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Effect of Stimulus Presentation Time on Visual Search Processes

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EFFECT OF STIMULUS PRESENTATION TIME ON VISUAL SEARCH PROCESSES

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ABSTRACT

This thesis examines the effect of presentation time on visual search tasks which require participants to make target present/absent decisions on a display with a varying number of distractor items. Past research has found that targets defined by the presence of a single distinctive feature are searched via a parallel search, while those defined by the absence of a feature are searched via a serial search. Based on these findings, researchers studying hemispheric specialization have employed visual search tasks to find hemispheric differences. This study found high error rates for presentation times shorter than the average scan time necessary for a complete search of the display. These high error rates made identification of serial searches through reaction time patterns problematic. Implications for hemispheric specialization studies are also presented.

CHAPTER I

INTRODUCTION

This thesis examines the effect of presentation time on visual search tasks and the implications of this effect for both visual search and hemispheric specialization research. It is well known that the two cerebral hemispheres are not identical in the way they process information (Gazzaniga, 1967; Springer & Deutsch, 1981). It was previously thought that the left hemisphere controlled language abilities and the right hemisphere controlled visual-spatial abilities. Hemispheric specialization researchers believed that the underlying processes in each hemisphere could be described as "global" or "analytic." Specifically, the language abilities of the left hemisphere were thought to be dependent on the actions of an analytic processor, while the visual-spatial abilities of the right hemisphere were thought to be dependent on the actions of a global processor. Studies of hemispheric specialization that have sought to demonstrate these processing differences have had limited success (e.g., Davis & Schmidt, 1973; Dimond & Beaumont, 1972; Polich, 1986; Polich, DeFrancesco, Garon, & Cohen, 1990; Umilta, Bagnari, & Simion, 1978; White & White, 1975). Some of the problem stems from difficulty in developing paradigms that can unambiguously distinguish analytic from global processing (see Bagnari, Boles, Simion, & Umilta, 1982; Patterson & Bradshaw, 1975). Recently, hemispheric specialization research has shifted away from an analytic versus global processing explanation to a "serial" versus "parallel" processing account for cerebral differences (Cohen, 1973; White & White, 1975; Polich, 1980; 1984).

To study possible hemispheric differences in serial versus parallel processing, visual search tasks have been employed. Experiments employing visual search paradigms have found that certain types of visual displays are scanned serially, while others must be searched in parallel. In their visual search studies, Treisman and her colleagues (Treisman, 1991; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985) have used a target-present/target-absent task. Using response-terminated display times, a robust "search asymmetry" was found. The researchers inferred that serial and parallel processing occurred by examining the reaction time patterns as a function of the number of items in the display. For example, increasing reaction time as set size increases suggests that the stimuli are searched via a serial processor. On the other hand, relatively flat reaction times as set size increases suggests that the stimuli are searched via a serial processor. Searches for targets defined by the absence of a feature (e.g., searching for an "O" among "Q's") were serial, while searches for targets containing a feature that is absent in distractors (e.g., searching for a "Q" among "O's") were spatially parallel.

In order to use visual search tasks and stimuli in the study of hemispheric specialization studies, several modifications to the method are necessary. To ensure that the visual input is initially sent to one hemisphere, hemispheric specialization experiments require brief stimulus presentation time and stimuli are presented to the periphery. Palmer and Tzeng (1992) present a study in which they employ visual search tasks to investigate hemispheric differences. They presented stimuli for 200 msec to the left and right visual fields. As a consequence of these changes to the conventional paradigm, error rates found were substantially elevated relative to those obtained for foveal, response-terminated presentations. In some instances, these error rates reached a magnitude of 40%, in which case, the ability to use reaction time to indicate serial or parallel processes is greatly diminished. Palmer and Tzeng instead used accuracy patterns to make inferences regarding the nature of the underlying search by looking at changes in error rates as a function of the number of items displayed. But, this author knows of no theoretical justification to support the use of accuracy rates in this manner; therefore, conclusions based on this logic are suspect.

The higher error rates that accompany brief presentation times might be brought on by an inability of the participants to scan all of the items in the display prior to the removal of the stimulus. Hence, only a few items in the display may have been searched due to insufficient stimulus exposure time. The data obtained would then be based on only a partial search of the display. Since visual search findings assume that a complete, not partial, search of the display was made, this hemispheric specialization experiment does not replicate findings by Treisman and her colleagues. Thus, identification of the underlying cognitive processes used in each hemisphere is also not possible.

Additionally, the presentation of stimuli to the periphery instead of to the fovea results in a degradation of visual acuity. This further impacts accuracy and reaction time results and makes the identification of serial and parallel search processes speculative at best. Both of these issues are discussed in more detail in Chapter II.

The present thesis uses a between-subjects design to assess the effect of presentation time on accuracy and reaction time in a visual search task. Both presentation time and distractor set size were manipulated to determine their effect on visual search processes. In order to make inferences to serial or parallel processing from reaction time by set size functions, an understanding of the underlying cognitive process that has to occur for the successful completion of a trial is required. If accuracy is low then it is difficult know what cognitive processes actually occurred during correct trials. Thus, identification of serial or parallel processes is not possible. The results indicate that for presentation times shorter than the average scan time necessary for a complete search of the display, reaction time patterns could not be used to identify serial or parallel searches due to high error rates. Implications for the use of these procedures in hemispheric specialization studies are also presented.

CHAPTER II

REVIEW OF THE RELATED LITERATURE

Hemispheric Specialization

Many researchers have found evidence that different cognitive processing mechanisms exist in the two hemispheres of the brain (Springer & Deutsch, 1981). Investigators of human cerebral asymmetry, or "hemispheric specialization" do not propose that hemispheric asymmetry is absolute, nor do they argue that one side of the brain is unable to process particular types of information compared to the other (indeed, it would certainly be naive to predict that the two sides of the brain work entirely independent of each other). However, theories of hemispheric specialization propose that different mechanisms exist within the two hemispheres and that performance differences on particular tasks results from this asymmetry (Hamilton & Vermeire, 1991).

This notion of hemispheric or cerebral asymmetry is founded in neurological research which connects specific areas of the brain to identifiable behaviors. Investigators observed patients who have sustained a head injury, suffered a stroke, or undergone brain surgery. Behavioral deficits are then correlated with damage to specific areas of the brain. Researchers have found that patients with brain damage in their left hemisphere tend to show a degradation in their verbal abilities (Gazzaniga, 1967; Gazzaniga & Sperry, 1967; Luria, 1973; Morton, 1970). Additionally, Rasmussen and Milner (1977) effectively isolated the two hemispheres from one another through anesthesia. They found that when the left hemisphere was anesthetized, only 5 percent of their right-handed participants were able to speak. Conversely, when only the right hemisphere was anesthetized, verbal communication was unaffected[1]. They concluded that the left hemisphere is integral to verbal abilities.

While the left hemisphere is believed to control verbal communication, the right hemisphere is believed to control visual and artistic demands. Similar to patients with left hemisphere damage, those with damage to their right hemisphere exhibited deficits in their ability to recognize complex geometrical shapes, perceive spatial relations, and read maps. These patients were able to talk, but showed no concept or understanding of things such as maps or shapes (Benton, 1969; Kimura, 1963; deRenzi & Spinnler, 1966; Warrington, James, & Kinsbourne, 1966).

In order to assess hemispheric differences more clearly, researchers experimented on split brain patients (i.e., patients with isolated hemispheres). Patients who have had their corpus collosum severed serve as ideal participants, because the corpus collosum is the nerve-fiber tract connecting the left and right hemispheres. When the corpus collosum is severed, communication between the hemispheres ceases (Springer & Deutsch, 1981). Since these split brain patients have isolated hemispheres, visual input can be limited to

[1] When the procedure is performed on left-handed participants, the results are somewhat weaker. About 30% of these participants were able to speak without the use of their left hemispheres, which suggests that left-handers show less cerebral asymmetry than right-handers (Rasmussen & Milner, 1977, in Carlson, 1991).

one hemisphere by presenting visual stimuli to only one visual field. For example, if both eyes are fixated on a single point and a stimulus is presented on the left side of one's field of view (LVF), then the stimulus will be registered to the right side of the brain. Conversely, if a stimulus is presented in the right visual field (RVF) then it is represented in the left hemisphere. This procedure provides researchers with a simple paradigm to test for hemispheric specialization (see Gazzaniga, 1967 or Springer & Deutsch, 1981 for a thorough review).

