Spring 1994

Visual Information Processing of Geometric Figures as a Function of Complexity and Field of Vision

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A Dissertation submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

DOCTOR OF PHILOSOPHY

INDUSTRIAL/ORGANIZATIONAL PSYCHOLOGY

OLD DOMINION UNIVERSITY
May, 1994

Approved by:

Glynn D. Coates, Director

ABSTRACT

VISUAL INFORMATION PROCESSING OF
GEOMETRIC FIGURES AS A FUNCTION OF
COMPLEXITY AND FIELD OF VISION

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The purpose of this study was to investigate whether human information processing does occur in parallel in the right hemisphere and serially in the left hemisphere as suggested by the hemisphere strategy model. In addition, this study was also designed to determine if there is a right hemisphere advantage in the processing of nonverbal information as indicated by the material specific theory.

In this 3x3x3x2x2 mixed design, Complexity (3) and Gender (2) were the between-subjects variables. Time Factor (3), Field of Vision (3), and Type (2) were the within-subjects variables. Complexity was defined in terms of the number of columns in the bargraphs--4, 6, and 8. The dependent variables were reaction time and accuracy.

The Time Factor determined the exposure duration of the bargraphs. The three different durations were 140, 210, and 280 msec. The three different field of vision were left (LFOV), right (RFOV), and center (CFOV). Single and double stimulus conditions were represented by the Type variable.

Complexity was the only variable that resulted in statistically significant differences between group means for both the reaction time and accuracy measures. However, the post hoc tests revealed that the differences between group means were significant only for the 4-column bargraphs. There were no differences between the 6- and the 8- column bargraphs.

Gender and Time Factor had no effect on performance, while Position and Type did demonstrate some differences among group means. In general, interaction effects were disappointing with very few significant effects.

The results of this study do not fully support the hemisphere strategy model and the material specific model. There was no clear indication that parallel processing of nonverbal information occurs exclusively in the right hemisphere and serial processing in the left hemisphere.

The pattern of results suggest that hemisphere advantage switches from one hemisphere to the other as complexity increases. This was also the case with other studies reported in the literature review section.

It was suggested that the measurement of complexity must be determined and generally adopted to ensure uniform measures. The problems and suggestions for future research on this important topic are discussed.

Acknowledgement

I would like to acknowledge several individuals who have affected me in special ways during this academic endeavor. First, I would like to acknowledge Dr. Glynn Coates, my dissertation director, who is a caring human being and a dedicated academician. I would like to thank him for his help and guidance throughout this dissertation process.

Second, I would like to express my gratitude to my young adult daughters, Denise and Geri Lee Mizumoto, for being supportive throughout the years I have spent pursuing my academic goals. I love them both dearly.

Finally and most importantly, my husband Steven who stood by me and supported my aspirations deserves special acknowledgment. Steven provided me with the freedom to continue my educational pursuits even when it meant relocating from Hawaii to Virginia and living a bi-coastal marriage for one year. He has endured years of personal sacrifice as I pursued my goals and has never ceased to be a genuinely unselfish person. I would like to express my deepest love for my husband Steven.

I truly am blessed in this lifetime to have so many wonderful people in my life--including those whom I could not acknowledge individually here.

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The modern technology of today and the future demands that human operators process a tremendous amount of information in a short period of time. The advanced technology of visual display systems affects nearly every aspect of our lives. The use of icons in computer software, head-up displays in aircraft and more recently in automobiles, and helmet mounted displays are just a few examples of how "high tech" can be used to present visual information.

There are many instances where observers or perceivers of visual information are not afforded the necessary time to focus on the visual information placed in less than convenient locations relative to the observer's field of view. (Frequently monitored displays are placed in the more convenient locations, while less frequently used displays are placed in less convenient locations). In order to assure that all information presented has been transmitted, especially when the information is located at the person's peripheral vision, individual symbols or elements within a display as well as entire displays should be designed to facilitate the human information processing system and its limitations.

The purpose of the present study is to investigate effects of the spatial location and stimulus complexity on visual information processing. Geometric shapes, rather than verbal stimuli, were used for this study because of the growing application of symbols in visual displays (e.g., icons, object displays, road signs). In addition, the use of nonverbal stimuli reduces the possibility that subjects will covertly verbalize the information presented to them thus resulting in a left hemisphere advantage.

The intent of this study is to investigate whether processing of nonverbal information occurs in a parallel, or all-at-once manner, or whether information is processed in a serial, or one-at-a-time manner. If processing is parallel in nature, does it occur in the right hemisphere? If processing is serial in nature, is it demonstrated in the left hemisphere?

Hemispheric Laterality

Cerebral dominance theories. According to recent theorizing, information processing of visual information is processed differently in the right and left cerebral hemispheres. There are two categories of cerebral dominance theories which implicate stimulus category and processing strategy as principal variables which determine the effectiveness of each cerebral hemisphere. Goodglass and Butters (1988) categorize the theories as (1) material specific theory, and (2) hemisphere strategy theory.

The material specific theory is the traditional view of hemispheric laterality (Goodglass & Butters, 1988). Traditionally, the right hemisphere is viewed as more efficient at processing perceptual information, that is, nonverbal or not easily verbalized stimuli. The left hemisphere is more efficient at processing verbal or easily verbalized stimuli. The hemisphere strategy theory is a more recent view (Goodglass & Butters, 1988) which suggests that the left hemisphere processes information in a sequential, analytic manner, while the right hemisphere is holistic or configurational in its strategy of processing information.

Although the hemispheric functions and strategies according to the two cerebral dominance models appear to be simple, research investigating the serial vs. parallel issues have suggested that the hemispheric strategies are much more complex than had been realized through earlier research. Apparently, the left hemisphere is not always superior in its processing of verbal material (e.g. Magaro & Moss, 1989). In addition, research has also suggested that the left hemisphere does not always employ analytic or serial strategies in a more superior manner when compared to the right hemisphere (Brand, van Bekkum, Stumpel, & Kroeze, 1983). The research literature also suggests that the right hemisphere is not always superior in the processing of nonverbal stimuli (e.g., Hanay, Rogers, & Durant, 1976) and neither is it always superior to the left hemisphere in processing in a holistic or parallel manner (Polich, 1980).

There are a variety of reasons why such inconsistencies occur. For example, it is possible that lateralization does not exist or that it does exist but popular methodology is insufficient to find consistent results. It is suggested here that the latter is more reasonable to assume because laterality studies on commissurotomy patients have demonstrated that the brain is lateralized for different information processing tasks (Levy & Trevarthan, 1976).

Methodological differences. Methodological differences which may account for inconsistent results include the use of different stimulus categories and characteristics. For example, the use of simple, nonverbal stimuli which can be easily verbalized such as simple geometric forms or alphanumeric symbols can result in null or opposite effects. That is, some nonverbal stimuli may be processed equally well by both hemispheres or may be processed more efficiently in the left hemisphere.

Another methodological issue concerns how stimuli are measured for laterality effects. Traditionally, visual task stimuli are presented unilaterally with a tachistoscope for a very short period of time (e.g, 50 msec, 180 msec, etc.). That is, stimuli are presented to the right visual field then to the left visual field or vice versa. Many studies do not include bilateral presentation in which stimuli are projected simultaneously to both visual fields. The unilateral and bilateral presentation may be necessary to determine whether one hemisphere has dominant control during the information processing task regardless of whether or not it is the hemisphere which is traditionally known to be superior in its ability to process a specific category of stimuli (e.g., verbal vs. nonverbal).

Hellige (1991) reviewed a number of studies on hemispheric laterality and provided some interesting insights to the topic. Several distinctions within the hemispheric laterality issue as first presented in Levy and Trevarthen (1976) may help to account for some of the inconsistencies in laterality studies.

<u>Hemisphere ability vs. hemisphere dominance.</u> Levy and Trevarthen (1976) discovered that the hemisphere involved in performing an information processing task in

commissurotomy patients was not the hemisphere with the superior ability to perform that particular task. Based on these findings, they made a distinction between the terms hemispheric ability and hemispheric dominance. The term hemispheric ability refers to how well a particular hemisphere can handle an information processing task. This topic has produced considerable research activity. Hemispheric dominance, on the other hand, refers to the degree to which a hemisphere tends to take over the processing of information. The neural mechanism (a hypothetical construct) which is involved in determining which hemisphere will control the cognitive operations is referred to as metacontrol (Levy & Trevarthen, 1976). Therefore, in some instances, it may not necessarily be true that the dominant hemisphere involved in a processing task is the hemisphere which has superior ability for that particular processing task. For example, studies described in Hellige (1991) on neurologically normal subjects demonstrated that the pattern of results was similar for the bilateral and left hemisphere conditions, but not for the right hemisphere condition. This was true for both nonverbal (cartoon faces) and letter stimuli.

In traditional laterality studies on subjects with normal, intact brains, stimuli are presented unilaterally to the subjects. Unilateral presentation of stimulus information does not provide the opportunity to determine which hemisphere will be dominant in normal subjects. At best, it examines the superiority of each hemisphere to perform the information processing task. In normal, everyday conditions, when a stimulus is presented to a person with a neurologically normal brain, both hemispheres are involved in processing the information.

In order to determine which hemisphere is dominant (but not necessarily superior in its ability perform the processing task), unilateral as well as bilateral presentation of the same stimulus information should be made (Hellige, 1991). In the unilateral condition, stimuli are presented to the right visual field-left hemisphere or the left visual field-right hemisphere. This procedure allows the researcher to identify which hemisphere is superior in performing the experimental task.

In the bilateral condition, stimuli are simultaneously presented to both visual fields (thereby simultaneously stimulating both cerebral hemispheres). There are several ways in which this can be accomplished. Hellige (1991) described how he and his colleagues accomplished bilateral presentation of stimuli. A target stimulus was presented at the fixation point. Then a probe stimulus was presented either to the left visual field or to the right visual field (unilateral presentation) or the same probe was presented to both visual fields simultaneously (bilateral presentation). In order to determine hemispheric dominance, that is which hemisphere assumes control of information processing, the pattern of results for the bilateral condition was compared to the pattern of results for the unilateral conditions. If, for example, the pattern between the bilateral condition and the right visual field-left hemisphere presentation of the unilateral condition were similar, then this may suggest that the left hemisphere is the dominant hemisphere in terms of how it processes information.

Another method of bilateral presentation is the use of chimeric stimuli. Levy and Trevarthan (1976) used chimeric stimuli which were comprised of drawings of common objects in which the left half and the right half of each of the stimuli were of two different half pictures. Each half picture was joined at the vertical midline. That is, for each chimeric stimulus, the right half of the stimulus was the right half of one drawing (e.g., the right half of a picture of a cake) and the left half of the stimulus was the left half of a different drawing (e.g., a pair of scissors). After the subjects viewed the chimeric stimulus in the tachistoscope, the subjects were asked to point to the picture from a set of pictures presented to them in free vision to indicate, for example, the picture most similar to the one that was viewed with the tachistoscope.

The bilateral presentation procedure can provide a means for the experimenter to determine the qualitative processing differences between the two hemispheres. For example, if the pattern of responses are similar for stimuli presented unilaterally and bilaterally to the left hemisphere, then it is likely that the left hemisphere assumes control in processing information for that particular task type. If the left hemisphere in the unilateral and bilateral cases are significantly better than the right hemisphere in a unilateral task, then for that particular stimulus, the left hemisphere is the dominant as well as the superior hemisphere in the information processing task. However, if the right hemisphere results in superior performance for a unilateral task, but the pattern of results are similar for the left hemisphere and the bilateral condition, then based on the concept of metacontrol, the right hemisphere is said to be superior but not dominant.

The significance of such a procedure is that statements can be made to the effect that, given a choice, (bilateral tasks offer a choice of which hemisphere will be used), one or the other hemisphere is likely to be dominant in a bilateral presentation of a particular stimulus.

Nonverbal Stimuli

Despite the earlier statement that not all research evidence support the cerebral laterality models, the results of lateralization studies have generally supported the material specific theory. Generally, the left hemisphere is more efficient in processing verbal stimuli compared to the right hemisphere and vice versa for nonverbal stimuli. The evidence, however, is more consistent for verbal stimuli than for nonverbal stimuli. The negative results of some studies are suspect because, in some cases, the nonverbal stimuli may have been easily encoded verbally as well as processed nonverbally by the subjects.

The material specific theory of the cerebral dominance model suggests that easily verbalized nonverbal stimuli are more efficiently processed in the left hemisphere because of its verbal nature and nonverbal stimuli which cannot be verbalized are processed in the right hemisphere. The results may be inconsistent because of the possibility that subjects were able to attach verbal labels to complex stimuli and that some subjects attached labels to low-complexity shapes while others did not.

Studies have used a variety of nonverbal stimuli such as dots, lines, symbols, pictures, and drawings, as well as novel stimuli such as random shapes and chimeric stimuli in the investigation of hemispheric laterality. No conclusive statements can be made regarding hemispheric laterality of nonverbal stimuli because of the lack of consistency in research results. For example, studies involving complex random shapes have resulted in left hemispheric advantage for low-complexity (4-, or 6- point) shapes (Hannay, Rogers, & Durant, 1976), or no hemispheric differences (Fontenot, 1973). What is more, for high-complexity (12-point) shapes, Hannay, et al.(1976) found a left hemisphere advantage, while Fontenot (1973) found a right hemisphere advantage for the high-complexity random shapes.

The use of geometric forms as nonverbal stimuli appear to result in equally conflicting outcomes. The right hemisphere is not always the superior hemisphere in processing geometric stimuli. Generally, there is a left hemisphere advantage for simple geometric forms. This is consistent with the cerebral dominance model which postulates that easily verbalized nonverbal stimuli are processed in the left hemisphere.

Studies by Umilta, Bagnara, and Simion (1978), and White and White (1975) reported a left hemisphere superiority for simple geometric forms. However, Umilta, et al. (1978) found a right hemisphere advantage for complex (4 to 12-sided) geometric shapes. Other researchers have demonstrated a right hemisphere superiority for geometric stimuli regardless of complexity level (e.g., Franco & Sperry, 1977; Manelis & Grebennikova, 1984).

The discussion thus far suggests that the evidence do not fully support the traditional model of cerebral laterality. One of the problems is that some nonverbal stimuli may be verbally encoded thereby resulting in a left hemisphere advantage. Another problem may be due to the complexity issue. It appears that, depending on the degree of complexity, the left hemisphere or the right hemisphere may be more efficient in processing nonverbal visual information. The evidence suggests that easily verbalized stimuli are processed in the left hemisphere more efficiently than in the right hemisphere. In addition, there may be a hemispheric shift in processing complex stimuli. That is, moderately complex stimuli may be processed in the right hemisphere, but as complexity increases, information processing shifts to the left hemisphere.

<u>Gender</u>

Gender is another important issue in the hemispheric laterality literature. Studies have shown that there are sex-related differences in cerebral lateralization. In general, right-handed normal male subjects have been shown to be more lateralized than females (McGlone, 1980) and left-handed subjects.

In a review of laterality studies, Bryden (1982) concludes that males are more lateralized than females on dichotic and tachistoscopic verbal tasks as well as for spatial processing tasks. In addition studies show gender-related differences in terms of performance on spatial and verbal tasks. Males exhibit superiority in spatial ability tasks (McKeever, 1991) while women demonstrate superior performance in verbal tasks (McGlone, 1980). What is more, right-handed males show a left hemisphere advantage for verbal (aural and visual) tasks and a right hemisphere advantage for visuo-spatial and visual perception tasks. Women show no significant field advantage (Goodglass & Butters, 1988).

Sex differences on verbal and spatial processing tasks have also been found in cerebral blood flow (CBF) studies (e.g., Bryden, 1982; Deutsch, et al., 1988). CBF measures were taken for males and females engaging in a task requiring mental activity. While all subjects demonstrated an increase in CBF for the left hemisphere while performing verbal tasks and an increase of CBF in the right hemisphere during spatial tasks, the degree of CBF was greater for women and left-handed males. However, Deutsch, et al. (1988) found that the pattern of hemisphere activation was not significantly different between males and females. The results of the Deutsch, et al. (1988) study suggests that there is little evidence that females depend less on the right hemisphere during visuospatial tasks compared to men.

Other studies, however, do support the differences between males and females for verbal and spatial tasks. For example, Bradshaw, Gates, and Nettleton (1977) presented words or nonwords unilaterally to male and female subjects who were required to respond with bimanual key presses to indicate whether the stimulus was a real word or a nonword. The results of the experiment demonstrated that, in general, right-handed subjects were faster than left-handed subjects. But in terms of gender-related differences, females were faster than males. In terms of cerebral asymmetry, right-handed males demonstrated a greater left hemisphere superiority (i.e., faster reaction time). The hemisphere differences for both females and left-handed males were not statistically significant. A follow-up study (Bradshaw & Gates, 1978) supported the hemisphere asymmetry in men.

Studies using nonverbal visual stimuli have also resulted in sex-related differences. However, the differences are not as dramatic or consistent as the studies employing verbal stimuli. After reviewing a number of studies which used dots or lines as the nonverbal stimulus in visual laterality studies, Bryden (1982) stated that, in general, male subjects show a right hemisphere advantage and females do not. The reasons for this sex-related difference are not clear. Two possible explanations are that women may use verbal strategies in nonverbal tasks (Bryden, 1982) or they may in fact be less lateralized for spatial tasks than are men.

Studies have also reported gender-related differences in spatial abilities with males demonstrating superior performance compared to females (McKeever, 1991). But the causes for gender-related differences are not clear. McKeever and other researchers (e.g., Halpern, 1986; and Kolb & Whishaw, 1990) reviewed a number of studies which suggest a variety of variables which may influence the gender-related difference in spatial abilities (eg., differential brain organization, genetic sex-linkages, maturation rate, the environment, preferred cognitive mode, hormones, and socialization).

Caution must be exercised, however, when making general statements regarding the sex-related differences in spatial tasks. There is general agreement that spatial ability involves multiple processes rather than a single process (Linn & Petersen, 1985). That is, it has been well established that visual-spatial ability is a multidimensional trait (McKeever, 1991). Researchers have identified several factors which underlie spatial ability. For example, after reviewing factor analytic studies, McGee (1979) identified two major factors of visual-spatial abilities--visualization and orientation. These factors are two components of mental rotation (Kolb & Whishaw, 1990).

The visualization factor involves the recognition of irregularly shaped objects or configurations as the same regardless of how they are positioned in space. That is, visualization is the ability to rotate cognitively or manipulate pictures of two- or three-dimensional objects such as in a mental rotation task. Orientation, the second factor, is described as the ability to recognize the relationship between different stimuli as well as the ability to perceive spatial patterns accurately (Halpern, 1986). This factor is often referred to as spatial relations ability (McKeever, 1991).

In addition to the two factors identified by McGee (1979), other categories have been identified. In a recent meta-analysis of spatial ability studies, Linn and Petersen (1985) described three different categories of spatial ability--spatial perception, mental rotation, and spatial visualization. Spatial perception ability can be measured, for example, with the Rod and Frame Test in which subjects must place a rod in a vertical position in the presence of a frame that is oriented at 22 degrees. Another example is the water level task which requires subjects to draw a horizontal line in a picture of a tilted bottle or to indicate or identify which drawing of a tilted bottle has a horizontal line.

Mental rotation, as described earlier, is the ability to rotate two or three dimensional pictorially represented objects as quickly and accurately as possible. The third category identified by Linn and Petersen (1985) is spatial visualization and may involve the same processes required for spatial perception and mental rotation tasks. Spatial visualization tasks include such tasks as the Embedded Figures and Paper Folding. Spatial visualization requires complex manipulations of spatially presented stimuli.

The meta-analysis of spatial ability suggests that the processes for each of the three categories (spatial perception, mental rotation, and spatial visualization) involve different processes. The spatial perception task can be accomplished by using a gravitational/kinesthetic process. Mental rotation can best be accomplished using a Gestalt, mental rotation process. Finally, efficient performance on the spatial visualization tasks requires an analytic process. Thus, because different spatial tasks require different processes, spatial ability is said to be a multidimensional ability.

Additional evidence to support the multidimensionality of spatial ability has been demonstrated by regional blood flow measures during different spatial abilities tasks (mental rotation, line orientation, and fragment puzzle tasks). Deutsch, et al., (1988) found that hemisphere asymmetry of regional cerebral blood flow was greatest for mental rotation tasks. In addition, while both the mental rotation and line orientation tasks demonstrated greater right frontal activity, the mental rotation task was the only task that showed asymmetry in the parietal region. (The parietal region is associated with visuospatial and visuoconstructive processing). Although there was no significant difference between males and females in terms of hemisphere asymmetry, the degree of asymmetry was greater for females than males. Deutsch, et al. (1988) suggested that this may have been due to the greater effort by women in performing these tasks.

Males generally perform better than females on spatial ability tasks. However, this is generally true only for spatial perception and mental rotation tasks with the greatest gender-related difference demonstrated on mental rotation tasks (Osaka, 1984). There is no evidence of sex differences in spatial visualization tasks. It has been suggested that spatial visualization performance may depend, to a large degree, on general abilities which do not demonstrate sex differences rather than on spatial ability.

