshold square-wave gratings is equal to the contrast of the fundamental sine-wave component (Ginsburg, Cannon and Nelson, 1980). Second, RT's to the higher harmonics in a square-wave grating would be considerably delayed relative to the fundamental response, given their higher frequency and reduced contrast. It is extremely unlikely, therefore, that subjects responded on the basis of the higher harmonic information, especially given the precision of the spatial frequency and contrast effects.

The choice of fundamental frequencies may have proven more critical in preventing a significant interaction between spatial frequency and visual field from being obtained. While the _a priori_ consideration in choosing the .9 and 5.5 c/d stimuli was to manipulate spatial frequency while equating for contrast sensitivity, the .9 c/d frequency may have been too low for the present purposes. Tieger and Ganz (1978), for instance, found that the most important spatial frequency component in the perception of the human face is centered at approximately 2.0 c/d, and a similar conclusion may be reached upon viewing the filtered images produced by Ginsburg (1978). In order to simulate the LVF advantage in facial perception, then, the choice of a 2.0 c/d grating would perhaps have been more appropriate.

A third explanation for the failure to demonstrate significant interactions between visual field and stimulus type is that the processing of information preceding the initiation of the RT response was not adequately confined to the relevant hemisphere. The principal source of this difficulty would have been subjects' failure to maintain central fixation, which would have prevented initial segregation of input to the hemispheres. Two pieces of evidence provide indirect support for this explanation: a) a significant visual field x hand of response interaction effect was not obtained in the present study; and b) the nonsignificant reduction in the RVF superiority during the discrimination of low as compared to high frequency gratings was least prominent at the lowest contrast level (.1). The failure to demonstrate a significant visual field x hand of response interaction allows for the possibility that stimuli were not actually presented to the left and right hemispheres, since an advantage for the RVF-RH (right hand) and LVF-LH (left hand) stimulus-response sequences should otherwise have resulted. The reduction in the predicted interaction between spatial frequency and visual field at the lowest contrast level is also disturbing, since, given its difficulty, the pressures upon maintaining fixation were presumably greatest in this condition.

In response to the above, the following arguments may be raised. First, all criteria set forth in CHAPTER I for controlling subjects' fixation in tachistoscopic discrimination experiments were fulfilled in the present study. In addition, RT responses were carefully controlled, as indicated by the fact that the mean and median RT latencies may have been the shortest yet obtained in a study investigating visual field differences in choice-RT performance. Second, the failure to obtain a statistically significant visual field x hand of response interaction effect must be viewed in the context of other failures to obtain such an interaction, even in carefully controlled studies involving "simple" RT's (see Berlucchi, 1978). Finally, the interaction between spatial frequency and visual field was not altered appreciably from the first to second replications, despite a highly significant improvement in discrimination performance during the latter. Since this improvement was presumably accompanied by increased fixational control on the part of subjects, it is unlikely that difficulties in achieving fixational control were a major factor in preventing a significant _visual field_ x _spatial frequency_ interaction effect from being obtained.

The final explanation for the failure to obtain a significant interaction involving the spatial frequency, contrast and visual field manipulations focuses upon the discrimination task which subjects were required to perform. On the one hand, it may not have provided a sufficiently direct assessment of contrast sensitivity differences between the hemispheres as a function of spatial frequency. On the other hand, it may have failed to activate sufficiently higher-order spatial filtering mechanisms, which, as will be described shortly, may mediate the role of spatial frequency and contrast in the perception of various visual forms.

As stated in CHAPTER I, orientation discrimination is largely mediated by primary cortical regions (Blake et al., 1977) and should, therefore, have reflected basic sensitivity differences between the hemispheres. Given, however, that the median RT latency in even the most rapid discriminations was approximately 400 msec, the neural activity associated with the initiation of the RT response must have occurred between 300-350 msec following the presentation of the stimulus (see Ritter, Simson and Vaughan, 1972). This activity would, therefore, have occurred long after a spatial frequency analysis had been performed by the visual system (see Towle, Harter and Previc, 1980). It may prove necessary, therefore, to engage in a more direct assessment of the capabilities of the left and right hemispheres in the realm of spatial vision, either by a direct measure of contrast sensitivity across a broad range of spatial frequencies, or by the use of the visual evoked potential (see Campbell and Maffei, 1970).