Clinical research in the 1940's on epileptic patients who had their corpus collosum surgically severed found differences between the two hemispheres. Using words, pictures, faces, and symbols as stimuli, studies on split-brain patients found support for hemispheric differences for linguistic and visual processes. For example, split-brain patients were able to identify and comprehend words when they were flashed into the left hemisphere, but they could not identify the same objects when flashed into the right hemisphere. Conversely, these patients were able to identify visual objects, such as pictures and faces when they were flashed into the right hemisphere, but not the left hemisphere (Robertson & Delis, 1986; Springer & Deutsch, 1981).

In research on normal participants must take into account the ability for information to pass between the two hemispheres. Since visual information has been found to take as little as 15-20 msec to go from one hemisphere to the other via the corpus collosum (Bradshaw, 1989), it would be difficult to expect to find significant asymmetric differences. Hence, the short processing lag time between hemispheres would allow both sides of the brain to acquire the necessary information to process the stimuli. For example, a visual stimulus was presented into the right hemisphere could be sent over to the left hemisphere to be processed. Thus, only very small hemispheric differences might be found, because which ever hemisphere completes the task first will be the first to submit output. This is analogous to a race between hemispheres. Since the latency between the hemispheres is so small, it would be difficult to assess differences in normal subjects because the more efficient process would typically take over. For example, if the left hemisphere were more efficient than the right hemisphere for a given stimulus, the small information lag time between the two hemispheres would render processing by the right hemisphere pointless. Thus, even if information were presented into the right hemisphere first and then passed to the left hemisphere, the left hemisphere might still process the information faster than the right. Following this perspective, one would never expect to find hemispheric differences using simple reaction time paradigms.

However, numerous studies have found hemispheric differences in normal subjects (e.g., Polich, 1986; Polich, DeFrancesco, Garon, & Cohen, 1990; White & White, 1975). Bradshaw (1989) accounts for the ability to assess hemispheric differences by contending that the corpus collosum is more than a pathway for information; it organizes cerebral processes. He argues that the corpus collosum not only transports the visual representation of the stimuli, it also transmits inhibitory and complementary information to regulate cognitive processes. For example, if a visual stimulus was presented to the right hemisphere, the visual process would begin in the right hemisphere. Information transported via the corpus collosum to the left hemisphere would be biased towards complementing the visual process already started (i.e., helping the right hemisphere complete the task). Thus, only information generated in the left hemisphere that would aid the process would be sent to the right hemisphere (Bradshaw, 1989). This explanation provides a theoretical interpretation of cerebral asymmetries (see Atkinson & Egeth, 1973; Egeth & Epstein, 1972; Gross, 1972; Springer & Deutsch, 1981).

Alternatively, a review of the literature also yields a number of studies that finds neither a left hemisphere superiority for language nor right hemisphere superiority for non-verbal stimuli (Gibson, Dimond, & Gazzaniga, 1972; White & White, 1975). Moreover, several studies have found the exact opposite hemispheric patterns (Davis & Schmidt, 1973; Dimond & Beaumont, 1972; Umilta, Bagnari, & Simion, 1978). With such mixed results, it is difficult to determine whether hemispheric differences in broad and complex general processes, such as language or spatial abilities, exist.

Analytic and Global Cognitive Processes

A resolution of these conflicting findings on hemispheric specialization may reside in a lower level account of the phenomenon. The underlying differences may not be whether the verbal or non-verbal stimuli are processed via specialized language or visual-spatial sections of the brain, but rather these differences may reflect more fundamental differences in the processing that takes place in the two hemispheres. Thus, the distinction between the two hemispheres may not be that they process different information, but that they process the same information using different processors. Presumably, these processors would be different in that one processor is more efficient with certain stimuli than the other. This view represents a shift from earlier research which emphasized that specific types of information were exclusively processed in specific areas of the brain. From the newer perspective, both hemispheres process incoming stimulus information, but they do so in somewhat different ways. For example, when presented with a complex visual stimulus one hemisphere might process the stimulus element-by-element, while the other hemisphere might process the stimulus in a global or holistic manner. If the task requires a fine-grained analysis then the hemisphere that processes each stimulus element sequentially might be better able to complete the task than the hemisphere with the global processor. Conversely, if the task required a holistic analysis of the visual stimulus then the hemisphere with the global processor would be perform better than the hemisphere with an analytic processor (Polich, 1982, 1986). This scheme of two independent processors, one analytic and one global, describes a much more powerful system than one with two independent hemispheres. In this system, information is passed into each hemisphere where the data are analyzed using different processors.

The research attempting to support a dual global and analytic processing system has produced mixed results. Martin (1979) and Sergent (1982) applied a variant of the visual Stroop task by Navon (1977) using verbal and non-verbal stimuli to assess hemispheric differences. Researchers believed that verbal tasks favor analytic processing and non-verbal tasks favor global processing. Studies by Martin and Sergent found support for an analytic and global processor distinction between the two hemispheres.

Specifically, the left hemisphere showed analytic processing, whereas, the right hemisphere exhibited global processing. However, studies by Boles (1984) and Alivisatos and Wilding (1982) have failed to replicate these findings. The one common thread between these contradictory findings is the difficulty in creating stimuli or tasks that truly tap into what is defined as "global or analytic" processing (see Bagnari, Boles, Simion, & Umilta, 1982; Patterson & Bradshaw, 1975). Hence, creating stimuli or tasks that are found to reliably invoke either global or analytic processing is integral to this field of research.

Serial and Parallel Processes

One benefit of using the analytic versus global processor explanation for hemispheric specialization is its similarity to the serial versus parallel processing distinction. It is believed that an analytic processor would execute a serial search or sequential item-by-item search of the stimulus array. Hence, the more items in a stimulus, the more processing that is necessary[2]. Using a technique similar to Sternberg (1966), researchers manipulate the number of items in the stimulus and measure the time required to correctly indicate the presence or absence of the target. As the number of items in the stimulus increases, more processing is required to complete the task. The additional processing used is shown in linearly increasing reaction times as the number of items in the stimulus increases[3].

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[2] In measurable terms, more processing relates to more processing time required to complete the task.

[3] Note that in Sternberg's experiment, accuracy was not meaningful, because it was assumed that as the number of items increased, error rates stayed relatively constant. Additionally, reaction times from only correct responses were used.

There are two types of serial searches: self-terminating and exhaustive. It is useful to explain the differences in terms of a visual search task where the system searches the display for a single target among a set of distractors (e.g., searching for an "O" among "Q's"). Serial self-terminating searches refer to processes which end when the target is found. For example, the system is given a stimulus with ten items to be searched. The serial processor begins an analysis on one item and then moves on to the next item. The process is completed if the target is found or if the search finds the target to be absent from the stimulus. Hence, the process is self-terminating because the search ends whenever the target is either found, or determined to be absent from the display.

Different reaction time patterns are found for serial self-terminating searches depending on whether the target is present or absent from the stimulus. If the target is absent from the stimulus, then the search must go though all the items and then conclude that the target is indeed absent. Searches where the target is absent produce much higher slopes than when the target is present (i.e., reaction time by number of items in stimulus). Mathematically, the ratio of target-present to target-absent slopes should be about 1:2. Thus, searches where the target is absent should take on average twice as long as searches where the target is present because half of the items, on average, are searched when the target is present[4]. If the target is present, the process ends when the target is identified, regardless of whether or not some items are left unanalyzed. This produces a positive reaction time slope as the number of items in the stimulus increase.