In general, it appears that (with the exception of mental rotation tasks and spatial visualization tasks) right-handed males are more lateralized than females and left-handed males. The evidence was especially compelling for tasks using verbal stimuli. According to Bryden (1982), audition and visual studies demonstrate the same pattern of results thereby supporting the argument for gender-related differences in hemisphere lateralization for verbal processing. Likewise, lateralization in spatial processing is supported by similar patterns of results in studies using tactual and visual modalities (Bryden, 1982).

Serial vs. Parallel Processing

One of the important issues of visual information processing is the serial vs. parallel processing issue (Howell, 1982). Serial vs. parallel processing is another variation of the global vs. local and the holistic vs. analytical processing strategy. Parallel processing occurs when stimuli are processed in parallel or all at once, while serial processing occurs when information is processed one unit at a time.

The common relationship among the terms global, holistic, and parallel is that processing of information occurs all at once or simultaneously. For local, analytic, and serial processing occurs one at a time or successively. Thus, researchers have used the dichotomous terms holistic/analytical, simultaneous/successive, global/local, and parallel/serial to describe processing strategies, functions, or operations as if they were interchangeable or defined closely related processes (e.g. Bradshaw & Sherlock, 1982; Boles, 1984; Brand, et al., 1983; Cohen, 1973; Folk & Egeth, 1989; Magaro & Moss, 1989; Martin, 1979; Polich, 1984; Umilta, et al., 1979). Thus, the terms parallel and serial processing are used loosely for this study to describe simultaneous and successive processing of information.

The distinction between the two systems is based on how information is processed. Traditionally, the difference deals with the amount of time necessary to process information. The serial system processes units of information one at a time. Processing of one unit of information is completed before processing begins on the next unit of information (Townsend, 1971, 1974, 1990). The parallel system processes units of information in a simultaneous manner. Processing proceeds simultaneously, but individual elements or units may be completed at different times (Townsend, 1974).

A linear increase of reaction time with increasing information load (complexity) may indicate that serial processing of information has occurred. Parallel processing could be indicated by a mean reaction time which does not increase as a function of increased load (e.g., Magaro & Moss, 1989; Nishikawa, 1982; Van der Heijden, et al, 1983).

While the linear increase in reaction time as a function of increasing set size, complexity, or information load has generally been used to determine serial processing, accuracy measures have also been used to demonstrate serial or parallel processing of information (e.g., Manelis & Grebennikova, 1984).

Research on the serial vs. parallel processing of visual information has not led to a clear understanding of the stimulus characteristics which require parallel or serial processing. In addition, studies which attempt to implicate hemispheric asymmetry in the serial vs. parallel processing issue are few. For example, early investigations described by Cohen (1973) suggest that serial processing was a left hemisphere function, while holistic or parallel processing of individual stimuli was a function of the right hemisphere. However, contrary evidence have suggested that this left-right hemisphere distinction in the serial vs. parallel processing is an oversimplification.

In an effort to investigate further the serial vs. parallel processing as a function of hemisphere, Cohen (1973) conducted a series of experiments and found evidence to support the left-right hemisphere distinction for serial vs. parallel processing. However, this distinction was limited to verbal material. That is, the left hemisphere showed increased reaction times with increasing number of letter stimuli. But reaction time did not significantly increase with increasing numbers of letter stimuli in the right hemisphere. Therefore, parallel (or holistic) processing of letter stimuli was indicated. However, when the stimuli consisted of nonverbal, unnameable symbols (i.e., [, <, and /) both left and right hemispheres appear to process in parallel.

Further attempts to establish a left-right hemisphere distinction for the serial vs. parallel processing issue have resulted in similar, contrary, or inconclusive evidence. Investigations using Cohen's (1973) verbal and nonverbal stimuli have resulted in different findings. For example, when Polich (1980) attempted to replicate Cohen's (1973) results, he found no evidence to support hemispheric differences between serial and parallel processing. But in a later study in which reaction time data were analyzed, Polich (1982) found a left hemisphere advantage for both serial and parallel processing (demonstrated by the use of letter stimuli and symbols, respectively). Although the difference in reaction time between serial and parallel processing was not statistically significant, error analysis showed a lower error rate for parallel processing of symbols in the left hemisphere. Therefore, it appears that there was a stronger left hemisphere advantage for parallel processing of nonverbal stimuli (symbols).

One of the problems with the results based on the nonverbal stimuli in Cohen's (1973) and Polich's (1980; 1982) studies is that some of these symbols may in fact have been processed verbally (a left hemisphere function) by some subjects and therefore mitigated any hemispheric differences that may otherwise exist.

Other research efforts investigating hemispheric differences in serial and parallel (or analytic vs. holistic) processing of various other types of stimuli have also resulted in conclusions that do not make a clear-cut distinction between the left hemisphere advantage for serial processing and right hemisphere advantage for parallel processing. For example, Eglin (1987) concluded that serial processing of conjunctive stimuli (Stroop-like stimuli) occurs in both hemispheres. Boles (1984) similarly concluded that there was no indication of hemispheric asymmetry for global and local processing during a Stroop-like test.

There have been studies which resulted in effects contrary to Cohen's (1973) investigation. That is, the right hemisphere is superior for serial processing and the left hemisphere for parallel (holistic or global) processing. Brand, van Bekkum, Stumpel, and Kroeze (1983) using word stimuli suggested a serial processing in the right hemisphere and a whole word (holistic/parallel processing) approach in the left hemisphere. Polich (1986) cites several references which support a right hemisphere advantage for analytic (serial) processing (e.g., Bryden & Allard, 1976; Jonides, 1979; and Salmaso & Umilta, 1982; cited in Polich, 1986). Umilta, Salmaso, Bagnara, and Simion (1979) also found evidence for a right hemisphere advantage for a serial search strategy in a simple dot detection task. There is also evidence to suggest that holistic (parallel) processing occurs in the left hemisphere (e.g., Martin, 1979; Umilta, Bagnara, & Simion, 1978).

There may be a variety of factors influencing the lack of consistent research evidence. Stimulus category (e.g., verbal vs. nonverbal) may have some effect on the outcome of the serial vs. parallel processing studies as it relates to hemispheric laterality. But other factors also influence how information is processed. The results of an investigation by Patterson and Bradshaw (1975) illustrate this point. A series of experiments was conducted to determine that the left-right hemispheric superiority does not entirely depend on the type of stimuli but rather on how the stimuli are processed. In their experiments, Patterson and Bradshaw (1975) demonstrated that the left hemisphere was superior in processing nonverbal stimuli (schematic faces) when the task required analytic processing of the schematic faces. It should be noted, however, that the task required the subjects to store information in long-term memory. The memory requirement may possibly have also influenced the outcome of the experiment. That is, it can be argued that overloading the memory in one hemisphere, for example, the right hemisphere, may force the processing to be transferred to the other hemisphere (the left hemisphere, in this case).

There is research evidence to suggest that laterality can be affected in situations where memory is tasked (Hellige & Cox, 1976; Hellige, Cox, & Litvac, 1979; Kinsbourne, 1975). Laterality studies have demonstrated that concurrent memory tasks can affect the recognition accuracy of stimuli in the different visual fields (Hellige & Cox, 1976). In some cases, memory set size interacted with cerebral hemisphere. For example, a concurrent verbal memory task can affect the recognition of complex polygons (Hellige & Cox, 1976). Compared to the no memory condition, a small memory set size improved the recognition accuracy of polygons presented to the left hemisphere. But when verbal memory set size was large (e.g., six words), then accuracy dropped to below the level in the no memory condition.

There are indications also that memory load can cause a shift in hemisphere advantage in terms of reaction time. For example, Hellige, Cox, and Litvac (1979) demonstrated that a concurrent verbal memory can cause a shift in hemisphere advantage for a verbal laterality task. During a no memory condition, responses to the verbal laterality task (same-pair letter trials) were faster on the left hemisphere trials than on the right hemisphere trials. However, when the subjects were required to engage in the concurrent memory task of different set sizes, then there was a shift in laterality. That is, responses to the verbal laterality task were faster for the right hemisphere trials compared to the left hemisphere trials. Thus, memory load may have an effect on the information processing strategy.

The research literature investigating the serial vs. parallel issue (including analytic vs. holistic and local vs. global issues) as it relates to cerebral hemispheric laterality has thus far presented no consistent or conclusive evidence to support the left hemisphere advantage for serial (including analytic) processing and the right hemisphere advantage for parallel (and holistic) processing. What remains certain is that the literature presents confusing evidence. Contributing to the confusion is the lack of consistency in the type of stimuli used in the studies as well as the apparent ability of subjects to use verbal labels for nonverbal stimuli.

Inconsistency of Results

A review of the research literature is organized in such a way that will facilitate a better understanding of why the results of past studies have been inconsistent. Most noticeable is the variety of conclusions based on studies using the same stimuli or highly similar stimuli, specifically the studies by Cohen (1973) and Polich (1980 and 1982) which were discussed earlier.

Some investigators have suggested that the serial vs. parallel issue really has to relate to the type of instructions given to the subjects (e.g., Patterson & Bradshaw, 1975). The instructions are thought to prime the subjects to utilize either serial or parallel processing of information and therefore result in the superiority of the hemisphere specialized in that type of processing strategy. However, in many cases, the type of stimuli appears to influence hemisphere advantage. Researchers investigating the serial vs. parallel processing issue use a variety of stimuli, such as words, letters, line segments, dots, symbols, complex random shapes, and geometric shapes. Therefore, the literature is categorized based on the type of stimulus used in the studies which were reviewed for this study.

Verbal stimuli (such as words and letters), easily verbalized nonverbal stimuli, and complex random shapes have been used in past research. Although the results of the research have not overwhelmingly supported the serial vs. parallel processing in the left and right hemispheres, respectively, the evidence thus far appears to support the view that verbal material and easily verbalized nonverbal material are best processed in the left hemisphere (e.g., Cohen, 1973; Martin, 1979). In addition, the evidence for a left hemisphere advantage for serial processing appear to weigh more heavily than a left hemisphere advantage for parallel processing (e.g., Cohen, 1973; Martin, 1979).

Letter stimuli. Results of studies using letter stimuli may have been influenced by the verbal nature (letters) of the stimulus when the experimenter attempted to elicit parallel processing.

The purpose of the Martin (1979) and Boles (1984) studies was to determine whether the right hemisphere was a global (holistic) processor and the left hemisphere was an analytic processor. Holistic processing is associated with processing of global (or large) characteristics while analytic processing is associated with processing the smaller (or local) characteristics of visual stimuli.

The experimental stimuli in Martin's (1979) and Boles' (1984) studies were designed to ensure that fair comparisons could be made between holistic and analytic processing. The global and local features were equal in complexity and recognizability and the whole stimulus could not be predicted from the individual or local elements, and vice versa.

For example, Martin (1979) and Boles (1984) used Stroop-like verbal stimuli in letter recognition tasks. The stimuli which were labeled as either global or local were utilized to stimulate holistic or analytical processing, respectively.

The term local letters refers to the individual letters which form the shape of a larger letter or pattern. For example:

```
A         A
A         A
A         A
A A A A A A
A         A
A         A
A         A
```

the letter 'A' is referred to as the local letter when it is grouped in the pattern or shape of a larger (global) letter (e.g., an 'H') or a symbol.

The task was similar to a Stroop test (Stroop, 1935). In a Stroop test, subjects, for example, are asked to name the color of the ink in which a word is written. Generally, the reaction time is slower when the word is the name of a color that conflicts with the color of the ink.

Martin (1979) and Boles (1984) incorporated a variation of the Stroop test and stimuli. Martin (1979) believed that this procedure could be used to determine the type of processing involved in the experimental task. Subjects were instructed to report either the global shape (e.g., H or S) or the local shape (e.g., H or S).

Martin's (1979) investigation resulted in a statistically significant interaction between type of processing and visual field. She found that reaction time of vocal response to the stimulus presented to the right visual field was significantly faster for local (i.e., individual) letters, which is thought to require serial or analytical processing. Therefore, her study provides evidence that serial processing of local letters is more effectively performed in the left hemisphere than in the right hemisphere. However, there were no field differences for global letters.

Boles (1984) conducted a series of experiments which resulted in null effects for visual fields when the subjects responded with a manual key press (response hand was controlled by balancing across subjects in Experiment 1 and by bimanual key response in Experiment 2). That is, contrary to Martin's (1979) study, there were no significant hemispheric differences in a manual key press task in response to neutral or conflicting Stroop-like stimuli. But when subjects were required to respond by vocally naming the stimuli as the response task, Boles (1984) did find a left hemisphere advantage. Taken together, Boles (1984) concluded that the left and the right hemispheres are equally specialized in processing local (analytic) and global (holistic) stimuli when a manual key press response was required. The asymmetry was a function of the vocal response which is lateralized in the left hemisphere.

Other examples of the confusion between serial vs. parallel processing can be seen in studies utilizing letter stimuli to elicit both serial and parallel processing. Magaro and Moss (1989) found a right hemisphere advantage for serial and parallel processing (as well as for analytic and holistic conditions). This study involved the detection of an 'X' in an array of either straight letters or curved letters. The straight letter condition was used as a serial processing condition while the curved letter set was used as the parallel processing condition.

Like many other studies, the lack of right hemisphere advantage for parallel (or global/holistic) processing in the studies discussed above involved the use of stimuli which were verbal (letters) in nature. Thus, a global (parallel processing), verbal pattern may have been processed either in parallel or serially. The discussion of Martin's (1979) and Boles' (1984) studies suggests that when using letters (verbal stimuli), it is not always the case that the left hemisphere is superior in the serial processing strategy.

Word stimuli. When words are used as stimuli in recognition tasks (Bradshaw, et al., 1977) and matching tasks (Brand, et al., 1983), results have also been inconsistent with the hemisphere strategy theory of the cerebral dominance model. Both studies found a left hemisphere advantage for parallel processing of word stimuli. Moreover, Brand, et al. (1983) also found a right hemisphere superiority for serial processing. This further adds to the question as to whether words used as stimuli in parallel processing tasks are appropriate because verbal stimuli may or may not be processed in the right hemisphere when used to mimic stimuli requiring parallel or holistic processing.

The use of letter stimuli to evoke both serial and parallel processing in the studies discussed above has resulted in inconclusive results. Therefore, the verbal stimuli may not have been appropriately designed to stimulate clearly the serial and the parallel processes.

Geometric stimuli. In addition to words, letters, and simple stimuli such as dots and lines, geometric stimuli have also served as experimental stimuli in serial vs. parallel processing research. There is evidence to suggest that serial processing of complex geometric forms occurs in the left hemisphere and parallel processing occurs in the right hemisphere. Manelis and Grebennikova (1984) reported that the left hemisphere was better at recognizing simple (single outline) forms than complex (double outline) forms. The right hemisphere, on the other hand, recognized both simple and complex levels of stimuli equally well. What is more, the right hemisphere performed better than the left hemisphere.

In terms of the serial vs. parallel processing and the implications for hemispheric laterality, Manelis and Grebennikova (1984) concluded that the results of the experiment support the view that the left hemisphere processes successively (or serially) while the right hemisphere is superior in processing in parallel as shown by its ability to process complex geometric shapes better than the left hemisphere. Their conclusion was based on the error analysis.

The difference in percent of errors between simple and complex figures (19.4 and 20.4 percent, respectively) was not statistically significant for figures presented to the right hemisphere. However, the left hemisphere committed significantly more errors for complex figures than for simple figures (38.3 percent vs. 21.9 percent).

Their analysis revealed that the left hemisphere committed significantly more errors than the right hemisphere in perceiving a double figure as a simple figure (29.2 and 13.7 percent, respectively). That is, subjects identified a double figure as a simple figure of the same shape or as a simple figure of a different shape.

Based on the error analysis, Manelis and Grebennikova (1984) postulated that the outer or external shape of the double figure was perceived first followed by the inner or internal shape of the double figure. However, when the amount of stimulus exposure time is too short, then this sequential analysis cannot be completed. (The stimulus exposure time ranged from 5 to 20 msec and was individually selected for each subject.) This explains why the double figures were more likely to be identified or recognized as a simple figure. Manelis and Grebennikova (1984) therefore concluded that serial processing occurs in the left hemisphere and parallel processing occurs in the right hemisphere.

In another study, Franco and Sperry (1977) investigated hemisphere laterality for the intuitive processing of geometrical forms. Although this study was not intended as a serial vs. parallel processing investigation, it does provide evidence of a holistic processing advantage in the right hemisphere for geometric stimuli.

In the Franco and Sperry (1977) study, the experimental group consisted of subjects who were patients with complete commissurotomy, partial commissurotomy, and hemispherectomy. Additionally, one subject had a total absence of the corpus callosum as evidenced by an X-ray diagnosis. (There was a total of ten subjects in the experimental group.) A group of five normal subjects served as the control group.

A cross-modality (visual-tactile) task was used. The procedure required the simultaneous presentation of two sets of geometric stimuli. The first set consisted of groups of two-dimensional and three-dimensional geometric forms presented in free vision to the subject for inspection. The second set of forms was set behind a screen directly in front of but out of the view of the subjects. The subjects were required to examine the set of forms hidden behind the screen by touch (left hand or right hand). Then the subjects were required to make a manual response (by manual signal with the involved hand) indicating which one of the objects belonged to the set of forms examined in free vision.

The results of the study indicated that the right hemisphere-left hand condition performed better than the left hemisphere-right hand condition. That is, speed and accuracy were superior for the right hemisphere-left hand condition. (The control group did not show laterality effects.) What is more, the differences in performance between the left and right hemisphere increased with the complexity of the geometrical forms represented by Euclidean, affine, projective, and topological forms (that is, triangles, four-sided forms, complex random forms, and curved random forms, respectively for the two-dimensional condition; blocks, cylinders, complex random forms, and curved random shapes, respectively, for the three-dimensional condition). However, there was very little difference between the hemispheres for the Euclidean forms.

Only descriptive statistics (percent correct, time in minutes, group mean, and standard deviations) were provided. Thus, although the analyses suggest the right hemisphere's superiority in processing geometric stimuli, no such statement regarding statistical significance between groups can be made.

In reviewing the literature, it appears that the type of stimuli may have an important effect on the outcome of hemispheric laterality and serial vs. parallel processing studies. That is, it may be questionable as to whether verbal stimuli are suitable to encourage or activate the type of hemispheric processing strategies which are under investigation.

Identification and detection of simple features. One might question whether the confusing results may have something to do with the complexity level of the stimuli. For example, some words or letters may be of a more complex shape such as some straight letters such as K, N, or T. Others may appear more simple such as O, C, or S. Studies using simple features in an array of short diagonal line segments where the subject must detect vertical or horizontal lines also result in contradictory results.

It has long been assumed that primitive features of objects such as color, size, brightness, and orientation are identified in parallel (e.g., Broadbent, 1982; Francolini & Egeth, 1980; and Mullin & Egeth, 1989; cited in Folk & Egeth, 1989). Sagi and Julesz (1985a; 1985b) suggest that the process of identification and detection require different processing strategies. They suggest that the "identification" of simple features occurs serially while the "detection" of simple features occurs in parallel. However, several studies support the suggestion that processing of simple features occurs in parallel. Folk and Egeth (1989) conducted a study to determine whether the identification of simple features are processed serially or in parallel. Based on the results of their study, they concluded that the identification of simple features (line segments) is done by parallel processing with unlimited capacity.

The Measurement of Speed and Accuracy

As stated earlier, reaction time is the index used most often by researchers in determining serial and parallel processing. A linear increase in reaction time with increasing complexity is an indication of serial processing. A lack of increase in reaction time is evidence of parallel processing.

In addition to the measure of reaction time, accuracy measures can also determine whether processing is serial or parallel in nature. A method based on accuracy described in Townsend (1990) is called Tests by Time Delimitation. This method is based on the assumption that accuracy will decline (when exposure duration is held constant) for serial processing of n items presented simultaneously when compared to parallel processing. The rationale underlying this method is that if n items are presented for T duration, then serial processing time of each item will be T/n. However, the parallel processing duration for n presented simultaneously will continue to be T since processing occurs simultaneously.

The Tests by Time Delimitation method requires two Conditions. That is, for the same time duration, items are presented either simultaneously (Condition 1) or successively (Condition 2). In the first condition (where the number of items is, for example five and the total duration is 250 msec) items are presented simultaneously. Thus, the time allotted for serial processing for each individual item would be T/n (or 50 msec each item). However, parallel processing would allot 250 msec for processing for each item since all items are assumed to be processed simultaneously.

Under Condition 2 where items are presented successively, each item is presented for 250 msec. Therefore, if processing is serial, each item would receive 250 msec of processing time (compared to 50 msec in Condition 1). If processing is parallel, then each item would continue to receive 250 msec of processing time which is the same as in Condition 1.

Based on this logic, parallel processing would be supported if accuracy in the first condition is not significantly lower than for the second condition. However, if the accuracy rate is lower for the first Condition than the second, then this can be taken as evidence for serial processing of information. This would be a logical conclusion because the processing time available in Condition 1 would be much lower than for Condition 2.

Townsend (1990) briefly describes a technique developed by him and his colleagues based on the logic described above. The first level (or condition) is identical to the first level described above. However, for the second condition, n items are presented successively, with the total exposure time per item of 50 msec (i.e., T/n). Under this model, serial processing would provide 50 msec processing time for each item which is the same under Condition 1. Therefore, if processing is serial, then accuracy should be about equal for both Condition 1 and Condition 2. If, however, accuracy declines from Condition 1 to Condition 2, then processing is parallel. In Condition 1, more time is allotted (250 msec) than for Condition 2 (50 msec), therefore performance is expected to be lower for Condition 2.