Alternatively, it is possible that the left and right hemispheres differ not in their contrast sensitivities to various spatial frequencies, but in higher-order spatial filtering mechanisms. One such proposed mechanism involves the concept of spatial frequency attention (Carpenter and Ganz, 1972; Davis, 1981; Harter and Previc, 1978), and has been invoked to explain the discrepancy between the psychophysically determined contribution of various spatial frequency components to the perception of the human face, and that predicted on the basis of the human contrast sensitivity function (Tieger and Ganz, 1978). The rationale for believing that the left and right hemispheres may differ in <u>active</u>, as opposed to <u>passive</u>, spatial filtering has a three-fold basis. First, forms for which the processing modes of the left and right hemispheres are specialized are typically comprised of a variety of spatial frequency components. Since only a small subset of these may be of assistance in perceiving the form, a means by which irrelevant spatial frequency components may be actively filtered out would clearly be advantageous to the visual system. Second, the presence of high frequency noise has been shown to impair the perception of letters (Hellige, 1976) and random-dot stereograms (Pitblado, 1980[Note 10]) more severely in the right visual field, whereas the converse has been demonstrated in the case of low frequency noise (Pitblado, 1980[Note 10]). This suggests, then, that the left and right hemispheres may be more proficient at filtering out low and high frequency information, respectively. A final argument supports the view that the left and right hemispheres differ not in terms of contrast sensitivity, but in the characteristics of their active spatial filtering mechanisms. In the present study, visual field differences in the processing of low and high frequency gratings were apparent only at the higher contrast levels. Such an occurrence would have been highly unlikely in the presence of true contrast sensitivity differences between the hemispheres, but would be compatible with the notion of hemispheric differences in the active filtering of suprathreshold information.

It should be noted that a recent hypothesis proposed by Harter and colleagues (Harter, Aine and Schroeder, submitted) has also invoked the concept of selective attention in accounting for hemispheric differences in visual information processing. This alternative view, however, holds that the left hemisphere may be generally specialized for selectively attending to cues which distinguish stimuli at a particular location (such as spatial frequency, orientation, color, etc.), as opposed to location cues per se. This hypothesis would, therefore, have predicted a left-hemispheric superiority in the filtering of both low and high spatial frequency information. Although the overall RVF superiority which was obtained in the present study is consistent with this prediction, further empirical testing is required to demonstrate the general validity of the Harter et al. proposal.

It is imperative, therefore, to design a set of stimuli and tasks which might test more directly for the presence of active spatial filtering differences between the hemispheres. An ideal setting for eliciting active spatial filtering would presumably occur when high and low frequency square-wave gratings are superimposed upon a background of random noise varying in spatial frequency content. Under these conditions, the active filtering hypothesis would predict a LVF advantage in the discrimination of low frequency gratings embedded in high frequency noise, and a RVF superiority in the discrimination of high frequency gratings embedded in low frequency noise.

In summary, the results of the present study have not convincingly demonstrated the existence of spatial filtering differences between the hemispheres, although several experiments have been proposed which could determine more conclusively not only if the left and right hemispheres differ in the processing of information varying in spatial frequency and contrast, but if these processing differences result from each hemisphere's active, as opposed to passive, spatial filtering. Since, however, it has already been mentioned that the spatial filtering hypothesis -- regardless of its ultimate validity -- is incapable of accounting for the overall RVF superiority exhibited in the present study, the next section will contain a discussion of the findings of this study in relationship to the three alternative hypotheses presented in CHAPTER I.