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[4] Empirically, the slope ratio found has been closer to 1:1.7 (Treisman & Gormican, 1988).

Serial exhaustive searches refer to processes which only end when all of the items have been searched. This can be achieved by using more than one target and requiring the observer to search the entire display to assess the total number of targets presented. Hence, the reaction time versus set size slopes are nearly the same for trials where the target is present and absent. However, these slopes are positive and also show the typical increasing reaction time by the number of items as expected with other serial search process mechanisms.

On the other hand, a search conducted in parallel shows negligible reaction time increases as set size increases. In a visual search consisting of numerous items, a serial processor conducts an analysis of each element one after another. Thus, increasing the number of elements in the display leads to greater reaction times. Alternatively, a parallel search process analyzes all elements at once. Thus, increases in the number of elements do not affect the reaction time of a parallel processor, because an analysis of all items is made in a simultaneous or holistic manner.

Researchers are able to use reaction time patterns to make inferences to types of cognitive processing. For example, one indicator of analytic processing is a linearly increasing reaction time as the number of items to be processed increases and one indicator of global processing is a reaction time slope that is relatively close to zero as items increase. Attempts to combine this paradigm with hemispheric specialization experiments have yielded mixed results. These experiments employed relatively simple tasks where participants made same/different responses to stimuli consisting of one to four letters, hemispheric specialization researchers found mixed results. Cohen (1973) found positive results for hemispheric asymmetry using letters, such that the left hemisphere showed a superiority over the right hemisphere. However, White and White (1975) applied a similar technique using geometric shapes instead of letters in an attempt to identify a right hemisphere superiority for visual-spatial stimuli. Their results indicated no hemispheric differences. Other studies have produced less than conclusive serial-parallel distinctions due to the difficulty in understanding the perceptual qualities of the stimuli combined with high error rates (Polich, 1980, 1984).

Visual Search Literature

One benefit of connecting the analytic versus global processor explanation for hemispheric specialization to the serial and parallel processing distinction is the wealth of data found in the visual search literature. Visual search experiments demonstrated that visual targets presented among distractors can lead to the two types of searches. Treisman and Gelade (1980), in their research on visual perception, alluded to global and analytic processing when they drew a distinction between pre-attentive processing and attentive processing in Treisman's feature integration model. Pre-attentive processing is characterized as being: 1) preliminary and "automatic," or independent of strategic control; 2) spatially parallel; and 3) unlimited in capacity. Conversely, attentive processing requires focused attention (i.e., attention is focused on one area then the focus is shifted to another area, etc.). This process is analogous to a mental spotlight light where fine-grained analyses are conducted only over an illuminated area (Treisman, 1986). Thus, increasing the number of elements that have to be searched increases the amount of processing that is required. On the other hand, a pre-attentive process should have little difficulty analyzing a display with many elements because the entire display is analyzed at once. These two processes were studied extensively by examining the slopes of the reaction time by set size functions (see also, Treisman, 1982, 1986, 1989, 1991; Treisman & Gelade, 1980).

In one experiment, Treisman and Souther (1985) used circles and circles with intersecting lines as stimuli. These stimulus items are visually similar to the letters "O" and "Q." In one condition, Treisman and Souther used a field of O's as distractors and a Q as target. Thus, the task involved searching for the presence of a feature (in his case, the absence of a line). In the other condition, the target and distractors were switched so the O was the target and Q's were distractors. Thus, the task involved searching for the absence of a feature. The two conditions were presented to participants in separate blocks. The stimuli were displayed on the screen until a response was made. The investigators varied the number of items in the display within a block and found that when the target was a single Q among O's, reaction time remained flat as the number of items in the display increased for both target present and target absent trials. This finding indicated that the search of the display for the target was spatially parallel. In this Q among O's condition, participants reported that the Q seemed to "pop out" of the field of distractors. Treisman (1986) concluded that these stimuli were processed pre-attentively because the visual system was able to analyze the display and identify the target very quickly in the process.

Conversely, when the target was a single O among Q's, increasing the number of elements in the display affected performance. Treisman found a linearly increasing reaction time slope as the number of display items increased, suggesting that a serial search was executed. Also, the approximately 1:2 ratio found between target-present and target-absent trials suggests that a serial self-terminating search occurred. Treisman and Souther (1985) attribute these results to the work of focused attention or a "mental spotlight" scan over each of the elements in the display.

Treisman and Souther (1985) concluded that as the number of display items increase, certain stimuli produce reaction time results that follow a serial processing pattern and other stimuli produce parallel processing patterns. Searching for the absence of a feature (e.g., searching for an O among Q's) was conducted in parallel, whereas, searching for the presence of a feature (e.g., searching for a Q among O's) was conducted serially. They found several types of stimuli that produce this search asymmetry, such as tilted and vertical line segments, long and short line segments, etc. (see Treisman, 1986; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985 for a review). These stimuli produce extremely robust effects for even single subjects. However, the most interesting feature of these two types of stimuli is that both displays are derived from the same two elements. When the target and distractor in one condition are interchanged in the other condition, the results indicate that the stimuli in condition are processed in parallel and the stimuli in the other condition are processed serially.

The dichotomous effects found with these stimuli are robust. However, there is a concern over the length of the presentation time (in most instances, the stimulus was displayed until a response was made). Although participants are instructed to focus their eyes on a single fixation point prior to stimulus presentation, it is possible for participants to make saccadic eye movements during each trial. These eye movements could confound the identification of focused attentional shifts associated with a serial search of the visual display. Hence, the increasing reaction time found as the number of items in the display increases could be due to successive eye movements and fixations rather than focused attentional shifts.

Pashler (1987a) proposed that attentional shifts occur when the attentional resources of the system are sufficiently taxed. He argues that the serial searches found with large set sizes are the result of a molar serial self-terminating search. Basically, he advocates a limited capacity parallel processing mechanism. When the number of items in the display is greater than the capacity of the parallel search system, the system is forced to "clump" the items and perform successive scans of each clump of items. Each "clump" of items is scanned in parallel. Thus, it is likely that these attentional shifts of attention manifest themselves in a serial search pattern of results.

However, Klein and Farrell (1989) concluded that saccadic eye movements play little role when assessing serial and parallel search processes. In their experiment, half of the participants was allowed to move their eyes freely while the other half was told to keep their eyes fixed to a single location. Eye movements were monitored for participants in the fixed eye movement condition and all trials where eye movements were found were removed from the final analysis. They found no difference in serial and parallel search patterns whether participants were able to move their eyes or not. While their conclusions do not rule out covert shifts of attention as the cause of serial search patterns, they do find that the serial and parallel search patterns observed cannot be attributed to scans of the stimuli through saccadic eye movements.

Treisman and Gormican (1988) ran conditions using a very brief presentation time and a limited set size. A presentation time of 180 msec was chosen because it would not allow for eye movements or changes in fixation. The researchers chose a small set size (1 to 6 items) because they anticipated extremely high error rates given the very brief presentation time used. In fact, 6 out of 14 participants were discarded due to their inability to maintain accuracy rates of 67% in all conditions. The stimuli presented were 8-mm lines, subtending 0.46 degrees and 6-mm lines, subtending 0.34 degrees. They presented only one condition to the participants. The target was a 6-mm line and the distractors were the 8-mm lines. Past research has shown that the search for the 6-mm shorter target is executed serially, while the search for the 8-mm longer target is executed in parallel (Treisman & Gormican, 1988).

Some unexplained differences were found using this limited presentation time. An analysis of the slopes suggested that a serial search process occurred. The average slope was 20.1 msec per item for positive trials and 35.8 msec per item for negative trials.