Experimental Stimuli

Metric Histoforms. The experimental stimuli for this study were selected based on several considerations. One of the important issues for this proposed study was to select the type of stimulus which cannot be verbally encoded (a left hemisphere function). According to the traditional view (material specific theory) of hemisphere laterality, easily verbalized stimuli are processed more efficiently in the left hemisphere. Therefore, a simple geometric form such as a triangle, circle, or square, for example, could result in a left hemisphere advantage due to its being encoded verbally rather than being processed in one hemisphere or the other based on its complexity level. Second, complexity levels must be easily manipulated in order to develop high-complexity levels to force a serial processing strategy. Third, memory must not be a factor in the experimental task.

In addition, the stimulus which will be computer-generated must not be characterized by any salient features such as jagged or ragged edges. Salient features may cause the subject to focus his or her attention to that particular feature rather than the entire stimulus. Therefore any shapes with diagonal lines cannot be used as stimuli for this study because the computer generating the stimuli does not have the capability to produce smooth diagonal lines.

Fortunately, "metric histoforms", a class of geometric figures which resemble solid contoured bar graphs, possess the necessary features required for this proposed study. Metric histoforms are metric figures that are relatively simple stimuli which cannot be easily verbalized, do not contain diagonal lines, and whose complexity can be manipulated by increasing the number of cells in the matrix. For example a 4x4 matrix (16 cells) containing four columns each with four possible column heights can represent a low complexity stimulus while an

8x8 matrix (64 cells) can be used to represent a high complexity stimulus.

Early research on form perception using the metric figures have shown that there is a difference in performance efficiency between matrices with different number of cells (4x4, 6x6, and 8x8). Early experiments have consistently shown that as complexity level increases, human performance becomes less efficient (e.g., Baker & Alluisi, 1962). That is, the more complex the forms, the slower the response time and the greater the error rate. Therefore, based on the results of early experiments, the manipulation of the number of cells in the metric histoforms does represent manipulation of complexity levels.

Complexity. The information load were represented by geometric figures in varying degrees of complexity. Degrees of complexity were low, moderate, and high represented by a 4x4 matrix, a 6x6 matrix, and an 8x8 matrix. According to Miller (1959), humans in an absolute identification situation have a memory capacity of seven, plus or minus two units of information. Research has shown this to be true also for visual information processing.

The literature described in the section on hemispheric laterality and serial vs. parallel processing suggests that stimulus complexity affects how information is processed. It is generally the case that verbal stimuli are processed in the left hemisphere. However, it is not quite clear whether there is generally a right hemisphere or a left hemisphere advantage in processing nonverbal stimuli.

However, the literature on the detection of simple features (e.g., Folk & Egeth, 1989) suggest that detection of simple features such as line segments occurs in parallel. The geometric stimuli chosen for this study is are similar in form to simple line segments since only horizonal and vertical lines are used to form the shape of the stimuli.

Summary

The literature on hemispheric laterality generally supports the material specific theory. However, the serial vs. parallel processing literature generally does not provide strong support for the hemisphere strategy theory. The evidence provides greater support for serial processing of verbal stimuli in the left hemisphere but not for parallel processing in the right hemisphere. That is, when stimuli which are verbal in nature are used to elicit parallel processing, the results of studies have been mixed.

Studies which provide less confusing evidence regarding parallel processing incorporate geometric forms in the experimental procedure. However, this body of research is quite small. The study by Manelis and Grebennikova (1984) provides some evidence to support the hemisphere strategy theory--parallel processing occurs in the right hemisphere and serial processing occurs in the left hemisphere. Another study also provides evidence to support the hemisphere strategy theory. Franco and Sperry (1977) used visuo-tactile modalities in identification tasks and supports a right hemisphere advantage in the identification of geometric forms. In addition, the left hemisphere (but not the right hemisphere) demonstrated an increase in reaction time with increased stimulus complexity which provides support for serial processing in the left hemisphere. More research along this line of investigation should be considered in order to provide a better insight as to the processing strategy required for symbols or nonverbal stimuli with inner details.

The gender issue suggests that right-handed males are more lateralized than females and left-handed males. In addition, right-handed males tend to be left hemisphere dominant for speech and verbal stimuli and right hemisphere dominant for nonverbal, visuo-spatial stimuli.

This study utilized bargraphs to represent geometric figures in order to determine the processing strategy and whether there is hemispheric asymmetry in the processing of such stimuli. Binocular viewing of stimuli presented unilaterally was used to determine the hemisphere advantage for visual information processing of the geometric stimuli. In addition, a bilateral condition was used to determine the dominance of one hemisphere over the other in the visual processing of the geometric stimuli.

The experimental hypotheses which follow have been developed after reviewing the literature on hemispheric laterality, serial vs. parallel processing, and gender differences.

The two models were used to determine how complex geometric stimuli are processed (serial or parallel) in a visual processing task and which cerebral hemisphere would result in the most efficient performance in terms of speed and accuracy. Therefore, field of vision will be manipulated to determine its effects on the identification speed and accuracy of geometric figures of varying degrees of complexity in different cerebral hemispheres.

Independent and Dependent Variables

Independent Variables

The independent variables for this study are Field of Vision (FOV), Complexity, Type (single vs. double stimulus conditions), Time Factor, and Gender. The three FOVs are left, right, and center vision. The experimental stimuli were projected to three visual fields, and it was assumed that stimulus exposed to a particular visual field is processed by the hemisphere contralateral to that field. Therefore, the left and right fields of vision were used to represent the right and left cerebral hemispheres, respectively, in order to determine hemispheric laterality in the serial or parallel processing of visual stimuli. The center field of vision which stimulates both hemispheres simultaneously, was used as the control stimulus. A double stimulus condition was also included in order to determine the presence of hemispheric dominance (metacontrol) by one hemisphere over the other.

Three levels of complexity were manipulated--low, moderate and high. The complexity variable was represented by the three different metric histoform matrices. The low complexity figure was represented by the 16-cell, 4x4 matrix stimuli and is referred to as the 4-column bargraphs. The moderate complexity figure and the high complexity figure were represented by the 36-cell, 6x6 matrix and the 64-cell, 8x8 matrix, respectively, and are referred to as the 6- and the 8-column bargraphs.

Three different stimulus exposure durations (Time Factor) were included (140, 210 and 280 msec) in order to analyze accuracy data based on Townsend's (1990) method, described earlier in this paper. According to Sternberg (1966) the amount of time to process a unit of information is 38.3 msec plus or minus 6.1 msec. For this study, a unit of information is represented by each column in the bargraph. Thus, for a 4-column bargraph presented at 140 msec, each column or bar receives 35 msec of exposure time. The four-column stimuli presented for 210 msec and 280 msec receive over 52 msec and 70 msec, respectively. The same logic can be applied to the 6- and 8-column bargraphs to determine the exposure duration for each column.

Two secondary variables were included as control variables. The order in which the time factors were presented was counterbalanced in order to control for any effects of time order. Therefore, there were six different time sequence orders. Response hand was also included as a control variable in order to control for any stimulus-response effects or effects due to hemisphere advantage of the responding hand. That is, the responding hand ipsilateral to the field of vision may demonstrate a faster reaction time than the hand contralateral to the field of view. Therefore, response hand was counterbalanced to control for any effects due to the responding hand. That is, half of the subjects were instructed to press the "yes" response key with the right index finger; the remaining subjects were instructed to press the "yes" key with the left index finger. These secondary variables were included in the design as control variables and therefore are not discussed in the results of this study.

Field of Vision, Type, and Time Factor were the within-subjects variables. Complexity and Gender were the between-subjects variables.

Dependent Variables

Reaction time and accuracy were the dependent variables. For this study, reaction time is defined as the interval from onset of the stimulus until the response was made by the subject. Accuracy is defined as the percent of correct responses.

Hypotheses

The following hypotheses were based on the research literature described earlier.

1. When hemispheres are simultaneously stimulated by stimuli presented to the center field of vision (CFOV), reaction time and accuracy are better than when each hemisphere is stimulated separately. In addition, according to the hemisphere strategy model (Goodglass & Butters, 1988), when nonverbal stimuli are presented to the left field of vision (LFOV)

reaction time and accuracy are better than for the right field of vision (RFOV).

2. Based on the literature describing gender differences in spatial abilities (e.g., McKeever, 1991), responses for males are faster and more accurate than females.

3. Based on the Hypotheses 1 and 2 above, males are faster and more accurate than females; but this difference is only for stimuli presented to the LFOV. Females do not demonstrate this type of cerebral asymmetry because the literature suggests that females are less lateralized than males (Goodglass & Butters, 1988).

4. Based on the Baker and Alluisi (1962) study, performance is faster and more accurate for the 4-column bargraphs than for the 6- or 8-column bargraphs. Performance on the 6-column bargraphs is faster and more accurate than for the 8-column bargraphs.

5. Based on the hemisphere strategy model (Goodglass & Butters, 1988), performance on the different complexity levels depends on the location of the

stimuli. Speed and accuracy do not differ among complexity levels for stimuli presented to the LFOV. This lack of difference among complexity levels is evidence of parallel processing in the right hemisphere (RH).

However, performance for stimuli presented to the RFOV is different. Speed and accuracy are better for the 4-column bargraphs than the 6- and 8-column bargraphs. But speed and accuracy are better for the 6-column than the 8-column bargraphs. This indicates serial processing in the left hemisphere (LH).

6. In accordance with Hypothesis 4 that performance for low complexity stimuli is better than for high complexity stimuli, speed and accuracy are better for the single stimulus condition than for the double stimulus condition. The single condition is assumed to be less complex than the double condition.

Based on the metacontrol literature (Hellige & Cox, 1976), the LH is the dominant hemisphere. Therefore, performance on the single and double stimulus conditions depends on the FOV where the stimuli are presented. The LH performs better than the RH during the double stimulus condition but not during the single stimulus condition.

7. According to the hemisphere strategy model (Goodglass & Butters, 1988), accuracy is better for stimuli presented for longer exposure durations when processing is serial. That is, the more time available to process information, the more accurate the responses are.

When the amount of time for each column within bargraphs of different complexity levels is 35 msec, accuracy is not different for those exposure durations and complexity levels. That is, accuracy is similar for the 4-column bargraph at 140 msec exposure duration, the 6-column bargraph at 210 msec exposure duration, and the 8-column bargraph at 280 msec. This logic was derived from the Method of Time Delimitation described in Townsend (1990).

Based on the hemisphere strategy model, serial processing is demonstrated in the LH. That is, when FOV is considered, only the RFOV (LH) demonstrates the differences in accuracy between the different exposure durations and complexity levels. Parallel processing is demonstrated when the accuracy measure for the 4-column bargraph across all exposure durations is less than or equal to the 6-column bargraph for the 210 msec and 280 msec exposure duration and the 8-column at 280 msec duration.

METHOD

A pilot test was on conducted on five male and seven female undergraduate students registered for a psychology course. This pilot test was conducted in order to determine the appropriateness of the stimulus exposure duration, size of the stimulus, and testing procedures. The subjects expressed the opinion that the instructions were clear and that the task was difficult, but most felt that eye movement was minimal. The data suggest that subjects were able to see the bargraphs adequately at all three complexity levels.

Experimental Design

The experimental design was a 3 (Complexity) by 3 (Field of Vision) by 3 (Time Factor) by 2 (Gender) by 2 (Type) mixed design. Complexity and Gender were the between-subjects variables; and Time Factor, Position (FOV), and Type (2) were the within-subjects variables.

The Type variable (single vs. double stimulus conditions) was presented in fixed order with the three blocks of the single condition presented first followed by the three blocks of the double stimulus condition. Because the Time Factor variable was counterbalanced, there were six different time sequence levels. However, this was not being considered as part of the design. In addition, Response Hand, a random order variable, was included as a control variable and was not included in the analyses discussed in the results section.

Subjects

Subjects were recruited from the undergraduate psychology students. Participation was voluntary and each subject received extra credit to be applied toward an undergraduate psychology course. Subjects were tested individually. The use of human subjects for this study was in accordance with the Commonwealth of Virginia regulations as well as American Psychological Association guidelines (1981). (See Appendix A.)

There were 108 female and 36 male subjects ranging in ages 18 through 48 years old. Eighty-four percent of the subjects ranged in ages 18 to 22 years. The mean age of the subjects was 21 years.

Hand Score indicated that subjects were predominantly right handed. None of the subjects had a minus score on the handedness questionnaire. (A minus score indicates left handedness or a tendency toward left handedness.) In addition, all subjects had normal vision (20/40 or better).

Material

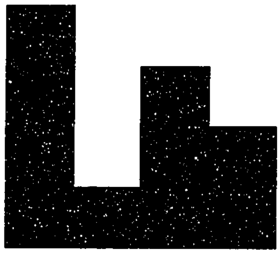
A VGA monitor was used to present stimuli, and subjects responded with key presses on a normal keyboard.

The subject consent form (Appendix A) is required for projects with human subjects to ensure that all the rights of the subjects are conveyed and understood.

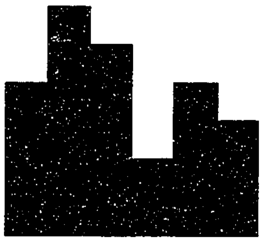
A handedness questionnaire (Bryden, 1982) was used to measure the degree of handedness for each subject. (See Appendix C.) In addition, a subject information section was included to gather demographic information.

Appendix D contains the instructional material and examples of target and non-target bargraphs (4-, 6-, and 8-column) as well as examples of single and double bargraph conditions. Each subject was shown the examples appropriate for the complexity condition being tested at that time (e.g., Figure 1). Target bargraphs were bargraphs which contained two non-contiguous columns of the same height. Non-target bargraphs were bargraphs with all columns of different heights.

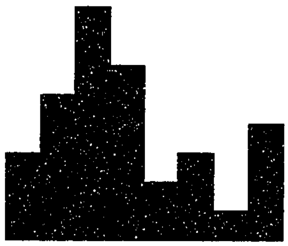
Each subject viewed examples of both the single and double bargraphs (e.g., Figure 2) in order for the experimenter to provide detailed instructions to ensure that the subjects fully understood the task. In the single bargraph condition, only one bargraph appeared on the screen for each trial. However, in the double bargraph condition for the LFOV and the RFOV, two



4-Column Bargraph

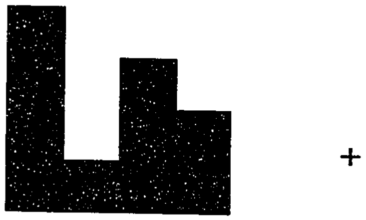


6-Column Bargraph

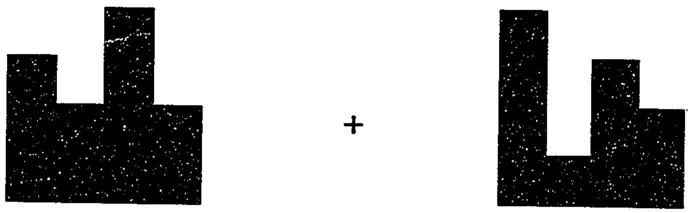


8-Column Bargraph

Figure 1. Examples of Three Complexity Levels.



Single Bargraph Condition



Double Bargraph Condition

Figure 2. Examples of Single Bargraph and Double Bargraph Conditions.

bargraphs, one on each side of the center fixation cross appeared simultaneously on the screen for each trial. For the CFOV in the double bargraph condition, only one bargraph appeared. The examples in Appendix D provided realistic examples of the bargraphs as they would appear on the monitor screen.

The subjects were not given practice trials. During the preliminary testing of the experimental task, the task as it was originally designed, would have been too fatiguing. As a result, the practice trials were not included because there was a concern that inclusion of practice trials would increase the subjects' fatigue level and consequently affect the subjects' responses. Therefore, the illustrations on paper provided a reasonably realistic representation of what the bargraphs might look like and detailed instructions eliminated confusion and/or misunderstanding of the subject's task.

Experimental Stimuli

The "metric histoform", a class of geometric forms was used as the target and non-target stimuli. This type of metric figure resembles a bargraph with a solid contour. That is, there are no vertical lines between the bars or columns to delineate the columns (Figure 1). These figures were computer-generated and randomly selected from the population of all possible forms defined by several rules. As noted above, the stimuli varied in complexity--low, moderate and high. These three levels of complexity were represented by three different matrices--4x4, 6x6, and 8x8, respectively. The 4x4 matrix contained 16 cells; the 6x6, 36 cells; and the 8x8, 64 cells. The overall maximum dimension of the matrices remained constant; therefore, cell dimension decreased with the increased number of cells in a matrix.

The different number of cells in the matrices allowed the manipulation of complexity as well as height of each of the columns in the matrices. As the number of cells increased, the population of different random metric figures also increased. The 4x4 matrix defined a population of 4^4 or 256 random figures. The population of random figures for a 6x6 matrix would be 6^6 or 46,656. The 8x8 matrix would yield a population size of 8^8 or 16,777,216 random metric figures. However, several rules were applied which reduced the population of metric figures in each of these matrices:

Rule 1. For target stimuli, only two non-contiguous columns had column heights that are "redundant". In other words, only two columns will be of the same height and these columns were separated by at least one column.

Rule 2. For non-target stimuli the column heights were "constrained". That is, each column height will be different from each of the other columns in the metric figure. That is, non-target figures contained columns whose heights appeared only once.

Target and non-target stimuli were selected randomly by the computer for each trial with target stimuli appearing on half of the trials.

Stimulus size. Each stimulus was approximately 4.45 cm (1.75 inches) wide and did not exceed 4.45 cm (1.75) inches in height. The stimuli subtended a visual angle of no more than 4.18 degrees horizontally and 4.18 degrees vertically when viewed at a distance of approximately 60 cm (24 inches). Visual angle (VA) in degrees was calculated by multiplying the height (H) or width of the stimulus by 57.3 and dividing the product by the viewing distance (D). That is, $VA = (H \times 57.3)/D$. No part of the stimuli was within the blind spot (between 12 and 17 degrees nasal) when viewed by the subject.

During the actual task, bargraphs were presented on the VDT screen. A 386SX computer generated the bargraphs drawn from a pool of bargraph data points. Bargraphs were white on a blue background. The size of the bargraphs was held constant to control for the size of the image which the subjects viewed.

Bargraphs in each of the three fields of view (FOV) were presented approximately 4.45 cm (1.75 inches) from the geometric center of the screen. The right edge of the bargraph appearing in the left FOV (LFOV) appeared approximately 4.45 cm (1.75 inches) to the left of the center of the screen. The left edge of the bargraph appearing in the right FOV (RFOV) appeared approximately 4.45 cm (1.75 inches) to the right of the center. The bottom edge of the center bargraph (CFOV) was approximately 8.9 cm (3-1/2 inches) below the center of the vertical axis, but centered on the horizontal axis. This procedure allowed for the control of peripheral vision.

Procedure

For each subject, the experimenter briefly described the study. Then, the subject consent form was read, dated, and signed by the subject. A copy of the consent form was given to each of the subjects as a receipt for his or her participation. A copy of the signed consent form was also retained by the experimenter.

After the consent form was read and signed, the experimenter then proceeded with the necessary information-gathering task. A handedness questionnaire (Bryden, 1982), shown in Appendix C, was completed in order to determine the degree of the subject's right-handedness. In addition, other subject information was also documented--name, social security number, age, and sex. Each subject was then binocularly tested on a vision tester to ensure he/she met the normal or corrected-to-normal vision requirement for the study. That is, each subject tested at 20/40 or better to be eligible for participation.

The experimenter then began the instructional process. The subject sat in a chair, making sure that the distance from his/her eyes was approximately 60 cm (24 inches) from the VDT screen. The subject was also positioned such that he/she was centered with the screen. To insure that all subjects sat the same distance and position, markers were used on the floor as well as on the chair to ensure consistency in terms of the location and distance of each subject during testing. Before each subject began his/her task, the experimenter emphasized the importance of the position and distance he/she sat from the screen. The experimenter also cautioned each subject not to move the chair or position of his/her body during the task.

All of the subjects were provided with the same information with the appropriate adjustments for the experimental conditions which were randomly assigned to each subject (Appendix D). The subjects were first informed of the number of blocks of trials (i.e., six) they would experience and the approximate time that it would take to complete each block (no more than five minutes). The subjects were then given instructions for the single bargraph condition. Each subject was then informed of the type and complexity of the bargraphs and that instructions and examples for the double condition would be given just prior to the double bargraph task.

In the single bargraph condition, a target or non-target appeared in one of the fields--LFOV, RFOV, or CFOV. When a stimulus appeared in one field, the other fields remained empty. That is, only one stimulus appeared during each trial for the single bargraph condition (Figure 2).

During the double bargraph trials for the LFOV and RFOV conditions, two stimuli were presented simultaneously. Either two non-target stimuli were presented (non-target condition) or a target and a non-target stimulus (target condition) appeared. For example, if the target appeared at the LFOV, then a non-target stimulus would appear simultaneously at the RFOV. If the subject detected a target stimulus at the LFOV, then he/she pressed the appropriate "yes" response key. (The CFOV condition was identical to the single condition in that only one stimulus appeared.)