### Implications of the Present Findings for Alternative Hypotheses Concerning Hemispheric Specialization in Visual Pattern Recognition

The stimuli employed in the present experiment would not appear to be typical of the class of stimuli which, according to the verbal/nonverbal hypothesis, should be processed better in the right visual field. Nevertheless, the following explanation could be put forth by proponents of this distinction. The overall RVF superiority may have resulted from the fact that the square-wave gratings employed in the present study were of relatively common orientations (45 and 135 degrees), and, therefore, subject to verbal labelling. This argument has previously been invoked in order to explain the RVF superiority in the discrimination of single-line orientations when only a few common orientations are presented to the subject (Umilta, Rizzolatti, Marzi, Zamboni, Franzini and Camarda, 1974; White, 1971), and the LVF superiority when multiple orientations are presented (Kimura and Durnford, 1974; Umilta et al., 1974). The major difficulty with this interpretation is that the median RT latency even in the most difficult conditions was considerably less than is typically found in tasks requiring the name-matching of letters (see Ledlow et al., 1978). It is doubtful, then, that the influence of verbal mediation could have been very pronounced in the majority of discriminative responses.

At first glance, it would seem difficult to characterize the stimuli of the present study along the analytic/gestalt dimension, and thereby to entertain predictions concerning their lateralization on the basis of this hypothesis. They may, however, be pertinent to the specific distinction between fragmented and embedded figures put forth by Zaidel (1978b). Since the individual bars of the square-wave gratings varied in orientation while the shape of the overall stimulus display remained constant, the square-wave gratings may be viewed as having been "embedded" in the overall display. According to Zaidel's hypothesis, then, an RVF superiority would have been expected in the processing of these stimuli. Since the differential processing of fragmented and embedded figures could conceivably occur in the early stages of the recognition process, the temporal difficulties associated with the verbal mediation hypothesis may not be as severe in this case.

Finally, the predictions of the perceptual complexity hypothesis must be considered. As mentioned in CHAPTER I, this hypothesis states that the right hemisphere is more highly involved in the perception of "complex" visual forms. Since the high frequency gratings not only contained a greater number of contours, but were, in addition, more difficult to discriminate, they should have exhibited a reduced RVF advantage. Since exactly the opposite result was obtained, the predictions of the "perceptual complexity" hypothesis were clearly disconfirmed.

In summary, then, only two of the four hypotheses outlined in CHAPTER I -- the verbal/nonverbal and Zaidel's specific formulation of the analytic/gestalt -- could have reasonably predicted the results of the present study, although even the former's interpretation is beset with certain difficulties. Unfortunately, neither of these hypotheses may account for the total set of findings concerning hemispheric differences in visual pattern recognition outlined in CHAPTER I. By contrast, the success of the spatial filtering hypotheses in accounting for previous findings concerning cerebral specialization in visual pattern recognition is somewhat mitigated by their failure to predict the outcome of the present study.

It is likely, therefore, that a combination of these hypotheses may ultimately prove necessary in order to account for the entire spectrum of findings concerning hemispheric specialization in visual pattern recognition. The spatial filtering and analytic/gestalt hypotheses would appear to be particularly compatible, given their common concern with the perception of internal details and closure, and their similar implications regarding differences between the hemispheres in terms of basic neural organization. In any event, it clearly remains the task of future research to determine conclusively the underlying basis of visual pattern recognition in the cerebral hemispheres, as well as the neural substrate and evolutionary origins thereof.

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# NOTES

[1] In this study, subjects′ handedness was either not specified, or both left- and right-handed subjects were employed.

[2] Subjects′ handedness was not specified, and insufficient stimulus lateralization accompanied the chimeric presentations.

[3] Insufficient stimulus lateralization and the use of a vocal response are not considered confounds in this case, since both LVF and RVF advantages were demonstrated.

[4] An LVF advantage was demonstrated only for successively presented stimuli.

[5] This study did not meet several of the methodological criteria established in CHAPTER I.

[6] <u>Contrast</u> in this instance was defined according to the formula:
luminance (max) - lum (min)/lum (max) + lum (min)

[7] The perceived contrasts of the 5.5 c/d gratings were probably less than the actual values, given that the contrast sensitivity for frequencies greater than 4-8 c/d is reduced when gratings are presented obliquely (Berkeley, Kitterle and Watkins, 1975; Campbell, Kulikowski and Levinson, 1966). While the discrepancy between the .9 and 5.5 c/d contrast levels could conceivably have resulted in a spurious main effect of <u>spatial</u> <u>frequency</u>, such an outcome would have been highly unlikely given that the magnitude of the oblique reduction at 5.5 c/d is very slight (i.e., less than 20%), whereas absolutely no overlap between the .9 and 5.5 c/d response latencies occurred over the considerably larger contrast range of 80% employed in the present study.