However, these slopes were significantly lower than the slopes found with response-terminated presentation (27.3 and 58.2 msec per item, respectively). The data obtained in this study were then transformed in an attempt to "correct" for errors. Treisman and Gormican (1988) assumed that for any given set size, the percent of misses observed was an indicator of the number of items not "scanned." The example they use is if a participant's error rate was 23% on the set size of six, then the participant only was able to scan 77% or 4.62 items. After correcting for errors using this procedure, they concluded that the differences in slopes appear to decreases, and thus, serial patterns found cannot be explained by eye movements. Yet, looking at the data, it appears that the similarity might be derived from a single data point. The largest set size might account for the slope similarity between the response-terminated and 180 msec studies. Removing the largest set size from the 180 msec condition produces a much lower slope. Additionally, Treisman and Gormican's contention that errors due to participants inability to finish searching can be tested by increasing presentation time. If errors are indeed due to time constraints (i.e., the stimulus disappeared before participants were done scanning), then this effect should disappear as presentation time increases. Thus, further study is needed to systematically investigate the effect of stimulus duration on the reaction time versus set size slope and error rates using both types of stimuli.

Integration of Two Disciplines

Hemispheric specialization studies seek to associate cognitive processes, such as verbal and visual-spatial abilities with the left and right hemisphere, respectively. Using an analogous interpretation, these cognitive processes can be defined as either analytic (serial) or global (parallel) processes. A review of the visual search literature yields studies that have identified tasks and stimuli that involve serial and parallel processes. Since visual search research has produced stimuli and tasks that favor one type of processing over another, the patterns of performance can be used in studies of hemispheric specialization to investigate search processes within each hemisphere.

Two procedural differences are necessary in order to employ visual search stimuli and tasks to separate hemispheres in normal participants: 1) Each stimulus is projected to either the left or right visual fields instead of foveal presentations and 2) very brief stimulus presentation times are used instead of response-terminated presentation times. This procedures enable researchers to present the stimuli to individual hemispheres. Based on the presumption that the left hemisphere processed information analytically and the right hemisphere processed information globally, researchers hypothesized that stimuli and tasks that favored serial processing would be processed faster and more accurately in the left hemisphere compared to the right hemisphere. Alternatively, the stimuli and tasks that favored parallel processing would be processed faster and more accurately in the right hemisphere compared to the left hemisphere.

A concern with integrating these two disciplines is the effect of stimulus placement. Hemispheric specialization studies must present stimuli outside the locus of the fovea to lateralize the stimuli into selected hemispheres. Bradshaw (1989) suggests that in order to have the stimuli presented to the left hemisphere, the stimulus must be presented 1.5 to 5.0 degrees to the right of fixation (i.e., the right visual field). Similarly, right hemisphere presentations are presented 1.5 to 5.0 degrees to the left of fixation. However, the locus of the fovea extends only about 1.5 to 2 degrees of visual angle (Carrasco, Evert, Chang, & Katz, 1995). Given this constraint, the decrease in visual resources accompanied by the location of the stimuli make comparisons between findings in the visual search literature problematic. Hemispheric specialization experiments cannot assume that reaction time patterns for stimuli presented to the periphery are the same as those presented to the fovea.

Visual acuity rapidly decreases as stimuli are placed further away from the fovea. Physiological differences between the fovea and the periphery explain this observation. Quite simply, lower acuity is found in the periphery compared to the fovea because of differences in ganglion cell to receptor field ratio found in these two areas. The higher receptor to ganglion cell ratio found in the periphery compared to the fovea means that greater spatial summation of information occurs in the periphery. This results in a lower level of acuity in the periphery (DeValois & DeValois, 1988). The decreased resolution of visual objects presented to the periphery in hemispheric specialization research might influence search processes in ways much different from visual searches conducted in the fovea.

Another difficulty with using the results found in visual search studies to infer hemispheric specialization is presentation time. As discussed previously, visual search studies typically use response-terminated presentation times and hemispheric specialization studies use very brief presentation times (i.e., between 100-200 msec). This difference presents a problem because changes in presentation time possibly affect search processes. This becomes especially problematic if the presentation time does not allow enough time for the visual search to be completed. In hemispheric specialization studies, the search would be interrupted by the removal of the stimulus because processing typically takes much more time than the 100-150 msec presentation times of hemispheric specialization studies. When the stimulus is removed before the search is complete, the task changes from a pure visual search of the display to a partial visual search and a partial memory search. This hybrid visual-memory task may require different or additional processes than those used in typical visual search tasks; and thus, results of this study should not be directly compared to Treisman's findings because the processes observed may be different.

Moreover, the subsequent search of memory instead of visual space is associated with extremely high error rates; sometimes on the magnitude of over 33-40% (see Palmer & Tseng, 1992; Treisman & Gormican, 1988). These error rates call in to question whether participants are able to perform the task in a fashion comparable to results found with response-terminated presentations. Participants in visual search tasks typically perform with a high degree of accuracy (i.e., around 90-95% accuracy rates, see Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985). In order to make sound judgments regarding underlying cognitive processes, investigators depend on a high degree of accuracy. The high error rates found using very brief stimulus presentation times makes reaction time patterns difficult to interpret.

Another possible effect of brief presentation time is suggested by anecdotal comments from hemispheric specialization participants. Participants in this study said that when the stimulus is removed, they made a response based on whatever information was available at the end of the presentation time. Hence, participants "gave up" and stopped monitoring processing output because they knew that no more visual input was forthcoming. If the visual search is not yet complete when the stimulus was removed, a response is made based on the processing that has been performed up to that point. In this example, the response given is especially error-prone because it is based on only a partial search of the data. In the data obtained from this study, one would not be able to differentiate between complete and incomplete searches. This makes comparisons between limited stimulus presentation time and unlimited presentation time studies problematic. Inferences based on this combination of visual/memory searches are not necessarily similar to typical Treisman-like tasks because they assume that the display was searched efficiently and completely.

Current Research Combining the Two Disciplines

Palmer and Tzeng (1992) represent the only study which assesses hemispheric specialization through stimuli used by Treisman and Gormican (1988) and Treisman and Souther (1985). In this study, subjects were presented with stimuli that Treisman and her colleagues found be processed pre-attentively or attentively. Palmer and Tzeng used the circle and circle with a line segment stimuli from Treisman and Souther and the vertical and tilted line stimuli from Treisman and Gormican. As discussed previously, depending on the condition, the stimuli were used as both targets and distractors. The "popout" condition (i.e., "feature present" targets) included two sets of stimuli: 1) Trials where the target was a circle with a line and the distractors were circle and 2) trials where the target was a tilted line and the distractors were vertical lines. The "non-popout" condition (i.e., "feature absent" targets) also included two sets of stimuli: 1) Trials where the target was a circle and distractors were circles with a line and 2) trials where the target was a vertical line and tilted line distractors. These stimuli were intermixed into a single block with half of the trials presented to the left visual field and half presented to the right visual field. Palmer and Tzeng selected the popout and non-popout stimuli to assess parallel and serial processing, respectively. The stimulus presentation time was 200 msec and reaction time and accuracy were recorded.

Palmer and Tzeng (1992) attempted to take the findings by Treisman and her colleagues one step further and associate specific hemispheres with parallel or serial processes. At first glance, this undertaking appears logical; use stimuli that have been found to favor either parallel or serial processing in a hemispheric specialization experiment to find out if these robust effects can be replicated in separate hemispheres. For example, if the left hemisphere is analytic and serial, then it should perform better for "feature absent" searches than the right hemisphere. This is because the left hemisphere's serial/analytic processing abilities would be better suited than the right hemisphere's parallel/global processor to analyze feature-absent searches.

However, several problems arise in their study. On one level, Palmer and Tzeng do not address the stimulus placement and presentation time questions associated with the integration of these two disciplines. No attempts were made to test the effects of brief presentation times for foveal presentations. Additionally, no attempts were made to test whether response-terminated presentations to the periphery replicate those to the fovea. On another level, Palmer and Tzeng's study contains several methodological confounds and inappropriate analysis that render their conclusions questionable at best.