The stimulus positions varied randomly within each of the three blocks of trials and the subjects were informed of this prior to the task.

After the instructions were given to the subject, the experimenter summarized the instructions and determined that the subject clearly understood his/her task. When the subject appeared confused about the task, the experimenter asked the subject to repeat the instructions in his/her own words. This ensured the experimenter that the subject did, in fact, understand the instructions. Each subject was instructed to perform the task without guessing and to respond as quickly as possible but to maintain a 95 percent accuracy rate.

After the instructions were provided and understood by the subject, the experimenter then proceeded to set the computer to the appropriate complexity and time factor level by entering the appropriate information, for example, S4 for the 4-column, single bargraph condition. Next, the time factor information was entered in milliseconds (140, 210, or 280).

After the experimenter had entered the necessary information to start the program, the subject was prompted to enter his/her social security number and his/her gender (M or F). After the subject entered the information, the experimental task began.

Each trial followed the same sequence. First, before each bargraph appeared on the screen, a center fixation cross would appear on the screen but was not present when the bargraphs appeared on the screen. Then a bargraph flashed on the screen (for 140, 210, or 280 msec) with a simultaneously presented auditory signal (beep).

The subject responded to each bargraph as quickly and accurately as possible. Half of the subjects responded to a target bargraph by pressing the "J" key on the keyboard with the right index finger and the "F" key with the left index finger for a non-target bargraph. The remaining subjects were instructed to respond in the opposite manner. After the response key was pressed, the next trial began approximately two seconds after the key press. This intertrial interval provided the opportunity for subjects to blink their eyes if it was necessary.

In order to facilitate center fixation by the subject, a dot approximately .32 cm (1/8 inch) was marked at the geometric center of the monitor screen (at the center of the fixation cross). The initial design of the experimental task did not include this center dot. However, during the preliminary testing prior to the pilot study, several subjects had commented about the difficulty of keeping the eyes fixed and steady at the center of the screen because the center fixation cross would disappear when the bargraphs appeared on the screen. It was difficult to keep the eyes fixated at the center of the screen in an empty field. Several of the subjects commented that the task would be easier if they could fixate on a mark that would always be there at the center. Further testing suggested that the center fixation dot enabled the subject to maintain center fixation more easily.

Each subject was exposed to 72 trials for each of the six blocks of trials. The total number of trials was 432 for each subject. Each block of trials consisted of 24 bargraphs in each of the three FOV positions. Within each of the three positions 12 of the bargraphs were target bargraphs and 12 were non-target bargraphs. Therefore, the probability of a target bargraph was .50. However, the subjects were not informed of this and none of the subjects tested during the preliminary testing, pilot test, or the experiment questioned the ratio of target vs. non-target bargraphs. After each block of trials was completed, the experimenter asked the subject whether he/she needed a few minutes to rest. Most subjects declined the rest period.

During the experimental task, the experimenter exited the task room and monitored the subject's performance from a separate monitor situated in an adjacent room. This procedure allowed the experimenter to determine whether the subject was responding appropriately and that he/she understood the instructions. In addition, the experimenter was also able to detect any problems in the electronic data collecting process. There were some instances where power slumps affected the task. Under these circumstances, the experimenter prematurely terminated the session and the subject's data was discarded.

Each subject was debriefed after completing the task. During the debriefing process, the experimenter provided a more detailed description of the experiment in terms of the purpose of the study, and in general, what this experimenter hoped to find. In addition, the experimenter asked for feedback from each subject in order to uncover any problems which may have had an effect on the outcome of the study. In general, many subjects felt slightly fatigued and remarked about the difficulty of the double stimulus condition. The majority of the subjects did convey that keeping their eyes fixated on the center, especially during the single stimulus condition, was difficult but not impossible.

At the completion of the debriefing, each subject was asked to complete the project credit form in order to receive credit for his/her voluntary participation.

The total duration of the task did not exceed one hour. The actual task lasted approximately 30 minutes. But introductory statements, hand questionnaire, vision testing, and debriefing required approximately 20 minutes to complete.

RESULTS

Data Analysis

The statistical analysis was completed using the SAS statistical package. Analyses of variance were performed on the reaction time data and the accuracy data. Post hoc analyses and simple effects analyses were performed for significant analysis of variance results.

The analyses were performed only on the responses to the positive (i.e., target) stimuli. In addition, the analyses were performed in three different ways in order to remain consistent with the stated hypotheses. For conditions where only left field of vision (LFOV) and right field of vision (RFOV) were involved in the hypotheses, responses to the center (CFOV) stimuli were deleted from the analyses. The double stimulus condition was used to determine metacontrol. Thus, when the hypotheses involved only the single stimulus condition, then the double stimulus condition was deleted from the analyses. Therefore the three different analyses included 1) all positive stimuli, 2) single, positive LFOV and RFOV stimuli and 3) positive, LFOV and RFOV stimuli. The full source of variation tables for the analyses are found in Appendix E.

Field of Vision (FOV) Variable

Reaction time (RT) differed significantly for the FOV variable [$F(2,264)=16.91$, $p<.05$]. As predicted, the Student Newman-Keuls post hoc analysis revealed that mean reaction time for the center (CFOV) position (0.858 s) was significantly lower than mean RT times for LFOV and RFOV (0.895 and 0.893 s, respectively).

The accuracy measure (PCT) was not statistically significant for the FOV main effect [$F(2,264)=2.21$, $p>.05$]. The mean PCT for the LFOV was 59.0 percent the RFOV and CFOV which had nearly identical PCT means were 60.5 and 60.5 percent, respectively. The hypothesis for the accuracy (PCT) measure was not supported.

Hypothesis 1 was only partially supported. While the RT data did demonstrate that the CFOV stimuli did result in faster reaction time, the analysis did not indicate significant differences between the LFOV and RFOV. In addition, the PCT, or accuracy, means were not significantly different.

Gender

Data analysis revealed that there was no significant main effect for the Gender variable. Both the RT and PCT measures were found to be not significantly different between male and female subjects, for RT [$F(1,132)=0.29$, $p>.05$] and for PCT [$F(1,132=0.18$, $p>.05$]. The mean reaction time for males was 0.859 s, and for females was 0.890 s. In addition, the mean PCT scores for males and females were nearly identical (60.7 and 59.8 percent, respectively).

Hypothesis 2 was not supported. Males and females behave similarly in terms of speed and accuracy in response to the positive experimental stimuli.

Complexity

The analysis of reaction time (RT) measure for the Complexity main effect was significant [$F(2,132)=24.32$, $p<.05$)].

Although RT measures increased with increasing complexity, the post hoc analysis demonstrates that the 4-column bargraph resulted in a significantly lower mean reaction time (0.646 s) when compared to the 6- and the 8-column bargraphs (0.962 s and 1.038 s, respectively). The mean reaction time for the 6-column bargraph was lower than the 8-column bargraph; however, the difference was not significant.

Accuracy (PCT) was also significantly different for the Complexity main effect for all positive stimuli [$F(2,132)=55.11$, $p<.05$].

Post hoc analysis, however, reveals that the PCT measure for the 4-column bargraph was significantly different from the 6- and the 8-column bargraphs (73, 54, and 52 percent, respectively). The difference between the 6-column and the 8-column bargraphs was not significant.

The results of the RT and PCT analyses for the Complexity variable only partially support Hypothesis 4 which states that RT and PCT would be significantly different for all three complexity levels. The hypothesis states that RT would be faster for the 4-column and slowest for the 8-column bargraphs and that PCT would be greater for the 4-column and lowest for the 8-column bargraphs. That is, the 4-column bargraph would result in performance that would be superior to both the 6- and the 8-column bargraphs--fastest reaction time and most accurate responses. Although the mean RT and mean PCT measures demonstrate that the best performance was for the lowest complexity and worst performance for the highest complexity, the difference between the 6-column and 8-column was not statistically significant.

Time Factor

The Time Factor analysis was performed only on the positive, single stimuli for the LFOV and RFOV in order to analyze the data in accordance with the stated hypothesis. In addition, only the PCT data are of interest for this analysis because the Time Factor variable was analyzed to determine performance accuracy. The source of variation table in Appendix E reveals that the analysis of the accuracy data (PCT) for the Time Factor variable did not support the stated hypothesis [$F(2,264)=0.86$, $p>.05$].

The lack of statistical significance combined with negligible, non-statistical differences between all TF groups suggest that subjects' accuracy was not influenced by the exposure duration of the experimental stimuli.

FOV by Gender

The LFOV and RFOV only were considered in this analysis because the study's focus was to look at possible hemisphere differences. Therefore, the CFOV was excluded from this analysis.

Hypothesis 3 states that the data analysis would reveal a significant FOV by Gender interaction for both the RT and PCT dependent variables. Further, it states that the difference in RT and PCT would be significant for males but not for females.

Analysis of variance demonstrates that the interaction effect was statistically significant for the RT measure [$F(1,132)=6.08$, $p<.05$] but not for the PCT measure [$F(1,132)=0.35$, $p>.05$].

Simple effects analysis did result in a significant difference in RT for males [$F(1,132)=5.33$, $p<.05$] but not for females [$F(1,132)=0.88$, $p>.05$] (Table 1). Inspection of the RT means for males reveals that RT was faster for the RFOV (0.863 s) compared to the LFOV (0.896 s). This is contrary to the theory that parallel processing occurs in the right hemisphere (RH) as demonstrated by faster RT, and serial processing occurs in the left hemisphere (LH) as shown by slower RT.

Females tend to perform similarly for both the LFOV and RFOV while males tend to respond faster to the LFOV stimuli than to the RFOV stimuli. In addition, as shown in Figure 3 male and female subjects do not differ in RT at the LFOV.

The FOV was manipulated to stimulate each hemisphere. The stimuli presented to the LFOV is assumed to stimulate the RH and the stimuli presented to the RFOV is assumed to stimulate the LH.

Table 1

Source Table--Simple Effects of FOV by Gender Reaction Time

Source	SS	DF	MS	F
FOV at Male	.1226	1	.1226	5.33*
FOV at Female	.0202	1	.0202	.88
FOV*Sn (Complx*Res*Gen)	3.0386	132	.0230	
Total	3.1814	134		

* $p < .05$

The results of the analyses suggest, therefore, that males are more lateralized than females in terms of RT to stimuli processed in the two cerebral hemispheres. This supports Hypothesis 3. However, in terms of the serial vs.

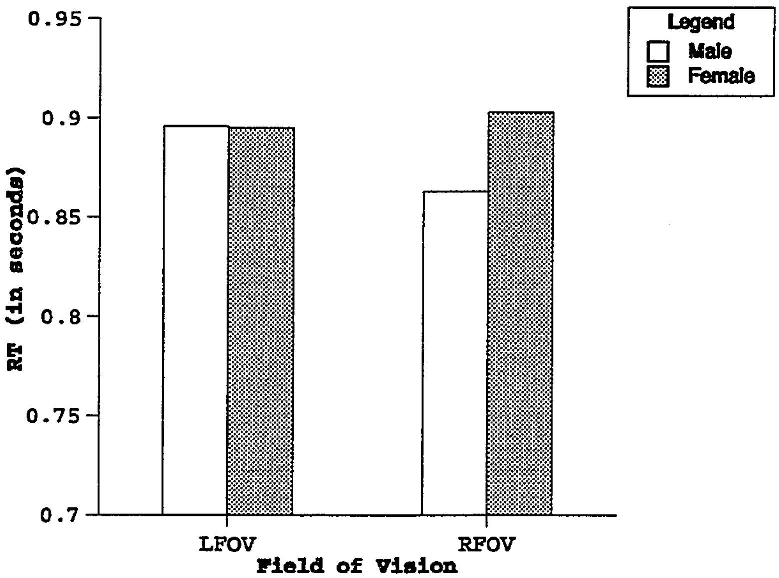


Figure 3. Field of Vision (FOV) by Gender Interaction For All Positive Stimuli

parallel processing in the LH and RH, respectively, the data suggest that this is not the case. In fact, the results of the FOV by Gender interaction suggest that the opposite is true. That is, if faster RT and higher PCT (accuracy) measures are indications of parallel processing, then for males, parallel processing occurs in the LH and serial processing in the RH.

Complexity by FOV

For this analysis, positive, single stimuli for the LFOV and RFOV were analyzed. The interest in this interaction is related to whether serial and parallel processing occurs in the LH or RH, respectively.

Analysis of variance resulted in a significant Complexity by FOV interaction for the PCT measure [$F(2,132)=3.48$, $p<.05$] but not for the RT measure [$F(2,132)=2.16$, $p>.05$].

Simple effects analysis of percent correct (Table 2) demonstrates that Complexity had significant effects for both the LFOV and RFOV [$F(2,132)=130.16$, $p<.05$ and $F(2,132)=101.22$, $p<.05$, respectively].

The Complexity by FOV interaction hypotheses were not supported because the differences in complexity levels were significant for both the LFOV and RFOV. But, it appears that both hemispheres behave differently for the different complexity level. Post hoc (Tukey) tests revealed that for

Table 2

Source Table--Simple Effects for Complexity by FOV (positive, single stimuli)

Source	SS	DF	MS	F
Complex at LFOV	6.00760	2	3.0380	130.16*
Complex at RFOV	4.7249	2	2.3625	101.22*
FOV by SN (complex by Res by Gen)	3.0840	132	.0234	

* $p < .05$

the LFOV the differences between all complexity levels were significant. PCT for the RFOV was significantly higher for the 4-column (C4) level compared to the 6-column (C6) and 8-column (C8) levels, but the difference between the C6 and C8 levels was not significantly different.

Figure 4 presents percent correct for each level of complexity for each of the two stimulus positions. In both positions, the patterns are similar with the greatest accuracy for the lowest complexity level, C4. There is a dramatic drop in accuracy for C6 and C8 levels.

The mean PCT scores indicate that for C4 and C6, accuracy was greater for the LFOV (77.8 and 56.2 percent, respectively) than for the RFOV (75.2 and 54.9). On the contrary, the C8 accuracy for the LFOV (49.7) is lower than the RFOV (53.7).

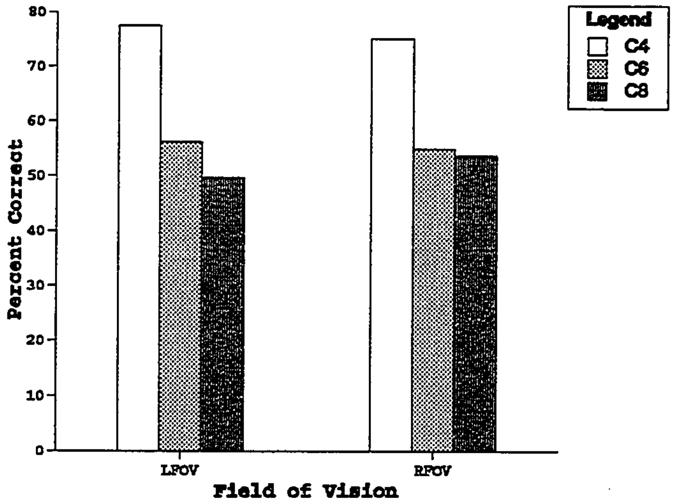


Figure 4. Complexity by Field of Vision (FOV) Interaction for Positive Single Stimuli

Complexity by Time Factor

Townsend's method of using accuracy to determine serial vs. parallel processing was used as a framework for this hypothesis.

The data analysis did not reveal significant effects [$F(2,264)=1.00$, $p>.05$]. The mean PCT suggests that, although not significant, the more complex stimuli generally result in lower accuracy rate, but accuracy was not significantly influenced by the Time Factor.

The results of the analysis do not support the hypothesis that accuracy depends on the amount of exposure duration and the level of complexity.

Complexity by Time Factor by FOV

This hypothesis predicts that parallel processing occurs in the RH and serial processing in the LH. (It is assumed that stimuli presented to the LFOV stimulates the RH and stimuli presented to the RFOV stimulate the LH.) To test this hypothesis, accuracy data for single positive stimuli for the LFOV and RFOV were analyzed. This three-way interaction was not significant [$F(4,264)=0.34$, $p>05$].

An inspection of the RT means and PCT measure was made to determine whether there was a speed and accuracy tradeoff. The data do not support a speed and accuracy tradeoff. Rather, the RT pattern is similar to the PCT data. That is, in general, RT for the RH is faster than the

LH and this occurs across all time levels. The differences, however, were not significant [$F(4,264)=0.53$, $p>.05$].

Although not hypothesized, a four-way interaction effect for the accuracy measure (Table 3) was significant.

Table 3

Analysis of Variance Summary Table Complexity by Time by FOV by Gender (Accuracy)

Source	SS	DF	MS	F
Complex x TF x FOV x Gender	0.2138	4	0.0535	2.82*
TF x FOV x SN (Complx x Res x Gend)	5.0005	264	0.0189	

* $p<.05$

Type

The results of the data analyses of positive stimuli demonstrate that there are no differences in RT between the single and double stimulus conditions [$F(1,132)=1.79$, $p>.05$].

However, the analysis of the accuracy (PCT) measure resulted in significant Type main effect [$F(1,132)=11.85$, $p<.05$]. There was a higher PCT score (higher accuracy) for the single stimulus condition (61.3 percent) compared to the double stimulus condition (58.7 percent).

Therefore, while responses to the single vs. double stimuli did not differ in terms of speed (RT), subjects generally were more accurate in their responses to the single stimuli. Taken together, the results of the reaction time and accuracy data suggest that for the single vs. double stimulus condition, there was a speed-accuracy tradeoff. That is, subjects may have maintained their speed in responding to the stimuli but sacrificed the response accuracy.

The hypothesis regarding Type main effect (single vs. double bargraphs condition) was only partially supported.

Type by FOV

The performance patterns for this interaction provide information regarding hemisphere metacontrol. Hellige (1991) suggests that metacontrol occurs in the LH. That is, the LH (RFOV condition) appears to be the dominant hemisphere when stimuli are presented to both hemispheres simultaneously. Metacontrol by the LH is suggested when performance for the single condition is poorer for the LH than the RH but significantly improves and exceeds performance by the RH in the double stimulus condition.

This interaction effect was not statistically significant for both RT and PCT [$F(1,132)=0.01$, $p>.05$ and $F(1,132)=3.88$, $p>.05$, respectively]. This two-way interaction effect therefore, does not support the metacontrol hypothesis due to the nonsignificant interaction.

Although not hypothesized, a three-way interaction effect (Complexity by Type by FOV) was significant for the accuracy (PCT) measure, but not for the RT measure (Table 4). Therefore, Complexity did influence metacontrol for the PCT measure, but not for RT.

Table 4 Analysis of Variance Summary Table--Type by FOV by Complexity (LFOV and RFOV)

Source	SS	DF	MS	F
RT:				
Type by FOV by Complex	0.0525	2	0.0263	1.21
FOV x SN x Type (Complex x Res x Gender	2.8626	132	0.0217	
Accuracy:				
Type by FOV by Complex	0.2502	2	0.1251	5.88*
FOV x Sn xType (Complex x Res x Gender)	2.8099	132	0.0213	

* $p<.05$

DISCUSSION

The literature review of studies on serial and parallel processing revealed that the results of earlier studies were mixed which suggests that the hemisphere strategy model suggesting separate hemispheres for serial and for parallel processing have not been supported. It was the intent of this study to provide some evidence in support of the hemisphere strategy model as well as the material specific model.

In general, the results of this study do not support the hypotheses that serial and parallel processing of nonverbal information occurs exclusively in the left and the right hemispheres, respectively.

FOV

The FOV variable was used to stimulate the right hemisphere (LFOV), the left hemisphere (RFOV,) or both hemispheres simultaneously (CFOV). The discussion therefore refers to hemispheres rather than FOV or positions.

The overall results of reaction time and accuracy data for the FOV variable revealed, for the most part, that there was no difference between the left hemisphere (LH) and the right hemisphere (RH). Although there was a significant difference in reaction time between the center position and the RH and LH, there was no difference in accuracy.

Therefore, the logical conclusion is that, in general, the processing strategy between the right and left hemispheres are similar in terms of reaction time and accuracy. In addition, when both hemispheres are simultaneously stimulated by the same stimuli, reaction time is faster, but not more accurate. Therefore, both hemispheres appear to process information either serially or in parallel.

The null or negative effects do not support other literature which demonstrated hemispheric strategy differences (i.e., serial and parallel processing in the left and right hemispheres). The results of the analyses, in general, do not support either of the cerebral dominance models--the material specific theory and the hemisphere strategy theory. This is not to say, however, that the serial vs. parallel processing issue is not a viable research topic.

Gender

In general, males and females performed equally well as indicated by the nonsignificant main effect for gender for both reaction time and accuracy. Males and females did not perform differently in the overall analysis of positive stimuli.

Although there is no real agreement about whether males and females do differ in terms of information processing and hemisphere advantage, the research literature does suggest that males are more lateralized than females. In addition, research evidence also suggests that females perform better than males on verbal tasks. Males tend to demonstrate a right hemisphere advantage on nonverbal tasks while females may be less lateralized for spatial tasks compared to men (Bryden, 1982).

As stated in the introduction section of this paper, spatial abilities is a multidimensional trait (Linn & Petersen, 1985; McKeever, 1991). Therefore, the type of spatial task may determine performance differences. Although there is no agreement on precisely what the different traits are, there are certain types of spatial tasks that do suggest gender differences.