[8] Based upon a rank ordering of the thirty-two RT latencies obtained in each experimental condition, the sixteenth fastest of these was defined as the <u>median</u>.

[9] In selected experimental conditions, the performance of a few subjects was flawless. Since such a performance level would have been associated with an infinite d′ value, single "Miss" and "False Alarm" values were included in all "Hit" and "False Alarm" percentages, from which d′ scores were calculated.

[10] Only monocular viewing was employed in this study.

# APPENDICES

# APPENDIX A

## The Handedness Test Utilized in the Present Study

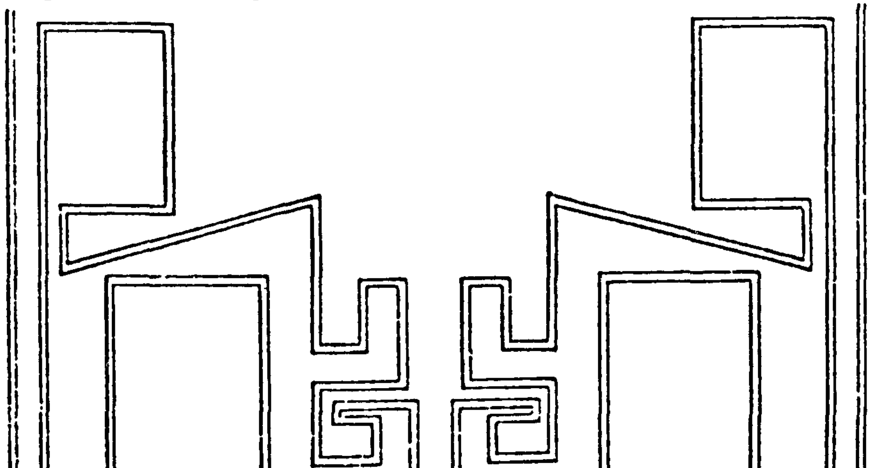
The composite handedness test administered to subjects in the present experiment was based upon that utilized by Previc (1976), for the reasons outlined in that manuscript. The six items selected, and their method of administration, are as follow:

[1] <u>Name-writing</u> — Each subject was asked to write his name on the first page of the test booklet. Scoring was based upon which hand was utilized.

[2] <u>Throwing</u> -- Each subject was asked to toss a ball to the experimenter. Scoring was based upon which hand was utilized.