Palmer and Tzeng (1992) mixed both the line and circle conditions into a single block. This is neither a replication of Treisman and Gormican (1988) nor Treisman and Souther (1985) because the line and circle stimuli were used in separate blocks. Moreover, in both of Treisman's experiments, conditions where the target was a search for the absence of a feature and where the target was a search for the presence of a feature were presented in separate blocks in an attempt to reduce participant confusion and ambiguity over which item is the correct target. Therefore, the task Palmer and Tzeng presented to their participants was far more complex than a simple replication of

Treisman's work (i.e., the same item was a target on some trials and a distractor on others within the same block). Participants made target present/absent decisions, as well as, a stimulus identification task. This resulted in an eight choice decision/response task (lines or circles x pre-attentive or attentive x target present or absent) instead of the usual two choice response task (i.e., is the target present or absent?). On each trial, participants in this study had to assess the correct target for this particular stimulus by first identifying the distractors. Once the target was determined, the participant then was required to make a target present/absent response. Palmer and Tzeng might argue that their participants made same/different decisions instead of target present/absent decisions, which would eliminate the additional processing steps or choices and reduce the task to a two choice decision. However, this explanation would further confound their results because a same/different task does not on face appear similar to the processing required for a target present/absent task. Treisman and her colleagues explicitly identified the target item, so their participants were not faced with different targets and distractors during any block of trials.

Further compounding the problem are the hemispheric projection requirements of Palmer and Tzeng. Participants had to make an identification of the stimulus, the target, and then make a response. All of these actions were required while the stimulus was presented to the periphery and with a presentation time of less than 200 msec. Since the key dependent measure in this experiment is reaction time, any methodological deviations from Treisman and her colleagues' procedure could affect the pattern of results found and should be carefully considered. The effects of brief presentation time and peripheral stimulus presentations need to be determined in order to adapt the visual search paradigm to the study of hemispheric specialization.

Another problem with Palmer and Tzeng's study (1992) is the limited number of trials that compose a condition. They presented four different stimulus types to their participants (i.e., line popout/non-popout and circle popout/non-popout). Each condition contained 24 stimulus presentations for a total of 96 trials. Half of these 24 presentations included a target and half did not. Thus, each condition included 12 trials with a target present and 12 trials with a target absent. Half of these trials were presented to the left visual field and half to the right visual field. Thus, 6 trials were presented 1.5 to 4.7 degrees to the left of center and 6 trials were presented 1.5 to 4.7 degrees to the right of center. These 6 trials were further divided such that the number of stimulus items was presented in sets of 2, 4, or 7. This set size variable reduced the number of cell replications to two. Therefore, each participant made a total of only two responses for any given condition. Given the complexity of the task Palmer and Tzeng presented, it would be prudent for further study to use a larger number of trials per condition to reduce variability.

Palmer and Tzeng (1992) found positive results for both reaction time and accuracy measures. An analysis of reaction time for correct responses found significant main effects for hemisphere and set size, as well as, a significant interaction between the two conditions. Despite the positive results found the direction of the effects does not replicate the findings by Treisman and her colleagues. For the non-popout target-present condition, where it was predicted that reaction time for the left hemisphere would increase linearly as set size increased and reaction time for the right hemisphere should remain constant, the reaction time slope for the left hemisphere presentation actually decreased such that the reaction time became equivalent to the reaction time of the popout stimuli with a display size of 7. This finding did not replicate Treisman and Souther's (1985) nor Treisman and Gormican's (1988) results as Palmer and Tzeng conclude. In both of these studies, the non-popout stimuli did not show decreasing reaction times as the number of display items increased. Palmer and Tzeng's results become more unusual considering that the number of display items used in both Treisman studies included a larger range of items (12 items maximum) compared to that of Palmer and Tzeng (7 items maximum). Thus, questions remain as to the whether Palmer and Tzeng truly replicated Treisman's findings.

However, despite significant effects, Palmer and Tzeng removed the reaction time data from their final analysis and conclusions. Instead, the investigators chose to use the differences in error rates to assess hemispheric specialization. This is problematic because serial and parallel processes are identified through reaction time data, not error rates. Although error rates may show patterns similar to reaction time data, the primary indicator must be reaction time. This author knows of no theoretical or empirical evidence that justifies substituting accuracy rates for reaction time. Palmer and Tzeng argue that Treisman and Gormican (1988) used a similar technique of analyzing error rates to indicate serial and parallel processing. However, a careful examination of Treisman and Gormican's work yields no such technique. In fact, all of Treisman and Gormican's analyses are based on reaction time data.

Inferences to mode of processing must be made through reaction time, because error rates can assess only the difficulty of the task. Thus, errors may be due to stimulus resolution or task complexity, which are independent of processing mode. Unlike error rates, reaction time patterns often conform to a mathematical model where inferences of serial and parallel processing can be made. By removing reaction time data from their results, Palmer and Tzeng effectively eliminated their ability to identify hemispheric processes in terms of serial and parallel mechanisms.

In addition to substituting reaction time data with error rates, Palmer and Tzeng went one step further: They removed half of the error rate data from the final analysis. The mean error rates found for both the circle and circle with line condition was 40 percent. Since chance alone in this task was 50%, the data from these trials were removed from their analyses and their conclusions are solely based on the remaining 48 trials composed of vertical and titled lines. An analysis of the mean error rates among the four conditions (popout target present/absent and non-popout target present/absent) found significant main effects for set size in all conditions except the popout target absent condition. Significant Set Size x Hemisphere interactions were found for both the non-popout target absent and present conditions. They concluded that error rates for the left hemisphere tended to increase linearly as the number of items in the display increased and error rates for the right hemisphere remained consistent as the number of items in the display increased. However, as stated earlier, error rates do not indicate serial or parallel search patterns, so this conclusion is invalid.

There are several possible reasons for the high error rates obtained by Palmer and Tzeng. One reason could be the small number of replications used by Palmer and Tzeng. Given that each cell contained only two replications, the high error rates might derive from small cell replications alone. Participant confusion could be another reason for the high error rates because all conditions were mixed together into a single block. Treisman and her colleagues present the popout and non-popout conditions in separate blocks to avoid this possible confound.

An area of possibly greater concern in Palmer and Tzeng's experiment is presentation time. Both of Treisman's experiments used long display times. The display was presented and disappeared only after a response from a subject. The brief display time that is necessary for hemispheric specialization in normal subjects might affect performance in ways not considered by Palmer and Tzeng. They assumed that their study would replicate the serial and parallel processing results found in Treisman's visual search experiments. This assumption has not yet been evaluated in a systematic manner.

The brief stimulus presentation times used by Palmer and Tzeng may have caused possible processing differences between their task and Treisman's. One possible difference arises if visual search only occurs while the stimulus is displayed. Following presentation, a response might be made based on processing up to that point because the participant decides that no new visual information is forthcoming. At that point, the response is based on partial processing. In this case, the response made uses incomplete information, but the reaction time results found could be used to imply serial or parallel processing. However, it is questionable whether enough items were processed to effectively determine the type of process used. For example, if it takes 75 msec to process each item then a stimulus with a set size of three would require approximately 225 msec analyze all of the items[5]. This would preclude all set sizes above three items from sufficient processing. Given that most hemispheric specialization experiments use presentation times under 225 msec due to possible eye movements, in this example, only two items would be effectively searched.

An alternative hypothesis about processing difference between limited and response-terminated stimulus presentation time conditions allows for the search to continue after the display is removed from view. Initially, processing identical to visual search occurs while the stimulus is displayed. However, another process must occur when the stimulus is removed from the display. The removal of the stimulus limits searches to iconic memory rather than real-time searches using fixed displays. This dual-stage process might not produce results similar to those found with response-terminated visual searches because searches of iconic memory might be conducted using an entirely different process. Additionally, the removal of the stimulus might disrupt cognitive processing in a manner not yet identified. This necessitates further study comparing brief presentation times to

[5] Of course, on average, only half of the items would be searched on trials where the target is present.

response terminated presentation time to assess possible process differences between the two tasks.