Therefore, it is not entirely surprising that there was no significant main effect for gender. In most likelihood, the task employed for this study may have required the use of general abilities which may not include those which have been shown to result in gender differences.

Osaka (1984), for example, demonstrated that while males tend to perform better than females on spatial ability tasks, this was generally true only for spatial perception and mental rotation tasks. Other tasks which are spatial visualization tasks may not necessarily result in gender differences.

Complexity

The results indicate that the C4 level was much less complex than the C6 and C8 levels. In human information processing terms, each level was nearly equidistant in terms of the number of bits of information to process. The C4 stimuli required 2 bits of information to be processed, the C6 required 2.58, and the C8 required 3 bits of information to be processed. The results indicate, however, that in terms of performance C4 was far less complex than C6 and C8. The C6 and the C8 stimuli, however, appear to be nearly equal in terms of complexity or difficulty as indicated by the reaction time data.

It was expected that the subjects' performance on the C6 stimuli would be significantly better than the C8 stimuli. As it was stated earlier, performance was similar for both the C6 and C8 complexity level.

Why did subjects process the C8 stimuli faster than was expected? One might speculate that given the information processing theory of decision-making described in Wickens (1984), the presence of anything less than 2^x bits of information (where "x" represents a whole number) would cause some confusion to the subject. The theory postulates that information is processed in terms of two bits of information per comparison. That is, information is compared on a pair-wise basis. For example, in the 4-column bargraph two comparisons are made (2^2 bits) and in the 8-column bargraph three comparisons are made (2^3 bits). However, the 6-column requires 2.58 (or more) comparisons. The number of comparisons are derived from the formula $H_s=\log_2 N$ (where Hs=the number of comparisons or stimulus information; N=the number of alternatives).

A more plausible speculation is that, despite the equal distance between the three complexity levels in terms of information processing units, the C6 and C8 levels could be similar in terms of information load. Therefore, the subjects would demonstrate little difference in performance between these two levels.

Time Factor

The Time Factor was not an important variable in determining accuracy. This variable was included in this study because it provided another dimension for measuring accuracy. The approach used in this study to measure accuracy was based on the Tests by Time Delimitation method (Townsend, 1990) which required the manipulation of a time variable and sequentially vs. simultaneously presented stimuli.

However, the approach to measuring accuracy for this study deviated somewhat from the Tests by Time Delimitation method described by Townsend (1990). This method required two different presentation conditions--a sequentially presented stimulus condition and a simultaneously presented stimulus condition.

If this study's design followed the method described by Townsend (1990), the C4 stimuli at the 140 msec Time Factor condition for the sequential condition would require that each column (or bar) be presented in successive order. That is, each column would be flashed or displayed on the screen for 35 msec. Therefore, the total exposure duration for the 4-column bargraph would be 140 msec. The second condition would require all four columns (the whole bargraph) to appear on screen for 140 msec (simultaneous condition).

This study, however, did not provide sequentially presented stimulus conditions as described above. Rather, this study utilized only the simultaneously presented stimulus condition. All elements or columns in the bargraphs were presented all-at-once and never one column at a time.

Sequential or serial presentation was inferred by the bargraphs of different complexity level together with the different time factor levels. For example, each column (element) in the C4 bargraphs presented at 140 msec would receive the same amount of exposure duration as the C8 bargraphs presented for 280 msec. Each column in these two complexity levels would receive 35 msec of exposure.

If the analysis did not reveal significant effects for these two complexity levels each at the time factor levels assigned above, then one could have inferred that serial processing occurred. If, on the other hand, the analysis for RT and PCT for the C4 level at 140 msec exposure duration and the C8 level at 140 msec duration was not significant, then one could infer parallel processing. Likewise, if performance on the C8 at 140 msec was better than the C4 at 140 msec, then one could also infer parallel processing. In this case, the C8 stimuli would be receiving less exposure time on screen.

This study's design included only simultaneous presentation conditions. Therefore, this difference may have affected the outcome to some extent.

FOV by Gender

While both male and female subjects performed equally well in terms of accuracy, only males demonstrated a significant difference in hemisphere reaction time. However, as stated in the results section, the amount of variance accounted for by Gender is quite small--only three percent. Thus, while males are more lateralized than females as indicated by the difference in reaction time between the left and right hemispheres for male subjects only, Gender is not considered to be an important variable in this study.

One of the problems which may have negatively affected the outcome of this study (as mentioned in the discussion of the results of the Gender variable) is the type of stimuli to which the subjects responded. As described earlier in this discussion, the task was more general than spatial. Therefore, the results say more about the type of ability required for this task rather than the gender differences in processing the stimuli.

<u>Complexity by FOV</u>

Only accuracy was significant for this interaction. Both the right hemisphere (LFOV) and left hemisphere (RFOV) demonstrated significant differences in accuracy level for stimuli at different complexity levels.

The mean accuracy data in Figure 4 indicate that, for the most part, as complexity increases, accuracy decreases. This was generally true for all levels. But there is no indication of a speed and accuracy tradeoff. Although RT was not significant, inspection of the RT data does not suggest a speed and accuracy tradeoff. That is, subjects did not sacrifice speed for accuracy for vice versa.

The difficulty in making sense out of these data lies in the low accuracy level for the RH at C8. As shown in Figure 4, the mean accuracy level falls below 50 percent which may be interpreted as "guessing" by the subjects. However, debriefing did not indicate that subjects were knowingly guessing at what had appeared on the screen.

On the other hand, the LH for the C6 and C8 stimuli resulted in very little difference (not significant) in mean PCT measures. It may be that the LH is a better processor of complex information compared to the RH.

As it relates to serial vs. parallel processing, it appears that there is an increase in reaction time and decrease in accuracy with increasing complexity. That is, there is a decrement in performance with increasing complexity. This does not support the idea of parallel processing in any hemisphere.

Type

The reaction time analyses for the type variable (i.e., single vs. double bargraphs) did not fully support the hypothesis which stated that performance on the single stimuli would be superior compared to the double. This hypothesis was developed primarily on the assumption that the more complex the stimuli, that is, the more information in terms of bargraphs and columns, the slower the reaction time.

As the results of the reaction time analysis indicate, type was not an important factor which influenced reaction time. The accuracy analysis did, however, support the hypothesis. Performance was more accurate on the single stimuli compared to the double.

It is not clear why accuracy was significant and reaction time was not. However, in addition to possible speed and accuracy tradeoff, there are several possible explanations. First, subjects may have been guessing which resulted in nonsignificant reaction time results. However, this may not be the case because guessing would probably have resulted in a nonsignificant accuracy outcome as well. Accuracy below the 50 percent level may suggest that subjects were guessing. However, while the mean accuracy score for the double stimulus condition was quite low, it did not drop below 50 percent. Second, subjects were instructed not to guess but do the best that they could in terms of their responses to the stimuli.

Another possible explanation is that as difficulty increases, subjects may tend to respond more quickly because they are not sure of what they saw and do not have a chance to think about what they saw.

Type by FOV

The negative results of the Type by FOV interaction does not support metacontrol by the left hemisphere. However, the mean accuracy data suggests a tendency towards hemisphere dominance or superiority by the left hemisphere.

Although not hypothesized, a three-way Complexity by Type by FOV interaction for the accuracy measure (PCT) was statistically significant (Table 4). However, simple effects analysis was not performed because this interaction was not hypothesized. Therefore, discussion of the differences only refers to possible patterns indicated by the interaction.

Figure 5 suggests that when Complexity is added to the interaction, subjects appear to respond similarly to single and double stimuli in terms of accuracy, especially for the C4 and C6 conditions.

While there is a noticeable decline in accuracy from the single to the double stimuli in the LFOV (RH) for C4 and C6 levels, this pattern is not evident for the RFOV (LH).

The lack of a significant two-way interaction effect may have been due to the response to the C8 stimuli. As can be seen in Figure 5, accuracy appears to increase for the double stimulus C8 condition. This increase in accuracy may have weakened the two-way interaction.

The pattern of responses between the LFOV (RH) and RFOV (LH) is quite interesting. Figure 5 suggests a slight advantage of RH for the single C4 and C6 stimuli. For the double stimulus condition for C4 and C6, performance on the RH stimuli declines below the LH stimuli. There appears to be an opposite tendency when we consider the C8 level. Accuracy for the C8 single stimuli for the RH falls below the accuracy for the LH stimuli but increases in accuracy to the same level as for the LH for the double stimulus condition. In addition, it appears that for the C8 double

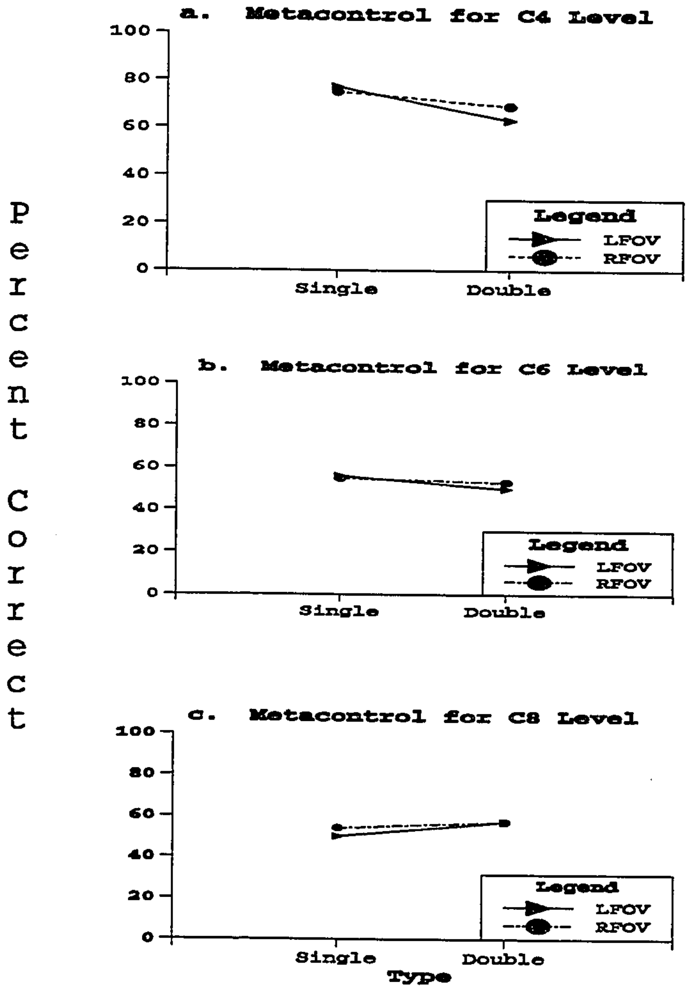


Figure 5. Type by Field of Vision by Complexity Interaction

stimulus condition, which is the most complex, accuracy is better than for the single condition.

Performance, in terms of accuracy, therefore appears to vacillate from one hemisphere to the other. From the three-way interaction, it appears that the LH assumes a more dominant role as indicated by the pattern between stimulus type.

These patterns are similar to earlier research (e.g., Hannay, et al., 1976; Hellige & Cox, 1976; and Polich, 1986) where there is a change in performance for the two hemispheres. This suggests that when one hemisphere becomes overloaded, the other becomes more dominant. The difficulty is to determine at what level of complexity this occurs. Complexity should be measured in a different way. It appears obvious from the performance data that C4 is much less complex than C6 and C8. But the difference in complexity between C6 and C8 does not appear to be as great as the difference between C4 and C6.

Complexity by Time Factor

Presumably, the longer stimulus exposure duration would result in higher accuracy rates for each level of complexity. Apparently, the Time Factor had very little influence on the performance accuracy (PCT). There was no significant main effect for Time Factor, and according to the interaction effect, Time Factor was also not important at the different complexity levels.

It is interesting to note that according to the accuracy data for the Complexity by Time Factor Interaction, at all complexity levels, stimuli receiving the longest exposure time (i.e., 280 msec) did not result in higher accuracy rates. Although reaction time was not a dependent variable of interest for this hypothesis, the reaction time data were provided in the data analysis but not reported in the results section. The reaction time data do not suggest a speed and accuracy tradeoff. Thus, the unexpected results suggest that a much more complex process occurs during the processing of complex stimuli.

Complexity by Time Factor by FOV

This three-way interaction effect and its associated hypothesis were crucial in determining whether or not there is evidence of hemisphere asymmetry in the serial and parallel processing of nonverbal visual information. Significant results in the right direction would have contributed positive evidence that parallel processing occurs in the right hemisphere and serial processing in the left hemisphere.

However, the result of the analysis was not statistically significant. Therefore, the results of this study do not provide evidence of hemisphere asymmetry in the serial and parallel processing of visually presented nonverbal information.

Apparently, as with other analyses in this study, at some point there is a crossover in hemisphere superiority in processing information. At a high complexity level, the left hemisphere appears to be superior in terms of accuracy. This effect was not due to a speed and accuracy tradeoff.

Further analysis revealed, however, that when gender is added to the interaction, there is a significant four-way interaction Complexity by Time by FOV by Gender (Table 3). This interaction effect was not hypothesized. Therefore, simple effects analysis was not performed. The following discussion merely describes possible patterns due to this effect.

Figure 6 suggests that females tend to respond in a similar pattern for both the RH and LH, while a more interesting pattern occurs for male subjects. For the RH at C6, the accuracy for TF140 is higher than for the TF210 and TF280 levels. At the C8 level, there appears to be a crossover between the TF280 and TF140 where accuracy is superior for the TF280 level than for both the TF210 and TF140 levels.

As shown in the analysis and in Figure 6, when gender is controlled, there is some evidence to suggest that significant differences do exist in terms of how the right and left hemispheres differ. Figure 6 demonstrates a

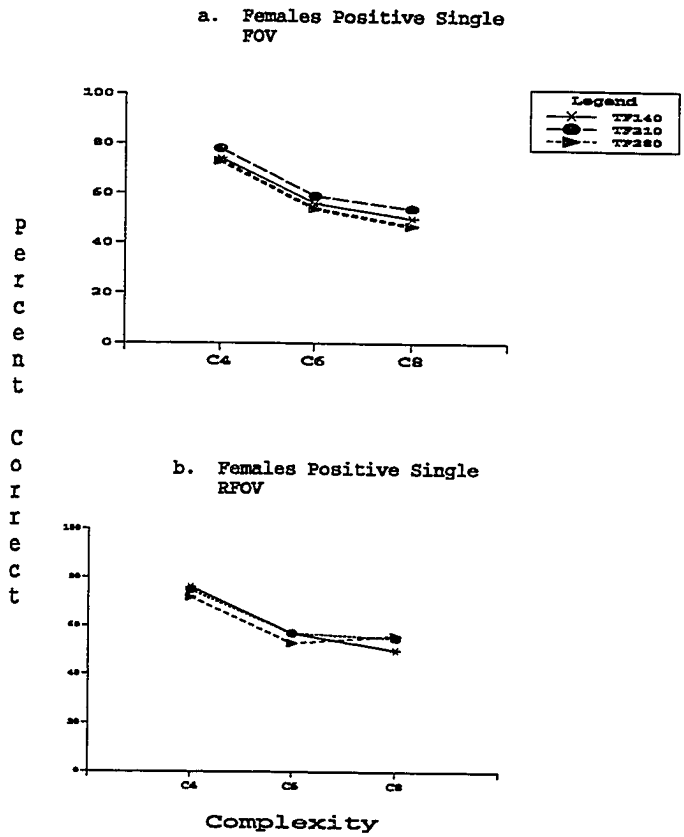


Figure 6. Complexity by Time Factor by Field of Vision by Gender Interaction

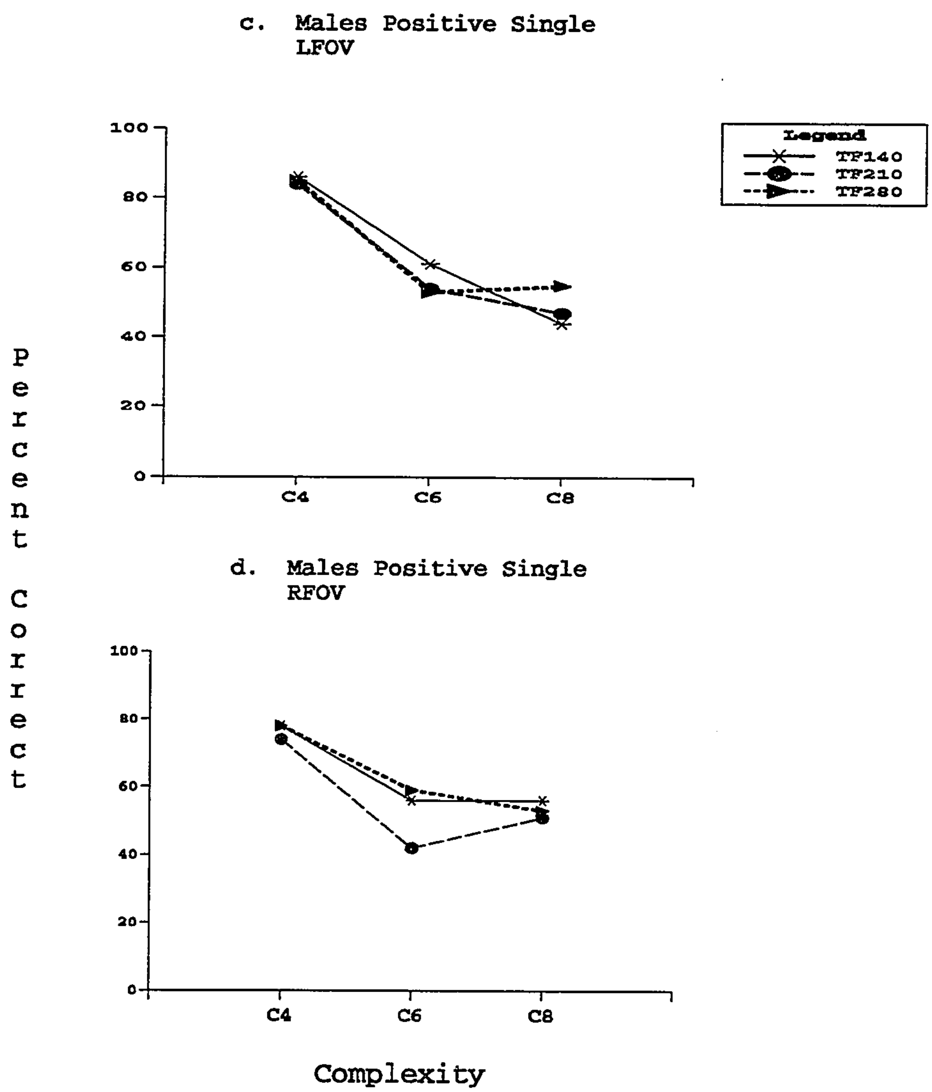


Figure 6 (cont'd.). Complexity by Time Factor by Field of Vision by Gender Interaction general tendency that for both hemispheres, there is a decrement in performance accuracy between C4 and C6 conditions. However, differences between the C6 and C8 conditions vary. Females show generally decreasing accuracy from C4 to C6 and C8 for both the right and left hemispheres. But the performance between the left and right hemispheres for male subjects did not demonstrate a consistent pattern.

These results are quite puzzling. Does this suggest that male subjects are more susceptible to hemisphere shift in terms of hemisphere superiority? Together, hemisphere lateralization and shifting of cerebral superiority may account for the strange behavioral patterns shown in Figure 6.

General Discussion

Unlike other studies using geometric stimuli which resulted in positive effects (Franco and Sperry, 1977; Manelis and Grebennikova, 1984), the results of this study do not provide evidence that hemispheric asymmetry occurs for serial and parallel processing. The inconsistency between this present study and the two studies cited above was probably due to several differences such as task type and stimulus complexity.

While these studies (including this present study) required manual responses, other factors may account for this study's lack of support for the hemisphere asymmetry hypothesis regarding hemisphere differences in serial and parallel processing of nonverbal stimuli. For example, the Franco and Sperry (1977) study required a cross-modal (visual-tactile) task and this present study required only visual examination of the stimuli.

Other issues such as complexity, hemisphere shifts, and increasing quality of subject data are discussed below.

Complexity Issues. Although this present study and the Manelis and Grebennikova (1984) study required visual tasks with manual responses, they differed in terms of stimulus complexity. The differences in the operational definition of complexity may have been the greatest contributor towards the differences in the outcome between these two studies.

The 1984 study defined a simple geometric form as a geometric figure with a single outline and a complex form as a geometric figure with a double outline, that is, one figure concentrically placed inside another of the same or different shape. The stimuli for this present study, however, were metric histoforms, that is, bargraphs. The complexity levels were defined by the number of columns (4, 6 and 8) in the bargraphs. Therefore, the complexity levels between the two studies were quite dissimilar.

Complexity adds to the memory load and thus affects performance. Researchers demonstrated that when memory load is increased, hemispheric shift also occurs (Hellige, et al., 1979; Umilta, et al., 1985). Similarly, increased complexity increases mental workload. Again, the question should therefore address the issue regarding at what level does parallel processing occur in the RH and at what level does serial processing occur in the LH. In addition, scientific investigation should also study when hemispheric shift occurs.