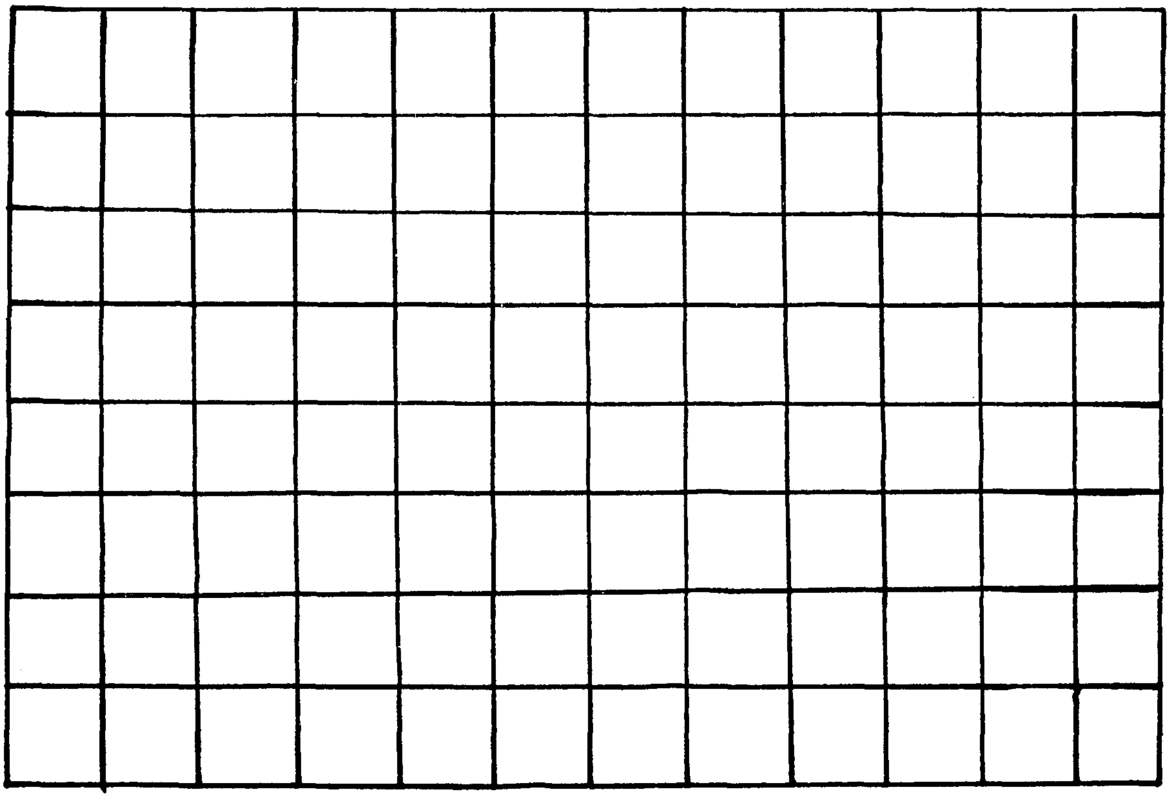
[3] <u>Match-striking</u> -- The subject was provided with a box of matches. Scoring was based upon which hand the subject utilized in holding the match, when requested to strike it against the box.

[4] <u>Tracing</u> -- Subjects were instructed to trace the pattern shown below, first with one hand moving in one direction, and then vice versa, in a procedure counterbalanced both within and across subjects for starting hand and direction. Given the absence of any pronounced legibility differences between hands, the difference between the combined time taken to complete the pattern by one hand in both directions formed the basis of classification. A ten percent or greater advantage in favor of the right hand resulted in the subject being categorized as right-handed.



[5] Simultaneous numbering — Subjects were instructed to hold a pencil in each hand, and to begin writing in adjacent columns the numbers 1-10 with both hands simultaneously. The subject was requested to write down the numbers as rapidly and legibly as possible. In order to give the impression of a timed test, an initial practice run was given in which subjects were deliberately prevented from completing the task; during the actual run, however, subjects were allowed to complete the numbering. A classification of right-handedness was dependent upon: a) evidence of superior legibility for right-hand numbering; and b) absence of any digit reversals.

[6] Tapping — In a procedure counterbalanced across subjects for hand and direction of motion, each subject was told to begin tapping one and only one dot into the series of squares shown below. The pen was gripped as if it were a peg to be placed into a peghole, with the subject's thumb placed over the top end. After an initial practice period, each subject began the fifteen second task using either the left or right hand. Subjects worked the first row in one direction, reversed direction on the second row, and then continued to reverse on succeeding rows. Upon completion of the task, the number of squares with one and only one dot in them were totalled for each hand's performance. The subject was classified as right-handed only if a ten percent or greater advantage was evidenced for the right hand.



# APPENDIX B

## The Stimuli Utilized in the Present Experiment

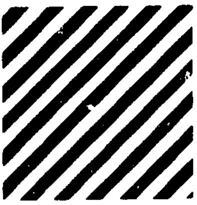
Photographic reproductions of the six square-wave gratings employed in the present study are shown on the following page.

| | c/d | Contrast |
|---|---|---|
| (a) | .9 | .6 |
| (b) | .9 | .4 |
| (c) | .9 | .1 |
| (d) | 5.5 | .6 |
| (e) | 5.5 | .4 |
| (f) | 5.5 | .1 |

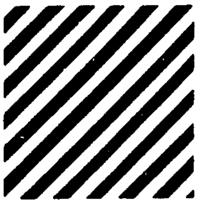
a

b

c



d



e

f