One experiment that addresses presentation time effects is a pilot study by Treisman and Gormican (1988). In this study, brief 180 msec display times were used in an attempt to rule out eye movements as a reason for finding serial search patterns. Again, high error rates were found which led the experimenters to remove almost half of the participants from the analysis. The experimenters suspected that visual search processing ended when the stimulus was removed. To support this claim, they performed an unusual transformation on the data. They assumed that participants were only able to scan some percentage of the total number of display items. They estimated this percentage by multiplying the accuracy-per-set-size-condition by the number of items in the condition. For example, if an accuracy rate of 77% was found for a set size of six items, then the transformation yielded 77% of six, or 4.62 items. Thus, on average, participants were only able to scan 4.62 items. Based on the transformed data, they concluded that serial search patterns emerge (Treisman & Gormican, 1988). The assumption used in the transformation is very liberal because errors do not necessarily indicate precisely how many items were scanned. The transformation does not differentiate between errors due to incomplete information and other kinds of errors (misidentification). For example, based on the 86.5% accuracy rates for a set size of twelve found in Treisman and Souther's (1980) Experiment 1, the transformation would argue that the number of items scanned would be only 10.4 items. Since the presentation was response-terminated, this transformation would be incorrect because all twelve items were scanned. However, Treisman and Gormican's goal was to assess eye movements. In this pilot study, a comparison condition using popout stimuli was not included. In order to make valid conclusions using Treisman's stimuli in a hemispheric specialization task, more thorough investigation is warranted using both popout and non-popout stimuli at various presentation times.

Another problem with Palmer and Tzeng's experiment is that the 200 msec presentation time used is extremely long for hemispheric specialization studies[6]. This display time allows eye movements to occur while the display is on the screen. Although Klein and Farrell (1989) and Treisman and Gormican (1988) found that eye movements do not affect serial search patterns, eye movements have a detrimental affect to hemispheric specialization studies. Any eye movements made following fixation invalidates the entire experiment because the visual input is no longer lateralized (confined to one hemisphere). Hence, it is possible that Palmer and Tzeng's data are corrupt because the stimuli were available to both hemispheres during presentation instead of presenting the stimuli to only one hemisphere.

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[6] Springer and Deutsch (1991) recommend presentation times between 100-150 msec to ensure lateralization between the two hemispheres by eliminating possible eye movements.

Experimental Design and Hypotheses

The use of stimuli from visual search experiments in hemispheric specialization research represents intriguing possibilities. However, the effect of presentation time must be established before any hemispheric specialization conclusions can be formed. The present thesis seeks to assess whether Treisman and Souther's (1985) findings using response terminated presentation times can be replicated using shorter presentation times. If accuracy and reaction time results are not replicated, one explanation is that the system makes a response based on incomplete information. In this case, a decision is made when the stimulus is removed. If this is true then increasing presentation time should result in increases in overall performance. This effect should be especially pronounced for large set sizes. The reason for the unusually high error rates found in Palmer and Tzeng's (1992) study could be due to participants inability to successfully complete the visual search in the amount of time the stimulus is displayed. If error rates are reduced to the levels found in visual search experiments, then it is hypothesized that reaction time rates will also replicate visual search findings. Therefore, present thesis uses reaction time and accuracy data to assess the viability of using very brief presentation times for visual search tasks.

Additionally, Palmer and Tzeng did not test the effect brief stimulus presentation times has on foveal or peripheral presentations. The difference in stimulus placement may adversely affect performance because of the reduction of acuity and resolution in the periphery (Bradshaw, 1989; Carrasco, Evert, Chang, & Katz, 1995; DeValois & DeValois, 1988). This thesis focused on foveal presentations with the assumption that if replication cannot be established with foveal presentations, then replication will not be found with peripheral presentations. If replication is found with foveal presentations then further study will be conducted using peripheral stimulus presentations.

A between subjects design manipulating presentation time and item set size was used. Experiment 1 used a response-terminated condition to replicate findings by Treisman and her colleagues. Using data obtained from this experiment, the time required to scan each item could be established from the reaction time by set size slope for the target absent condition[7]. Assuming that this slope estimate indicates item scan time as Treisman and her colleagues suggest (Treisman, 1991; Treisman & Gormican, 1988; Treisman & Souther, 1985), this slope estimate can be multiplied by the maximum number of items presented to compute the average presentation time necessary to effectively complete the search. Experiment 2 varied presentation time to investigate the following hypothesis: If the high error rates found with brief presentation times are due to participants' inability to effectively search the entire display then increasing presentation time should yield improvements in performance. For example, if high error rates are found with brief presentation times, then increasing presentation time should lower error rates which will allow the robust reaction time serial and parallel search patterns to emerge. Hence, the majority of errors occur because participants simply do not have sufficient time to search the display. If this hypothesis is true, then accuracy should improve as presentation time increases, until results similar to those in the response terminated

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[7] Target absent trials are chosen because in these trials all items are scanned; whereas, on average, only have of the items are scanned when the target is present.

presentation time are found. Additionally, the average presentation time required to effectively search the display derived in experiment 1 should correspond to results found in Experiment 2. Thus, at presentation times above the average scan time necessary, results should replicate Treisman and Souther (1980) and at presentation times lower than the average scan time, no replication should be found.

CHAPTER III

EXPERIMENT 1

The purpose of the first experiment is to replicate of Treisman and Souther's (1980) findings with response-terminated presentation time and to establish a baseline from which to assess the effect of presentation time on visual search tasks (Experiment 2). Since response-terminated presentation time represents the maximum amount of time necessary for an effective search of the display, it serves as an appropriate baseline to compare the results of Experiment 2 to assess the effect of varying presentation time on visual search tasks.

The key difference between the stimuli used in this experiment and those used by Treisman and Souther (1980) is the number of items in each display. Treisman and Souther used displays with 1, 6, and 12 items. In this experiment, displays with 1, 3, 5, 7, and 9 items are used. The set sizes selected in this experiment serve as a suitable equivalent to the various set sizes used in Treisman and Souther (1980), Treisman and Gormican (1988) and Palmer and Tzeng's (1992) experiments.

Method

Participants

Ten Loyola University Chicago undergraduates participated in this experiment. Participants were given a consent form and handedness questionnaire to document whether they were right- or left-handed (see Appendices A and B, respectively). All of the subjects had normal or corrected-to-normal vision and were naive to the experimental procedures and purpose. Participants received one class credit for their participation and were debriefed following the session (see Appendix C). Each session lasted approximately 30 min. Up to three participants were run through as session at one time.

Stimuli and Materials

Stimuli similar to Treisman and Souther's Experiment 1 (1985) were used in this experiment. The stimuli were presented to the participants on a computer screen using an experimental program written in MEL (Micro Experimental Laboratory) programming language (Schneider, 1988). The computer also recorded reaction time and accuracy for each trial.

The experiment consisted of 240 stimulus presentations. A total of 120 unique stimuli were created (see Appendix D for examples). Due to computer memory restrictions, each stimulus was repeated once. For half of the stimuli, the target was a single Q with distractors of O's (Q among O's condition) and in the other half, the target was a single O with distractors of Q's (O among Q's condition). Half of the stimuli included a target and half did not. Thus, each condition included stimuli where the target was present and stimuli where the target was absent. The stimuli were further divided into 5 set sizes (1, 3, 5, 7, and 9 items per display). Another set of stimuli were created for the practice trials. The colors used in the stimuli were black stimulus items on a light gray background.

Each stimulus item was randomly placed on a grid with 72 positions (6 rows wide by 12 columns). The grid measured 3.9-cm long by 3.5-cm wide. The stimuli subtended a visual angle of 2.0 degrees to above and below the point of fixation and 1.84 degrees to the left and right of fixation. The presentations were viewed binocularly with the participant's head held in position by a chin rest at a distance of 56 cm from the screen.