The stimuli used for this study may have been more difficult than in other studies which demonstrate parallel processing in the RH and serial processing in the LH (e.g., Manelis & Grebennikova, 1984). In this study the subjects responded to 4-, 6- and 8-column bargraphs. Other studies which demonstrated mixed results also used more complex stimuli (e.g., polygons).

Therefore, complexity in serial vs. parallel processing studies is relative and unique to each study. Thus, it is not surprising that there is no clear evidence of parallel processing in the RH and serial processing in the LH as postulated by the hemispheric strategy model.

Hemisphere Shifts. There are several problems and/or concerns which have made interpreting the outcome of this study difficult. One of the problems which may have influenced the outcome of the subjects' performance which resulted in either null or opposite effects, is the issue of hemisphere shifts. Results of the analysis indicate that, at some point, the LH takes over or dominates information processing (refer to Figures 4 to 6).

As shown in Table 4 of the results section, the accuracy measure for the Type by FOV by Complexity interaction was significant. The data in Figure 6 suggest that for the single C4 condition, which is the simplest, least complex level, the RH performed more accurately than the LH. However, at the C6 level, while overall accuracy was far below that of the overall C4 level, the difference between the RH and the LH was smaller than for the C4. At the C8 level for the single bargraph condition, there was a switch. Unlike the C4 and the C6 levels, accuracy was higher for the LH (RFOV) than for the RH (LFOV). In addition, at the most difficult level, the double bargraph C8 level, both the LH and the RH performed equally well in terms of accuracy (Figure 5). As noted previously, however, simple effects analysis was not performed for this interaction. Therefore, any statements regarding significant differences cannot be made.

It appears that as the information load (complexity) increases from easy to difficult (single C4 to single C8), the LH becomes the superior hemisphere. However, as the load becomes much more difficult (double C8 condition), both hemispheres perform equally well--sharing in the processing of highly complex and difficult information.

Other studies have also shown a shift in hemisphere advantage. For example, Hellige and Cox (1976) demonstrated a shift in hemisphere superiority during a visual recognition task. They found a RH advantage for 12-point polygons and a LH advantage for 16-point polygons. A study by Polich (1986) also demonstrated that during a visual detection task, a shift in hemisphere occurs. Circular or asymmetric arrays of vertical lines (4, 16, 32, or 64 lines) were shown to subjects whose task was to respond by key presses for same or different arrays. The experiment resulted in a LH advantage for 'same' response for the 4 and 16 element arrays. There was a RH advantage for 'same' response when array size was 32 and 64 lines. Others have also noted a shift in hemisphere advantage (e.g., Kittler, et al., 1989).

Apparently, as the visual system becomes overloaded, it compensates by shifting the workload from one hemisphere to the other in trying to perform the task or process the information as quickly and as accurately as possible. This is speculation on my part, however.

Improve Data Quality. Several issues of concern are subject motivation and fatigue. Although these issues were not problematic in terms of the outcome of the study, these issues should be addressed to insure quality subject performance.

During the debriefing period, many subjects commented that they were surprisingly fatigued visually. Although the subjects stated that the fatigue did not affect their performance, it is possible that performance decrement and decreasing motivation might have occurred as a result of fatigue.

Future Research Possibilities

Future research should consider complexity as well as image discriminability. That is, a follow-up study should also include column width as an independent variable. One of the problems affecting the outcome of this study may have been that while the size of the stimuli remained constant (i.e., 1.75 inches in width and no more than 1.75 in height) the bars or columns decreased in width as the complexity (number of columns or bars) increased.

Discriminability may have been a confounding variable. That is, the 4-column bargraphs have wider columns and therefore may have been easier to discriminate between bar heights while the columns of the 8-column bargraphs were only half as wide as the 4-column bargraphs. Therefore, complexity for the 8-column bargraphs may have been more than twice as complex as the 4-column bargraphs. That is, the results may have been affected by column width.

Controlling for column width may provide more information in terms of the effect of discriminability. However, visual angle must also be considered. If the standard 4-column bargraph results in performance that is equal to performance on 4-column bargraphs whose column width is only half as wide, then size or visual angle of the bargraph did not affect performance. However, if the results between the two different size column width differ significantly, then discriminability may have been a problem for this study.

Because of the nature of the visual system to change its processing strategy depending on the complexity of the visual stimulus, it is difficult to design an experiment which would indicate the degree of complexity and at what degree of difficulty there would be a shift. One method to measure difficulty would be to measure workload. There are a variety of methods to measure workload, ranging from subjective measures such as the NASA TLX measure of workload to physiological measures such as cerebral bloodflow.

Rather than defining complexity in terms of number of elements, types of polygons, or number of columns in a bargraph, other possibilities should be considered. Research of the serial vs. parallel processing issue should proceed based on a unified definition in terms of workload. It is only at this point that researchers can continue to determine when parallel processing occurs in the RH and when it occurs in the LH and vice versa for serial processing.

Conclusion

Although the results of this study demonstrate little support for the hypotheses, there are a number of issues which must be resolved before any conclusive statements can be made regarding the serial and parallel processing of nonverbal information in terms of hemisphere asymmetry. Complexity, image discriminability, defining complexity in terms of workload, and shorter testing period for subjects are some of the issues which may have contributed to this project's lack of significant outcomes.

In conclusion, research should continue to investigate the hemisphere asymmetry of serial vs. parallel processing of nonverbal information. The information gained from research will contribute to a better understanding of the human visual information processing of nonverbal information. The information can be useful in the future designs of visual displays which will enhance human performance. However, many issues must be resolved before research on this topic can progress.

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APPENDIX A

Human Subjects Committee
Approval Form

BARGRAPHS

531

HUMAN SUBJECTS COMMITTEE

DEPARTMENT OF PSYCHOLOGY

Research Review Notification Form

TO: Karen Emm/Coates DATE: 10-19-92
Principle Investigator

RE: Serial vs Parallel processing of complex geometric
Name of Project

Please be informed that your research proposal has been reviewed by the committee and:

Approved ✓

Approved, contingent upon the following modifications:

1. ______

2. ______

3. ______

Refused ______

Do not hesitate to contact me should you desire further clarification of the committee's decision.

______
Chairperson, Committee for the Protection of Human Subjects

ECL
forms:humsubj.app

APPENDIX B

Subject Consent Form

SUBJECT CONSENT FORM

Project: Bargraphs (#531)
Experimenter: Karen Inn

You are invited to participate in this research project which is designed to investigate how well different types of bargraphs can be visually processed. In order to be selected as a participant and receive one (1) credit for your participation, you must meet several subject requirements: 1) be 18 years of age or older, 2) be right-handed, and 3) have normal or corrected-to-normal vision.

If you decide to participate in this study, you will be asked to answer several questions regarding your age, whether you have normal or corrected-to-normal vision, and the degree of your right-handedness. During the study, you will be viewing 4-column, 6-column, or 8-column bargraphs. The bargraphs will appear for a fraction of a second on the monitor screen. You will be asked to keep a steady eye while viewing the screen and to respond to each bargraph with key press responses. This procedure will require less than one hour to complete. Further instructions will be provided prior to the start of the testing procedure.

Information regarding the true nature of this study will be provided during the debriefing period at the end of the study because full disclosure prior to the study may affect the results.

There is no risk anticipated in this procedure. However, it may be possible that you may experience slight discomfort from sitting in front of the monitor and pressing keys.

You can be assured that your identity will remain confidential. Any information obtained in this study which can be used to identify you will remain confidential and will be disclosed only with your permission. The results of the study will be presented in such as way that no individual participant will be identified.

Your participation is voluntary. You have the right to withdraw your consent and terminate your participation at any time, without penalty. If, however, you do not meet the subject requirements (age, right-handedness, and vision), the experimenter may terminate the procedure and no credit will be awarded to you. The experimenter must make this determination early in the process before the testing procedure begins.

If you have any questions, please contact me, Karen Inn, at 683-3461 at the Department of Psychology, Old Dominion University.

After you have read and understood the information provided above and consent to participate in this study, please date and sign this form in the spaces provided below.

____________________ ______________________________

Date Signature

____

Witness

APPENDIX C

Handedness Questionnaire

Project: BARGRAPH (#531) Code ______________

Name: ______________________________

Subject ID: ________________________

Age: ________ Sex: ____

Hand Preference Questionnaire (Simplified version)

Instructions:

For each of the items listed below, make a + (a plus symbol) under the appropriate hand column (left or right) to indicate which hand you normally use to perform the activity. If you would use the other hand only if forced to indicate by marking the column with a ++ (double plus). For example, if you normally write a message with your right hand, you would put a + sign under the right hand column for that item. However, if you would use your left hand to write a message because you are forced to use your left hand, then put a ++ (double plus) under the right hand column. If you use both hands equally often, then place a + in each of the columns.

Score	Left	Right	
1. Writing a message	____	____	____
2. Drawing a picture	____	____	____
3. Using a toothbrush	____	____	____
4. Throwing a ball	____	____	____
5. Using a pair of scissors	____	____	____
Score sum			____
Results (Sum minus 15 divided by 10)			____

Scoring instructions for the experimenter is as follows:

Assign a 1 for L++, 2 for L+, 3 for a + in each column, a 4 for R+, and 5 for R++. Sum the scores, subtract 15, and divide by 10. The result will be a score ranging from -1.00 (extreme left-handed) through +1.00 (extreme right-handed).

APPENDIX D

Subjects' Instructions

INSTRUCTIONS TO SUBJECTS

FOR DISSERTATION PROJECT "BARGRAPHS"

Instructions to Subjects:

I. Welcome and Introduction

Thank you for volunteering for project BARGRAPHS.

My name is Karen Inn and I will be conducting this study.

Before we begin, let me explain briefly what we'll be doing.

First, I'll give you a brief description of this project is about.

Then you'll be asked to read and sign a consent form before we can begin. Let me say, however, that your participation must be voluntary and that you may terminate your participation at any time.

After that, I need to get some basic information from you--name, social security number, age, and some information regarding which hand you normally use for doing specific tasks. Then I'll need to test your vision.

After these preliminary information are gathered, I'll give you specific information on what you are supposed to do for this project.

II. Project Description

Let me begin by giving you a brief description of the project.

This project was developed and designed to examine how people's visual system process information that is presented to them at different locations on the monitor screen. The information that you will be given will be represented by bargraphs.

You will be looking at 4-column (6-, 8-column) bargraphs which will appear on the screen for less than a half second.

Your task will be to respond to the target and non-target stimuli by pressing the assigned keys on the keyboard in front of you.

III. Now, you need to read and sign the consent form before we can proceed. Keep one copy of the consent form and I'll retain one copy for my records.

IV. The next thing we need to do is to get some basic information from you.

(RECORD INFORMATION ON HANDEDNESS QUESTIONNAIRE)

a) Name
b) SS #
c) Age

V. Now I need to ask you some questions regarding which hand you normally use to do certain things.

(Handedness Questionnaire)

The next thing we need to do is to test your vision.

(Vision Testing)

Now that all the preliminaries have been taken care of, we can start the study.

VI. General Instructions

Sit in front of the monitor, making sure you are about 24 inches from the monitor. To make it easier, I provided some markings on the floor to indicate the chair position.

This project has two parts to it. Each part consists of three block of trials. Therefore, you'll be working with a total of six blocks of trials. Each block should not take you more than five minutes to complete.

In part one, you'll be working with single bargraphs with 4 (6, or 8) columns. The bargraphs you will see will be similar to these drawings I have here (SHOW SAMPLES OF APPROPRIATE BARGRAPHS). A target is a bargraph with two bars of the same height; a non-target is a bargraph whose bars are all different heights.

Part two will consist of double bargraphs, so I'll explain the procedure as we come to part two.

During the actual experiment you will be viewing bargraphs on the monitor screen. Before any bargraphs appear on the screen, you will see a fixation cross in the middle of the screen. You must keep your eye on this fixation point. (In order to assist you in maintaining this center fixation, I drew a dot on the geometric center of the screen.) After a few seconds a bargraph will appear for less than a half second. While KEEPING A STEADY EYE, press the key which corresponds to what you saw, think you saw, or felt that you saw, but you must not guess.

Your task is to press the J (F) key with your right (left) index finger when you see a target bargraph with two non-adjacent columns of the same height and press the F (J) key with your left (right) index finger when you see a non-target bargraph with all columns of different heights.

Part One (Single Bargraphs) Instructions

(Show sample bargraphs in different positions as I am explaining the positions to the subject.)

In part one, the bargraphs will appear either to the left, to the right, or middle of the screen slightly below the center of the screen. The bargraphs are randomly selected by the computer and displayed on the monitor screen. The location of the bargraphs are also selected randomly by the computer, so there is no real pattern as to where the bargraphs will appear. The only thing is that bargraphs will appear at all three locations on the screen.

Respond by pressing the appropriate key as fast as possible, but try to maintain a 95 percent accuracy rate. The best way to do this is to respond as quickly as possible. That is, don't sit and think about what you saw.

Immediately after you press the response key the fixation cross will appear again for two seconds before another bargraph appears and the whole process repeats itself. So, if you must blink you should do so before the bargraph appears.

The important thing to remember is to keep your eyes fixated on the fixation dot and keep a steady eye as the bargraphs are flashed on the screen. This is important since we don't know where the bargraphs will appear since the computer is randomly selecting the location where the bargraph will appear.

In addition, you should respond as quickly as you can with 95 percent accuracy.

Part Two (Double Bargraphs) Instructions

You've just completed part one (blocks 1-3). Part two (blocks 4-6) is similar to part one except that part two consists of a double bargraph condition.

(Show sample of double bargraphs as I describe them in different positions.)

That is, two bargraphs will appear simultaneously--one appearing to the left of the center fixation dot and one appearing to the right of the center fixation dot. In some cases, both bargraphs will be non-identical, non-target bargraphs; this is the non-target event and you respond by pressing the same key for the non-target bargraph as you did in part one. In the target condition, either the left or the right bargraph will be a target bargraph; the other will be a non-target bargraph. In this case, press the target response key. For the middle bargraph, you'll see only a single bargraph and you'll respond by pressing the appropriate response key.

Do you have any questions at this point?

(Question and answer period)

Summarize general procedure:

1. You will be looking at bargraphs.
2. Targets are bargraphs that have two columns of the same height.
3. Non-targets are bargraphs whose columns are of different heights.
4. Make keypress responses as quickly but as accurately as possible.
5. Keep eyes fixated on fixation cross; do not move your eyes until after you made your response.

Are you ready to get started?

VII. Debriefing

Now that you've completed the task I need to get some feedback from you.

Was this a difficult task? Why?

Do you think that you moved your eyes while the bargraphs were on the screen? If yes, about what percent of the time do you think you moved your eyes?

In general, were there any problems in performing the task?

Were the instructions clear?

Any general comments about the project?

In your opinion what do you feel this project was about?

True nature of this research project:

This is my dissertation project and the nature of this project is to determine whether there are differences in the speed and accuracy at which non-verbal information can be processed. Research has suggested that information presented to the left and the right visual fields are processed differently and can be measured in terms of the speed and accuracy of responses.

VIII. Results

A summary of the results of this project will be posted on the bulletin board.

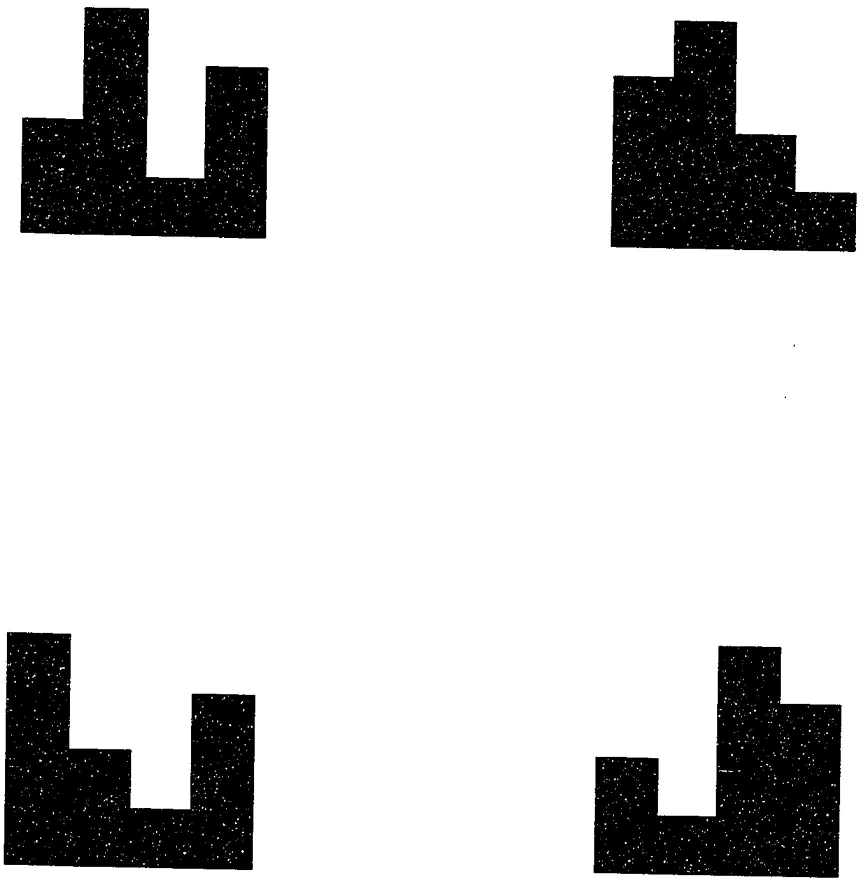
IX. End Session

Thank you very much for your cooperation and participation in this project.

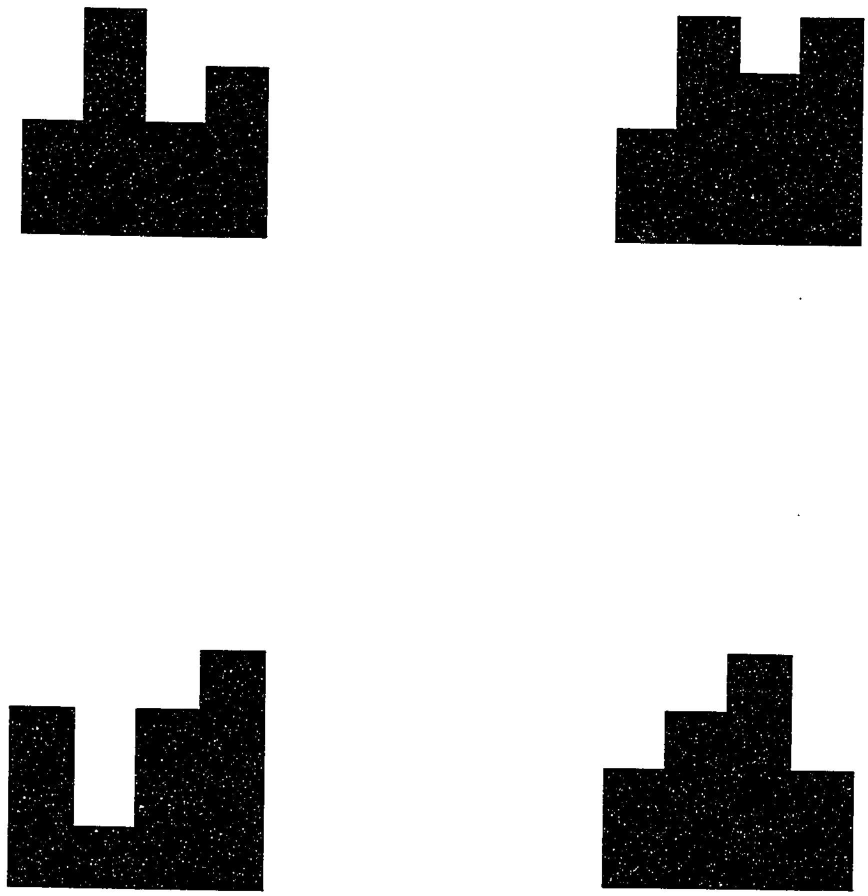
SAMPLE BARGRAPHS

TARGET AND NON-TARGET

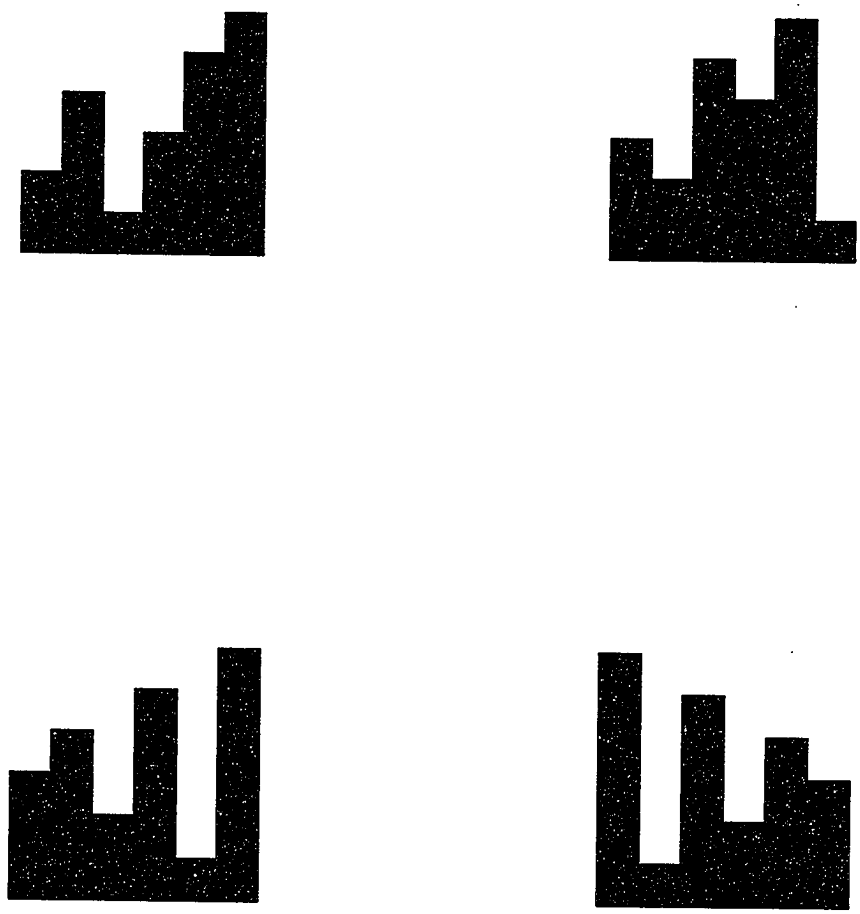
(4-, 6-, and 8-Columns)



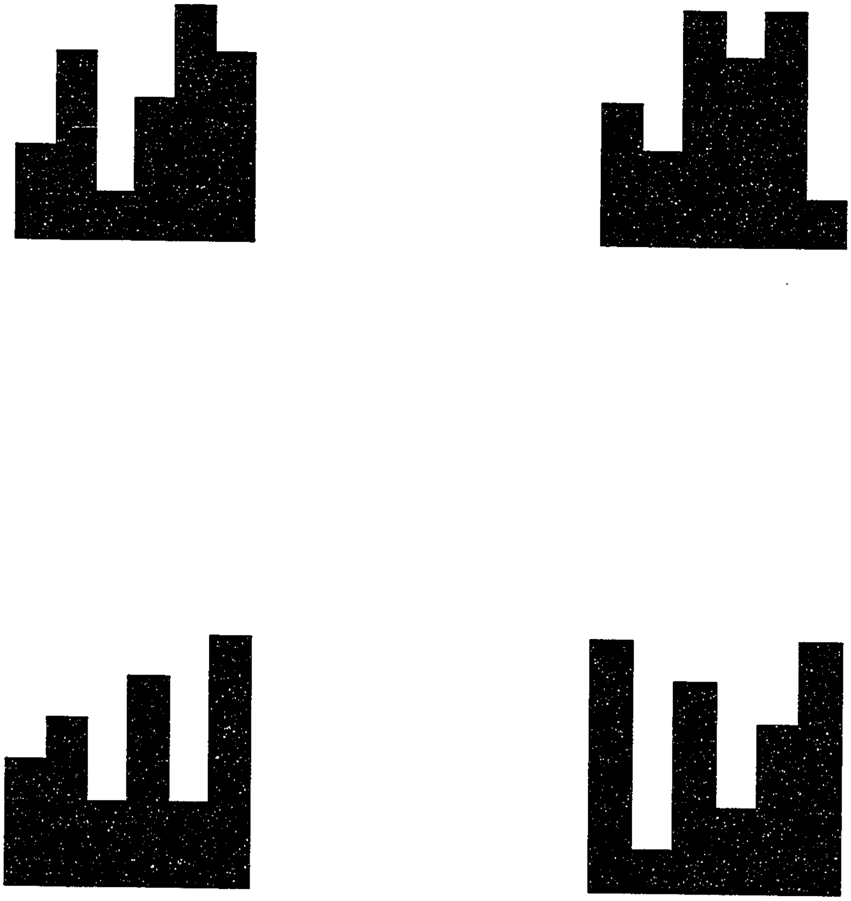
EXAMPLE: 4-COLUMN NON-TARGET BARGRAPHS



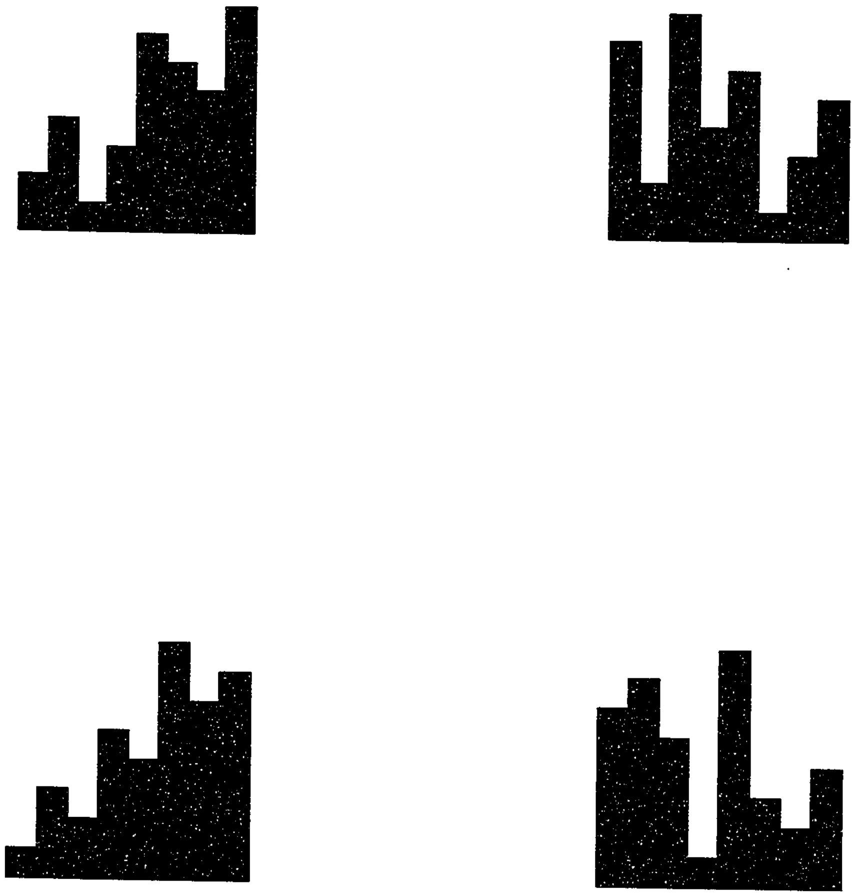
EXAMPLE: 4-COLUMN TARGET BARGRAPHS



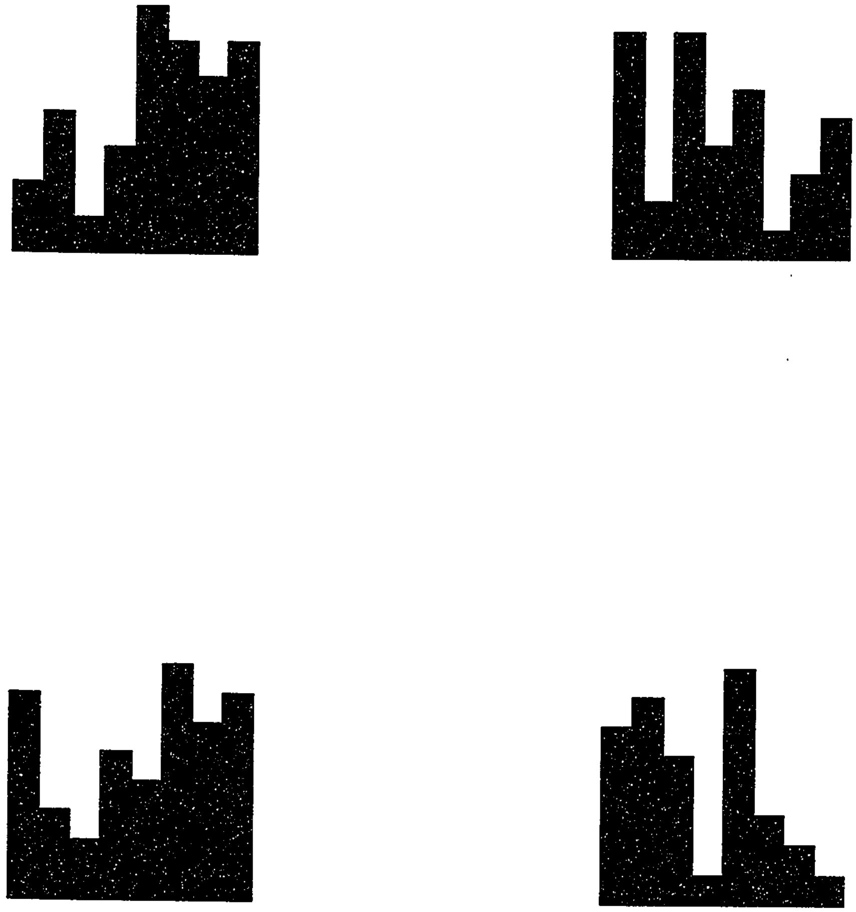
EXAMPLE: 6-COLUMN NON-TARGET BARGRAPHS



EXAMPLE: 6-COLUMN TARGET BARGRAPHS



EXAMPLE: 8-COLUMN NON-TARGET BARGRAPHS



EXAMPLE: 8-COLUMN TARGET BARGRAPHS

EXAMPLE: 4-COLUMN TARGET WITH 2 BARGRAPHS

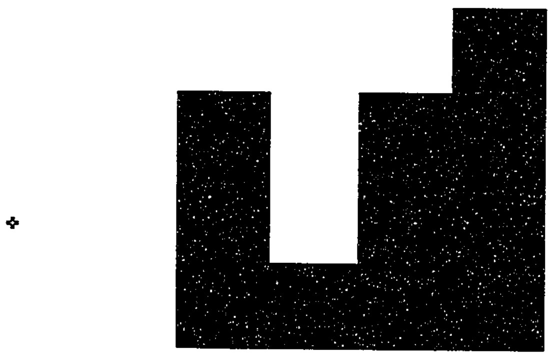
EXAMPLE: 4-COLUMN NON-TARGET WITH 2 BARGRAPHS

EXAMPLE: 6-COLUMN TARGET WITH 2 BARGRAPHS

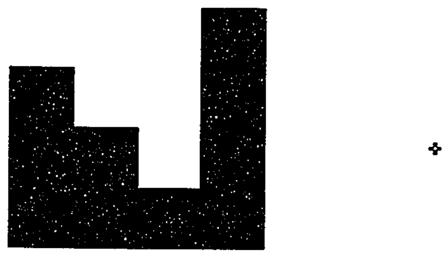
EXAMPLE: 6-COLUMN NON-TARGET WITH 2 BARGRAPHS

EXAMPLE: 8-COLUMN TARGET WITH 2 BARGRAPHS

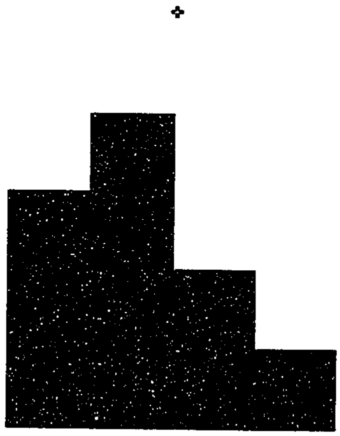
EXAMPLE: 8-COLUMN NON-TARGET WITH 2 BARGRAPHS



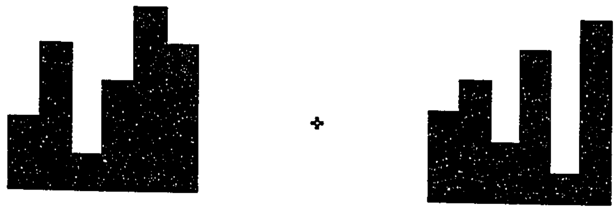
EXAMPLE: TARGET IN RIGHT VISUAL FIELD



EXAMPLE: NON-TARGET IN LEFT VISUAL FIELD



EXAMPLE: NON-TARGET CENTER VISUAL FIELD



EXAMPLE: TARGET BILATERAL BARGRAPH
LEFT VISUAL FIELD

APPENDIX E

SOURCE OF VARIATION TABLES

Summary of Analysis of Variance
RT -- POSITIVE
All Positive Stimuli

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
TYPE	1	0.35061008	0.35061008	1.79	
TF	2	3.52074251	1.76037126	12.06	0.0001
COMPLX	2	74.72246052	37.36123026	24.32	0.0001
RESP	1	1.48283334	1.48283334	0.97	
POSI[1]	2	0.76256037	0.38128019	16.91	0.0001
GENDER	1	0.44981689	0.44981689	0.29	
TF*TYPE	2	0.08350566	0.04175283	0.89	
COMPLX*TYPE	2	8.08689511	4.04344756	20.60	0.0001
RESP*TYPE	1	0.01057704	0.01057704	0.05	
POSI*TYPE	2	1.13343501	0.56671751	18.54	0.0001
GENDER*TYPE	1	0.21933189	0.21933189	1.12	
COMPLX*TF	4	0.28079061	0.07019765	0.48	
RESP*TF	2	0.01429126	0.00714563	0.05	
TF*POSI	4	0.05198371	0.01299593	0.83	
TF*GENDER	2	0.17268546	0.08634273	0.59	
COMPLX*RESP	2	1.93214806	0.96607403	0.63	
COMPLX*POSI	4	0.72571862	0.18142966	8.04	0.0001
COMPLX*GENDER	2	7.36324871	3.68162435	2.40	
RESP*POSI	2	0.03264893	0.01632446	0.72	
RESP*GENDER	1	4.06616896	4.06616896	2.65	
POSI*GENDER	2	0.25554595	0.12777298	5.67	0.0039
COMPLX*TF*TYPE	4	0.11346024	0.02836506	0.61	
RESP*TF*TYPE	2	0.15668297	0.07834148	1.68	
TF*POSI*TYPE	4	0.17082821	0.04270705	2.51	0.0412
TF*GENDER*TYPE	2	0.25808674	0.12904337	2.76	
COMPLX*RESP*TYPE	2	0.26488223	0.13244111	0.67	
COMPLX*POSI*TYPE	4	0.58921416	0.14730354	4.82	0.0009
COMPLX*GENDER*TYPE	2	0.49134289	0.24567145	1.25	
RESP*POSI*TYPE	2	0.14711280	0.07355640	2.41	
RESP*GENDER*TYPE	1	0.29758164	0.29758164	1.52	
POSI*GENDER*TYPE	2	0.00178409	0.00089204	0.03	
COMPLX*RESP*TF	4	0.09215623	0.02303906	0.16	
COMPLX*TF*POSI	8	0.11020072	0.01377509	0.88	
COMPLX*TF*GENDER	4	0.17960532	0.04490133	0.31	
RESP*TF*POSI	4	0.03720904	0.00930226	0.59	
RESP*TF*GENDER	2	0.08116524	0.04058262	0.28	
TF*POSI*GENDER	4	0.02503338	0.00625835	0.40	
COMPLX*RESP*POSI	4	0.09632902	0.02408225	1.07	
COMPLX*RESP*GENDER	2	8.00306328	4.00153164	2.61	
COMPLX*POSI*GENDER	4	0.13242432	0.03310608	1.47	
RESP*POSI*GENDER	2	0.09590002	0.04795001	2.13	
COMPLX*RESP*TF*TYPE	4	0.08622154	0.02155539	0.46	
COMPLX*TF*POSI*TYPE	8	0.09964698	0.01245587	0.73	

[1]The text refers to the Position (Posi) variable as Field of Vision or FOV.

Summary of Analysis of Variance
RT -- POSITIVE
(Continued)

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
COMPL*TF*GENDER*TYPE	4	0.05472901	0.01368225	0.29	
RESP*TF*POSI*TYPE	4	0.13785532	0.03446383	2.02	
RESP*TF*GENDER*TYPE	2	0.02530148	0.01265074	0.27	
TF*POSI*GENDER*TYPE	4	0.01967638	0.00491909	0.29	
COMPL*RESP*POSI*TYPE	4	0.13615378	0.03403844	1.11	
COMP*RESP*GENDE*TYPE	2	0.25428750	0.12714375	0.65	
COMP*POSI*GENDE*TYPE	4	0.04068940	0.01017235	0.33	
RESP*POSI*GENDE*TYPE	2	0.02592288	0.01296144	0.42	
COMPLX*RESP*TF*POSI	8	0.22385666	0.02798208	1.78	
COMPL*RESP*TF*GENDER	4	0.29448358	0.07362090	0.50	
COMPL*TF*POSI*GENDER	8	0.08777228	0.01097154	0.70	
RESP*TF*POSI*GENDER	4	0.06261093	0.01565273	1.00	
COMP*RESP*POSI*GENDE	4	0.02875465	0.00718866	0.32	
COM*RES*TF*POSI*TYPE	8	0.07459603	0.00932450	0.55	
COM*RES*TF*GEND*TYPE	4	0.31781205	0.07945301	1.70	
COM*TF*POS*GEND*TYPE	8	0.09367378	0.01170922	0.69	
RES*TF*POS*GEND*TYPE	4	0.03631119	0.00907780	0.53	
COM*RES*POS*GEN*TYPE	4	0.03964804	0.00991201	0.32	
COM*RES*TF*POSI*GEND	8	0.16272365	0.02034046	1.30	
CO*RE*TF*POS*GEN*TYP	8	0.08008425	0.01001053	0.59	
SN(COMPL*RESP*GENDE)	132	202.7448363	1.5359457	.	.
SN*TYP(COM*RES*GEND)	132	25.9074505	0.1962686	.	.
TF*SN(COM*RESP*GEND)	264	38.5405372	0.1459869	.	.
POS*SN(COM*RES*GEND)	264	5.9539022	0.0225527	.	.
TF*SN*TY(CO*RES*GEN)	264	12.3379617	0.0467347	.	.
PO*SN*TY(CO*RES*GEN)	264	8.0708140	0.0305713	.	.
TF*PO*SN(CO*RES*GEN)	528	8.2929885	0.0157064	.	.
T*PO*SN*TY(CO*RE*GE)	528	8.9945234	0.0170351	.	.

Summary of Analysis of Variance
PCT (Accuracy) -- POSITIVE
All Positive Stimuli

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
TYPE	1	0.46545168	0.46545168	11.85	0.0008
TF	2	0.01178345	0.00589172	0.21	
COMPLX	2	24.14215051	12.07107526	55.11	0.0001
RESP	1	0.09680000	0.09680000	0.44	
POSI[2]	2	0.13064382	0.06532191	2.21	
GENDER	1	0.03871174	0.03871174	0.18	
TF*TYPE	2	0.03683126	0.01841563	0.82	
COMPLX*TYPE	2	1.06695447	0.53347723	13.59	0.0001
RESP*TYPE	1	0.01379645	0.01379645	0.35	
POSI*TYPE	2	0.08869197	0.04434599	1.71	
GENDER*TYPE	1	0.01321747	0.01321747	0.34	
COMPLX*TF	4	0.07834693	0.01958673	0.69	
RESP*TF	2	0.02033703	0.01016852	0.36	
TF*POSI	4	0.02200910	0.00550228	0.27	
TF*GENDER	2	0.33105062	0.16552531	5.85	0.0033
COMPLX*RESP	2	0.49561472	0.24780736	1.13	
COMPLX*POSI	4	1.81720411	0.45430103	15.37	0.0001
COMPLX*GENDER	2	0.27173036	0.13586518	0.62	
RESP*POSI	2	0.06311422	0.03155711	1.07	
RESP*GENDER	1	0.03468979	0.03468979	0.16	
POSI*GENDER	2	0.09500066	0.04750033	1.61	
COMPLX*TF*TYPE	4	0.11287585	0.02821896	1.25	
RESP*TF*TYPE	2	0.08474364	0.04237182	1.88	
TF*POSI*TYPE	4	0.13271327	0.03317832	1.73	
TF*GENDER*TYPE	2	0.01128866	0.00564433	0.25	
COMPLX*RESP*TYPE	2	0.15524499	0.07762250	1.98	
COMPLX*POSI*TYPE	4	1.05759462	0.26439865	10.22	0.0001
COMPLX*GENDER*TYPE	2	0.14030030	0.07015015	1.79	
RESP*POSI*TYPE	2	0.28565449	0.14282725	5.52	0.0045
RESP*GENDER*TYPE	1	0.01880356	0.01880356	0.48	
POSI*GENDER*TYPE	2	0.18394408	0.09197204	3.56	0.0299
COMPLX*RESP*TF	4	0.01364412	0.00341103	0.12	
COMPLX*TF*POSI	8	0.06960938	0.00870117	0.43	
COMPLX*TF*GENDER	4	0.04717076	0.01179269	0.42	
RESP*TF*POSI	4	0.14208428	0.03552107	1.77	
RESP*TF*GENDER	2	0.01184546	0.00592273	0.21	
TF*POSI*GENDER	4	0.04959352	0.01239838	0.62	
COMPLX*RESP*POSI	4	0.20189152	0.05047288	1.71	
COMPLX*RESP*GENDER	2	0.95795329	0.47897665	2.19	
COMPLX*POSI*GENDER	4	0.06617912	0.01654478	0.56	
RESP*POSI*GENDER	2	0.02673472	0.01336736	0.45	
COMPLX*RESP*TF*TYPE	4	0.05457895	0.01364474	0.61	
COMPLX*TF*POSI*TYPE	8	0.07718618	0.00964827	0.50	
COMPL*TF*GENDER*TYPE	4	0.02307080	0.00576770	0.26	

[2] The text refers to the Position (Posi) variable as Field of Vision or FOV.