The O among Q's and Q among O's conditions were blocked such that half of the participants received the O among Q's first and the other half received the and Q among O's. The experiment was conducted in a dimly lit room.

Procedure

The participant's task was to indicate whether the target was present or absent by pressing one of two keys on the keyboard. Specifically, the letter "m" was used to indicate "target present" and the letter "c" was used to indicate "target absent." After instructions were read to the participants, the experimenter identified the target and distractor items and twenty practice trials were presented. Following completion of the practice trials, the experimental trials were presented.

The presentation sequence for each trial was as follows. A message which stated, "Place your fingers over the c and m keys and press the spacebar when ready" was presented to begin each trial. Participants pressed the space bar to initiate each trial. After which a fixation point appeared in the center of the display for 500 msec. The stimulus was then displayed on the screen until the participant made a response. Following each response, a 1000 msec visual feedback signal ("correct" or "incorrect") was presented to the participant and the spacebar message then reappeared. Hence, participants were able to pace themselves through the experiment. Subjects were instructed to respond as quickly as possible, while keeping errors to a minimum. Between each condition, participants were given a break lasting a few minutes.

Results and Discussion

Accuracy Data

The mean accuracy rates for each condition as a function of set size are depicted in Figure 1. Results similar to Treisman and Souther (1985) were found. Accuracy rates remained relatively high and constant as the number of items in the display increased (with a slight decrease in the largest set size). The mean error rate for the Q among O's condition was 5.2%. This is comparable to Treisman and Souther's reported error rate of 4% for the same condition. The mean error rate found for the O among Q's condition was also similar the Treisman and Souther. The highest error rate found in the present experiment was 12.5% at nine items. Again, this was comparable to Treisman and Souther's reported error rate of 13.9% at a set size of 12 items.

Insert Figure 1 about here

It appears that participants had little difficulty performing the task. In these trials, the target was absent from the display; hence, these responses are classified as misses. In this instance, the type of errors participants tended to make were misses, as opposed to, false alarms. This result is often found in visual search tasks and could be explained as a speed-accuracy tradeoff (i.e., participants make responses before targets that are present are found).

Reaction Time Data

The reaction time was recorded for all trials in which a correct response was made. Reaction times greater than 5000 msec were removed from the analysis. The mean reaction time for each condition as a function of set size is depicted in Figure 2. As illustrated in this figure, reaction time for the Q among O's condition is relatively flat as a function of set size. As expected, in the O among Q's condition, reaction time tended to increase as set size increases.

Insert Figure 2 about here

A two factor (O among Q's and Q among O's x Set Size) ANOVA was performed. As expected, a significant main effect was found for condition, suggesting that reaction time in the Q among O's condition was significantly lower than reaction time in the O among Q's condition, $\underline{F}(1,90) = 227.29$, $\underline{p} < .001$. A significant main effect for set size was also found,

$F(4,90) = 14.01$, $p < .001$. Thus, reaction time increased as set size increased. A significant interaction was found between these two variables, $F(4,90) = 7.27$, $p < .001$.

Individual (Set Size) ANOVAs on each condition describes this interaction. Reaction time did not significantly increase as set size increased in the Q among O's condition, $F(1,45) = 1.55$, $p = 0.204$. However, reaction time significantly increased as set size increased for O among Q's condition, $F(4,45) = 13.50$, $p < .001$. These results replicate Treisman and Souther's (1980) findings showing flat reaction time increases for the Q among O's stimuli and linearly increasing reaction time as set size increased for the O among Q's stimuli.

Analysis of Reaction Time Slopes

Given the necessity to use reaction time data to make inferences to serial/parallel processes, converting the reaction time by set size data into slopes is a more appropriate measure. According to Treisman and Souther (1985), a slope close to zero indicates a parallel process and a positive slope indicates a serial process. The reaction time by set size slopes were obtained taking the slope of a best fitting regression line to the data. The slope data are listed on Table 1. The Q among O's slopes found were fairly low, while the O among Q's slopes were much greater than zero.

Insert Table 1 about here

The data are separated into target present and target absent conditions because the target present conditions reflect trials where on average half of the items were scanned and target absent conditions reflect trials where presumably all items were scanned. For the O among Q's condition, the slope was approximately 72 msec/item. Assuming that this slope reflects item scan time as Treisman and her colleagues suggest (see Treisman, 1991, Treisman & Gormican, 1988: Treisman & Souther, 1980), multiplying this estimate by the largest set size of nine items produces an average presentation time necessary to scan all items in the display. Using this average presentation time, participants in the O among Q's condition needed 650 msec to effectively complete the task (not including motor response time). If this estimate actually reflects the average presentation time necessary, it is expected that presentation times below 650 msec in Experiment 2 should yield degradation in performance, while presentation times above 650 msec should show similar accuracy and reaction time patterns to those found in Experiment 1.

A two factor (O among Q's and Q among O's x Target) ANOVA was performed on the slope data. As expected, a significant main effect was found for condition, suggesting that slopes found in the Q among O's condition were significantly lower than those in the O among Q's condition, $F(1,36) = 51.84$, $p < .001$. Slopes where the target was absent were significantly higher than when the target was present, $F(1,36) = 6.77$, $p < .05$. A significant interaction was found between these two variables, $F(1,36) = 4.78$, $p < .05$. Individual one factor (Target) ANOVAs on each condition describes this interaction. No significant difference was found between slopes where the target was present or absent for the Q among O's condition. However, a significant difference was found for O among Q's condition. In this condition, the slope was much greater for the reaction time versus set size function when the target was absent than when it was present, $F(1,18) = 6.29$, $p < .05$. Moreover, evidence supporting a serial self-terminating search was found due to the significant difference between trials where the "O" was absent and present from the display. In fact, the slope ratio found in this experiment was 1:1.75, which replicates empirical serial self-terminating visual searches (Treisman & Gormican, 1988). Therefore, the findings in this experiment replicate findings by Treisman and her colleagues to further support the notion that a search for a Q among O's is processed pre-attentively or in parallel and a search for an O among Q's requires focused attention and is located via a serial process. As a result, the findings from Experiment 1 can be used to as a baseline to compare the effect of presentation time on visual search tasks.

CHAPTER IV

EXPERIMENT 2

In this experiment, presentation time is manipulated. Instead of having the stimulus remain on the screen until a response is given, various stimulus presentation times are used. The robust effects found using Treisman's response-terminated stimuli have not been documented at short duration presentation times. Experiments in which stimuli were displayed with short presentation times have produced error rates that are too large for inferences to be made regarding underlying cognitive processes. It is conceivable that limiting presentation time significantly alters the task. Removing the stimulus from the screen can have several effects on search processes. For example, the presentation and subsequent removal of the stimulus may produce a search-medium shift from visual space to memory. Thus, the stimulus display is searched while the stimulus is available, but after its removal, a different search continues (possibly in iconic memory), presumably where the earlier process left off. However, because of the possible involvement of a memory search, one would not necessarily expect results with limited duration stimuli to replicate those with response-terminated stimuli. When the stimulus is presented briefly (e.g., in hemispheric specialization studies), the stimulus is likely to be removed before the search is fully completed. The information input to the system may be insufficient and the task may change from a presumed serial self-terminating search to an unidentifiable search where presentation time becomes the terminating factor to the system instead of target identification.

In order to determine the effect of brief presentation time on visual search experiments, several stimulus presentation times are used. If the hypothesis is that a hybrid visual-memory process occurs, then accuracy rates should remain high and reaction times may or may not be elevated because of the additional processing time that occurs in memory. If the hypothesis is true that errors result from the insufficient information input to the visual process, then accuracy should be poor for shorter presentation times. When presentation time is increased, increases in task performance should be found. Based on the 72 msec/item slope found in Experiment 1, the average amount of time required to process nine items is approximately 650 msec. Hence, conditions where the presentation time was over 650 msec should produce results similar to those found during response-terminated presentation times because these presentation times present the stimuli long enough for effective performance. All other presentation time conditions should produce degraded accuracy performance as presentation time decreases.