Summary of Analysis of Variance
PCT (Accuracy)-- POSITIVE
All Positive Stimuli
(Continued)

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
RESP*TF*POSI*TYPE	4	0.05527113	0.01381778	0.72	
RESP*TF*GENDER*TYPE	2	0.00048108	0.00024054	0.01	
TF*POSI*GENDER*TYPE	4	0.03170748	0.00792687	0.41	
COMPL*RESP*POSI*TYPE	4	0.53150602	0.13287651	5.14	0.0005
COMP*RESP*GENDE*TYPE	2	0.11765631	0.05882815	1.50	
COMP*POSI*GENDE*TYPE	4	0.10998374	0.02749593	1.06	
RESP*POSI*GENDE*TYPE	2	0.07079268	0.03539634	1.37	
COMPLX*RESP*TF*POSI	8	0.14492361	0.01811545	0.90	
COMPL*RESP*TF*GENDER	4	0.20851526	0.05212881	1.84	
COMPL*TF*POSI*GENDER	8	0.27248992	0.03406124	1.70	
RESP*TF*POSI*GENDER	4	0.01026766	0.00256692	0.13	
COMP*RESP*POSI*GENDE	4	0.12196047	0.03049012	1.03	
COM*RES*TF*POSI*TYPE	8	0.10435200	0.01304400	0.68	
COM*RES*TF*GEND*TYPE	4	0.11903175	0.02975794	1.32	
COM*TF*POS*GEND*TYPE	8	0.16198609	0.02024826	1.05	
RES*TF*POS*GEND*TYPE	4	0.04323467	0.01080867	0.56	
COM*RES*POS*GEN*TYPE	4	0.25123835	0.06280959	2.43	0.0482
COM*RES*TF*POSI*GEND	8	0.03818880	0.00477360	0.24	
CO*RE*TF*POS*GEN*TYP	8	0.12322071	0.01540259	0.80	
SN(COMPL*RESP*GENDE)	132	28.91520777	0.21905460	.	.
SN*TYP(COM*RES*GEND)	132	5.18303800	0.03926544	.	.
TF*SN(COM*RESP*GEND)	264	7.47610836	0.02831859	.	.
POS*SN(COM*RES*GEND)	264	7.80282370	0.02955615	.	.
TF*SN*TY(CO*RES*GEN)	264	5.94653713	0.02252476	.	.
PO*SN*TY(CO*RES*GEN)	264	6.82653017	0.02585807	.	.
TF*PO*SN(CO*RES*GEN)	528	10.59694440	0.02006997	.	.
T*PO*SN*TY(CO*RE*GE)	528	10.13902404	0.01920270	.	.

Summary of Analysis of Variance
RT -- POSITI_1
All Positive, LFOV & RFOV

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
TYPE	1	0.01720156	0.01720156	0.10	
TF	2	2.49440331	1.24720166	10.65	0.0001
COMPLX	2	43.77762746	21.88881373	19.80	0.0001
RESP	1	0.86421223	0.86421223	0.78	
POSI[3]	1	0.00280602	0.00280602	0.12	
GENDER	1	0.12341559	0.12341559	0.11	
TF*TYPE	2	0.18567856	0.09283928	2.33	
COMPLX*TYPE	2	7.52661425	3.76330713	22.85	0.0001
RESP*TYPE	1	0.00913928	0.00913928	0.06	
POSI*TYPE	1	0.00015648	0.00015648	0.01	
GENDER*TYPE	1	0.14058334	0.14058334	0.85	
COMPLX*TF	4	0.11577369	0.02894342	0.25	
RESP*TF	2	0.04150800	0.02075400	0.18	
TF*POSI	2	0.02888816	0.01444408	1.13	
TF*GENDER	2	0.16792171	0.08396085	0.72	
COMPLX*RESP	2	1.13883569	0.56941784	0.52	
COMPLX*POSI	2	0.09618510	0.04809255	2.09	
COMPLX*GENDER	2	5.62619890	2.81309945	2.55	
RESP*POSI	1	0.02011737	0.02011737	0.87	
RESP*GENDER	1	3.12209267	3.12209267	2.82	
POSI*GENDER	1	0.13993834	0.13993834	6.08	0.0150
COMPLX*TF*TYPE	4	0.16785759	0.04196440	1.06	
RESP*TF*TYPE	2	0.22476427	0.11238214	2.83	
TF*POSI*TYPE	2	0.01857363	0.00928681	0.66	
TF*GENDER*TYPE	2	0.14323913	0.07161956	1.80	
COMPLX*RESP*TYPE	2	0.09034703	0.04517352	0.27	
COMPLX*POSI*TYPE	2	0.05251357	0.02625679	1.21	
COMPLX*GENDER*TYPE	2	0.27726705	0.13863352	0.84	
RESP*POSI*TYPE	1	0.14670722	0.14670722	6.76	0.0104
RESP*GENDER*TYPE	1	0.15966684	0.15966684	0.97	
POSI*GENDER*TYPE	1	0.00161783	0.00161783	0.07	
COMPLX*RESP*TF	4	0.13210359	0.03302590	0.28	
COMPLX*TF*POSI	4	0.04853128	0.01213282	0.95	
COMPLX*TF*GENDER	4	0.15217713	0.03804428	0.32	
RESP*TF*POSI	2	0.00251695	0.00125847	0.10	
RESP*TF*GENDER	2	0.04609064	0.02304532	0.20	
TF*POSI*GENDER	2	0.00475177	0.00237588	0.19	
COMPLX*RESP*POSI	2	0.07014937	0.03507468	1.52	
COMPLX*RESP*GENDER	2	5.55923893	2.77961947	2.51	
COMPLX*POSI*GENDER	2	0.05570635	0.02785317	1.21	
RESP*POSI*GENDER	1	0.05233927	0.05233927	2.27	
COMPLX*RESP*TF*TYPE	4	0.09721501	0.02430375	0.61	
COMPLX*TF*POSI*TYPE	4	0.03435841	0.00858960	0.61	
COMPL*TF*GENDER*TYPE	4	0.06725420	0.01681355	0.42	

[3]The text refers to the Position (Posi) variable as Field of Vision or FOV.

Summary of Analysis of Variance
RT -- POSITI_1
(Continued)

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
RESP*TF*POSI*TYPE	2	0.06840056	0.03420028	2.42	
RESP*TF*GENDER*TYPE	2	0.05617201	0.02808601	0.71	
TF*POSI*GENDER*TYPE	2	0.01566819	0.00783410	0.55	
COMPL*RESP*POSI*TYPE	2	0.06212669	0.03106334	1.43	
COMP*RESP*GENDE*TYPE	2	0.13393339	0.06696670	0.41	
COMP*POSI*GENDE*TYPE	2	0.02975856	0.01487928	0.69	
RESP*POSI*GENDE*TYPE	1	0.01962334	0.01962334	0.90	
COMPLX*RESP*TF*POSI	4	0.11448329	0.02862082	2.24	
COMPL*RESP*TF*GENDER	4	0.29879454	0.07469864	0.64	
COMPL*TF*POSI*GENDER	4	0.07343909	0.01835977	1.44	
RESP*TF*POSI*GENDER	2	0.06105503	0.03052751	2.39	
COMP*RESP*POSI*GENDE	2	0.01725210	0.00862605	0.37	
COM*RES*TF*POSI*TYPE	4	0.02574095	0.00643524	0.46	
COM*RES*TF*GEND*TYPE	4	0.22178429	0.05544607	1.39	
COM*TF*POS*GEND*TYPE	4	0.01577298	0.00394324	0.28	
RES*TF*POS*GEND*TYPE	2	0.00029685	0.00014842	0.01	
COM*RES*POS*GEN*TYPE	2	0.03129557	0.01564779	0.72	
COM*RES*TF*POSI*GEND	4	0.10561367	0.02640342	2.07	
CO*RE*TF*POS*GEN*TYP	4	0.02574857	0.00643714	0.46	
SN(COMPL*RESP*GENDE)	132	145.8923180	1.1052448	.	.
SN*TYP(COM*RES*GEND)	132	21.7387987	0.1646879	.	.
TF*SN(COM*RESP*GEND)	264	30.9213567	0.1171264	.	.
POS*SN(COM*RES*GEND)	132	3.0386202	0.0230199	.	.
TF*SN*TY(CO*RES*GEN)	264	10.4977319	0.0397641	.	.
PO*SN*TY(CO*RES*GEN)	132	2.8626306	0.0216866	.	.
TF*PO*SN(CO*RES*GEN)	264	3.3749061	0.0127837	.	.
T*PO*SN*TY(CO*RE*GE)	264	3.7313875	0.0141340	.	.

Summary of Analysis of Variance
PCT (Accuracy)-- POSITI_1
All Positive, LFOV and RFOV

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
TYPE	1	0.36284815	0.36284815	9.61	0.0024
TF	2	0.02466490	0.01233245	0.50	
COMPLX	2	11.34893404	5.67446702	35.39	0.0001
RESP	1	0.02373334	0.02373334	0.15	
POSI[4]	1	0.09404601	0.09404601	2.98	
GENDER	1	0.00004482	0.00004482	0.00	
TF*TYPE	2	0.02758649	0.01379324	0.70	
COMPLX*TYPE	2	1.83912112	0.91956056	24.35	0.0001
RESP*TYPE	1	0.00373945	0.00373945	0.10	
POSI*TYPE	1	0.08252972	0.08252972	3.88	
GENDER*TYPE	1	0.05361798	0.05361798	1.42	
COMPLX*TF	4	0.03751188	0.00937797	0.38	
RESP*TF	2	0.03658352	0.01829176	0.74	
TF*POSI	2	0.00180846	0.00090423	0.05	
TF*GENDER	2	0.34499675	0.17249837	6.99	0.0011
COMPLX*RESP	2	0.37716711	0.18858355	1.18	
COMPLX*POSI	2	0.01098213	0.00549107	0.17	
COMPLX*GENDER	2	0.24765795	0.12382898	0.77	
RESP*POSI	1	0.03312752	0.03312752	1.05	
RESP*GENDER	1	0.05918408	0.05918408	0.37	
POSI*GENDER	1	0.01099003	0.01099003	0.35	
COMPLX*TF*TYPE	4	0.09160201	0.02290050	1.17	
RESP*TF*TYPE	2	0.04402531	0.02201266	1.12	
TF*POSI*TYPE	2	0.11888980	0.05944490	3.10	0.0468
TF*GENDER*TYPE	2	0.02993317	0.01496658	0.76	
COMPLX*RESP*TYPE	2	0.13842816	0.06921408	1.83	
COMPLX*POSI*TYPE	2	0.25018917	0.12509459	5.88	0.0036
COMPLX*GENDER*TYPE	2	0.17478381	0.08739191	2.31	
RESP*POSI*TYPE	1	0.28203112	0.28203112	13.25	0.0004
RESP*GENDER*TYPE	1	0.00171534	0.00171534	0.05	
POSI*GENDER*TYPE	1	0.12707245	0.12707245	5.97	0.0159
COMPLX*RESP*TF	4	0.02893759	0.00723440	0.29	
COMPLX*TF*POSI	4	0.02688641	0.00672160	0.33	
COMPLX*TF*GENDER	4	0.06462011	0.01615503	0.65	
RESP*TF*POSI	2	0.03939763	0.01969881	0.98	
RESP*TF*GENDER	2	0.00453577	0.00226788	0.09	
TF*POSI*GENDER	2	0.00098383	0.00049191	0.02	
COMPLX*RESP*POSI	2	0.18038296	0.09019148	2.86	
COMPLX*RESP*GENDER	2	0.78191684	0.39095842	2.44	
COMPLX*POSI*GENDER	2	0.02702952	0.01351476	0.43	
RESP*POSI*GENDER	1	0.00178037	0.00178037	0.06	
COMPLX*RESP*TF*TYPE	4	0.03175846	0.00793962	0.40	
COMPLX*TF*POSI*TYPE	4	0.03642994	0.00910748	0.47	
COMPL*TF*GENDER*TYPE	4	0.01950465	0.00487616	0.25	
RESP*TF*POSI*TYPE	2	0.05143589	0.02571795	1.34	

[4]The text refers to the Position (Posi) variable as Field of Vision or FOV.

Summary of Analysis of Variance
PCT(Accuracy)-- POSITI_1
(Continued)

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
RESP*TF*GENDER*TYPE	2	0.00331981	0.00165990	0.08	
TF*POSI*GENDER*TYPE	2	0.00587695	0.00293847	0.15	
COMPL*RESP*POSI*TYPE	2	0.37199916	0.18599958	8.74	0.0003
COMP*RESP*GENDE*TYPE	2	0.22726340	0.11363170	3.01	
COMP*POSI*GENDE*TYPE	2	0.04270104	0.02135052	1.00	
RESP*POSI*GENDE*TYPE	1	0.00021674	0.00021674	0.01	
COMPLX*RESP*TF*POSI	4	0.09942494	0.02485624	1.24	
COMPL*RESP*TF*GENDER	4	0.12490315	0.03122579	1.27	
COMPL*TF*POSI*GENDER	4	0.20652361	0.05163090	2.57	0.0384
RESP*TF*POSI*GENDER	2	0.00712993	0.00356497	0.18	
COMP*RESP*POSI*GENDE	2	0.10022473	0.05011236	1.59	
COM*RES*TF*POSI*TYPE	4	0.07743192	0.01935798	1.01	
COM*RES*TF*GEND*TYPE	4	0.07316537	0.01829134	0.93	
COM*TF*POS*GEND*TYPE	4	0.07616234	0.01904059	0.99	
RES*TF*POS*GEND*TYPE	2	0.03797277	0.01898639	0.99	
COM*RES*POS*GEN*TYPE	2	0.12070185	0.06035092	2.84	
COM*RES*TF*POSI*GEND	4	0.00988369	0.00247092	0.12	
CO*RE*TF*POS*GEN*TYP	4	0.05381640	0.01345410	0.70	
SN(COMPL*RESP*GENDE)	132	21.16223706	0.16031998	.	.
SN*TYP(COM*RES*GEND)	132	4.98526893	0.03776719	.	.
TF*SN(COM*RESP*GEND)	264	6.51270733	0.02466935	.	.
POS*SN(COM*RES*GEND)	132	4.16723272	0.03156994	.	.
TF*SN*TY(CO*RES*GEN)	264	5.18337641	0.01963400	.	.
PO*SN*TY(CO*RES*GEN)	132	2.80988641	0.02128702	.	.
TF*PO*SN(CO*RES*GEN)	264	5.30282550	0.02008646	.	.
T*PO*SN*TY(CO*RE*GE)	264	5.06799331	0.01919694	.	.

Summary of Analysis of Variance
RT--POSITI_2
Positive Single, LFOV and RFOV

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
TF	2	1.94932790	0.97466395	12.42	0.0001
COMPLX	2	42.06950022	21.03475011	40.70	0.0001
RESP	1	0.52554801	0.52554801	1.02	
POSI[5]	1	0.00214389	0.00214389	0.08	
GENDER	1	0.00027940	0.00027940	0.00	
COMPLX*TF	4	0.21272528	0.05318132	0.68	
RESP*TF	2	0.22964947	0.11482473	1.46	
TF*POSI	2	0.01911002	0.00955501	0.69	
TF*GENDER	2	0.28829135	0.14414567	1.84	
COMPLX*RESP	2	0.90585047	0.45292523	0.88	
COMPLX*POSI	2	0.11714453	0.05857227	2.16	
COMPLX*GENDER	2	4.11356418	2.05678209	3.98	0.0210
RESP*POSI	1	0.02908584	0.02908584	1.07	
RESP*GENDER	1	0.93483820	0.93483820	1.81	
POSI*GENDER	1	0.08582455	0.08582455	3.16	
COMPLX*RESP*TF	4	0.13277113	0.03319278	0.42	
COMPLX*TF*POSI	4	0.02931647	0.00732912	0.53	
COMPLX*TF*GENDER	4	0.12745232	0.03186308	0.41	
RESP*TF*POSI	2	0.02312077	0.01156039	0.83	
RESP*TF*GENDER	2	0.09989991	0.04994995	0.64	
TF*POSI*GENDER	2	0.00248854	0.00124427	0.09	
COMPLX*RESP*POSI	2	0.06284527	0.03142264	1.16	
COMPLX*RESP*GENDER	2	2.09352043	1.04676021	2.03	
COMPLX*POSI*GENDER	2	0.01564010	0.00782005	0.29	
RESP*POSI*GENDER	1	0.06802926	0.06802926	2.50	
COMPLX*RESP*TF*POSI	4	0.10021760	0.02505440	1.80	
COMPL*RESP*TF*GENDER	4	0.37097279	0.09274320	1.18	
COMP*RESP*POSI*GENDER	2	0.00605512	0.00302756	0.11	
COMPL*TF*POSI*GENDER	4	0.01826058	0.00456515	0.33	
RESP*TF*POSI*GENDER	2	0.03492473	0.01746237	1.25	
COM*RES*TF*POSI*GENDE	4	0.11567924	0.02891981	2.07	
SN(COMPL*RESP*GENDE)	132	68.21374334	0.51677078	.	.
TF*SN(COM*RESP*GEND)	264	20.72355252	0.07849830	.	.
POS*SN(COM*RES*GEND)	132	3.58490160	0.02715835	.	.
TF*PO*SN(CO*RES*GEN)	264	3.68078537	0.01394237	.	.

[5]The text refers to the Position (Posi) variable as Field of Vision or FOV.

Summary of Analysis of Variance
PCT -- POSITI_2
Positive Single, LFOV and RFOV

Source	df	Sum of Squares	Mean Square	F Value	Pr ≥ F
TF	2	0.03404627	0.01702314	0.86	
COMPLX	2	10.12413344	5.06206672	59.31	0.0001
RESP	1	0.00431570	0.00431570	0.05	
POSI[6]	1	0.00018797	0.00018797	0.01	
GENDER	1	0.02528126	0.02528126	0.30	
COMPLX*TF	4	0.07954303	0.01988576	1.00	
RESP*TF	2	0.07746545	0.03873272	1.95	
TF*POSI	2	0.07438500	0.03719250	1.96	
TF*GENDER	2	0.24596216	0.12298108	6.19	0.0023
COMPLX*RESP	2	0.08372737	0.04186369	0.49	
COMPLX*POSI	2	0.16268768	0.08134384	3.48	0.0336
COMPLX*GENDER	2	0.20361579	0.10180790	1.19	
RESP*POSI	1	0.06092017	0.06092017	2.61	
RESP*GENDER	1	0.02037395	0.02037395	0.24	
POSI*GENDER	1	0.03166107	0.03166107	1.36	
COMPLX*RESP*TF	4	0.01076204	0.00269051	0.14	
COMPLX*TF*POSI	4	0.02540419	0.00635105	0.34	
COMPLX*TF*GENDER	4	0.03331349	0.00832837	0.42	
RESP*TF*POSI	2	0.07158109	0.03579054	1.89	
RESP*TF*GENDER	2	0.00780748	0.00390374	0.20	
TF*POSI*GENDER	2	0.00488163	0.00244082	0.13	
COMPLX*RESP*POSI	2	0.12470129	0.06235064	2.67	
COMPLX*RESP*GENDER	2	0.13645694	0.06822847	0.80	
COMPLX*POSI*GENDER	2	0.05443402	0.02721701	1.16	
RESP*POSI*GENDER	1	0.00161975	0.00161975	0.07	
COMPLX*RESP*TF*POSI	4	0.06119084	0.01529771	0.81	
COMPL*RESP*TF*GENDER	4	0.08483311	0.02120828	1.07	
COMPL*TF*POSI*GENDER	4	0.21381498	0.05345375	2.82	0.0255
COMP*RESP*POSI*GENDER	2	0.02726306	0.01363153	0.58	
RESP*TF*POSI*GENDER	2	0.03153107	0.01576554	0.83	
COM*RES*TF*POSI*GENDER	4	0.02467960	0.00616990	0.33	
SN(COMPL*RESP*GENDE)	132	11.26698079	0.08535592	.	.
TF*SN(COM*RESP*GEND)	264	5.24133896	0.01985356	.	.
POS*SN(COM*RES*GEND)	132	3.08399616	0.02336361	.	.
TF*PO*SN(CO*RES*GEN)	264	5.00046893	0.01894117	.	.

[6]The text refers to the Position (Posi) variable as Field of Vision or FOV.

AUTOBIOGRAPHICAL STATEMENT

I was born in Honolulu, Hawaii on May 11, 1945. After working for 15 years in private and government offices, I pursued my academic goals. Before pursuing a Ph.D. in Industrial/Organizational Psychology at Old dominion University, I earned both a Bachelor's and Master's degree in Psychology from the University of Hawaii in Honolulu, Hawaii. I received my Bachelor's degree in May 1984 and Master's degree in December 1986.

From January 1990 until February 1991 I fulfilled the internship requirement for the Ph.D. program at the Department of Defense, Army Research Institute at Fort Knox, Kentucky as a Research Psychologist.

I am currently the Director of Quality Assurance for Continental Dynamics, Inc. which is an organization that specializes in developing computer-based interactive multimedia training programs.