Several presentation times were chosen to evaluate the presentation times used in the current research fields. Presentation times of 150, 180, and 200 msec presentation time conditions encompass the range of times used in hemispheric specialization and saccadic eye movement research. Presentation times of 330, 360, 390, 420, and 450 msec allow for eye movements and should produce systematic improvements in accuracy. In addition, reaction time slopes (reaction time versus set size) should more closely resemble the slopes found in Experiment 1 as presentation time increases. Theoretically, the 750 and 1000 msec presentation time conditions should be comparable to the response-terminated condition because these durations are larger than the estimated total scan time necessary for the largest set sizes.

Method

Participants

One hundred Loyola University Chicago undergraduates participated in this study. None of them participated in Experiment 1. These participants were assigned to one of ten presentation time conditions (150, 180, 210, 330, 360, 390, 420, 450, 750, 1000 msec). Participants were given a consent form and handedness questionnaire to document whether they were right- or left-handed (see Appendices A and B, respectively). All of the subjects had normal or corrected-to-normal vision and were naive to the experimental procedures and purpose. Each participant received one class credit for their participation and were debriefed following the session (see Appendix C). Each session lasted approximately 30 min.

Stimuli and Materials

The same practice and experimental stimuli used in Experiment 1 were used in this experiment.

Procedure

The same procedure used in Experiment 1 was used in Experiment 2 except participants were told that following the presentation of a fixation point, the stimulus would appear on the screen and then disappear. If a response was given before the stimulus presentation time had not fully elapsed, similar to Experiment 1, the response was recorded and the stimulus terminated.

Results and Discussion

Accuracy Data

The mean accuracy rates for each presentation time condition as a function of set size are depicted in Figures 3 through 12. In the Q among O's condition, accuracy remained high across set size for all presentation times, suggesting that participants were able to complete the task effectively even at the shortest presentation time (150 msec). The O among Q's condition displayed a very different pattern at the various presentation times. For this condition, as set size increased, accuracy decreased. The effect was more pronounced when the target was present, suggesting that participants make more misses than false alarms with relatively large set sizes. The largest dip in accuracy was found at the largest set sizes. For the 750 and 1000 msec presentation times, accuracy rates are consistent with previous findings (e.g., Treisman & Souther, 1980; Treisman & Gormican, 1988). However, for the other presentation times, the magnitude of the errors across all of the set sizes is too large to conclude that this experiment replicated either Experiment 1 or Treisman's previous studies with response-terminated presentation times.

Insert Figures 3-12 about here

For the O among Q's condition, as set size increased, the error rates found were often around 40%. Considering that chance alone is 50%, these error rates indicate that participants were unable to perform the task effectively. At very brief presentation times of 150, 180 and 210 msec, accuracy was above 95% for a set size of one, but accuracy decreases abruptly for all larger set sizes. Given the average 72 msec/item scan time estimate derived from Experiment 1, all presentation times that were used allowed enough time to effectively scan one item.

Using the 72 msec/item scan time estimate, some brief presentation time conditions would limit effective scans of stimuli with larger set sizes. For example, the presentation time necessary to effectively scan a three-item display is approximately 216 msec. Thus, the 210 msec presentation time condition might be just long enough to allow for a scan of all three items. For a set size of three, accuracy was below 80% for presentation times of 150 and 180 msec. The drop in accuracy at three items only began to rise above 80% in the 210 msec condition. This drop in accuracy practically disappears with presentation time conditions greater than 210 msec. For example, accuracy increased to 95% for a set size of three on the 330 msec presentation time condition. This trend in improved accuracy was found with all other presentation times. Thus, effective scans of three items or less occur primarily in presentation time conditions of 210 msec or greater.

The systematic improvement in accuracy as presentation time increases was found at the other set sizes as well. For a set size of five items, the average required presentation time based on the 72 msec/item scan time estimate is approximately 360 msec. Hence, improvement in accuracy rate for a set size of five should only appear in presentation time conditions at or above 360 msec. The 150 to 210 msec presentation time conditions for a set size of five revealed accuracy rates below 80%. Similar to the 210 msec condition, which was near the average presentation time for a set size of three, the trend towards an improvement in accuracy was found near the average presentation time for a set size of five. At the 330 and 360 msec durations, accuracy rates rose to well above 80%. This trend continued as presentation time increased such that accuracy rates increased to above 90% for 450 msec presentation times or greater.

Based on the estimated scan time, the average required presentation time for a set size of seven items is 505 msec. Based on this estimate, the trend in improved performance should begin with presentation times above 450 msec. However, the improvement in accuracy at the 450 msec condition increased only slightly. This finding could be due to a ceiling effect because accuracy at 450 msec conditions for a set size of seven starts at 80%. Presentation times above 450 msec showed the similar trend in accuracy performance found with smaller set sizes.

The average presentation time for a set size of nine items is approximately 650 msec. Thus, one would expect to see accuracy rates that replicate those found in Experiment 1 in the 750 and 1000 msec presentation time conditions. Similar to findings in Experiment 1, the target absent trials had an accuracy rate above 95% in the 750 and 1000 msec conditions. Accuracy rates at all other presentation times for target absent trials steadily decreased, suggesting that these conditions replicated the results found using response terminated presentation times. performance only occurs in presentation time conditions above 650 msec. The target present trials also showed this trend. In Experiment 1, an accuracy rate of 77% was found for response-terminated presentation time for target present trials with a set size of nine items. Thus, this accuracy rate is the optimal performance that is expected to be replicated in the 750 and 1000 msec conditions. Accuracy rates in presentation time conditions of 150, 180, 210, 330, 360, 390, and 420 msec were all below 65%. Accuracy began to rise at the 450 msec condition. Accuracy rose to 72% and 71% for the 750 and 1000 msec presentation time conditions, respectively. Although performance at these conditions did not reach the performance found in Experiment 1, the trend illustrating increased performance after 650 msec is clear.

Based on these findings, the average presentation time needed can be estimated from the average scan time found in Experiment 1. Computing this estimated scan time by the number of items in the display produces the minimum presentation time required to effectively perform the task. Thus, optimal performance can only be expected at presentation times that allow enough time for processing to occur. For example, if presentation time provides only enough time to process three items, then the system will only effectively process displays with set sizes of three items or less. Regardless of how many items are presented in any given trial, the key determinant for performance is the number of items able to be processed. This is mediated by the amount of stimulus exposure time. Implications for finding to hemispheric specialization experiments or other visual search studies involving very brief presentation times are substantial because it points out potential problems using reaction time data from brief presentations to make serial and parallel search distinctions.

Reaction Time Data

Reaction times were recorded for each trial on which there was a correct response. Reaction times greater than 5000 msec were discarded. For each presentation time condition, the mean reaction times as a function of set size for the Q among O's and O among Q's condition are depicted in Figures 13 through 22. As illustrated in the figures, reaction time for the Q among O's condition stayed relatively flat as a function of set size regardless of whether the target was present or absent. Given the high accuracy rates found for this condition, the reaction time pattern suggests that the stimuli were processed in parallel. This finding held across all presentation times. These results replicate the findings in Experiment 1. Comparing both accuracy and response time patterns found in Experiment 1 with this experiment suggests that participants were able to effectively complete the task with as little as 150 msec of presentation time. Hence, brief presentation time does not appear to have an effect on visual stimuli and tasks that can be accomplished through the activity of a parallel processor (e.g., Q among O's condition or stimuli where the target "pops out" of the field of distractors).

Insert Figures 13-22 about here

However, presentation time does appear to affect reaction time patterns for the O among Q's condition. In Experiment 1 reaction time increased as a function of set size and similar to Treisman and Souther's (1985) findings, reaction time when the target was absent increased at a much steeper rate than when the target was present. In Experiment 2, across presentation time, overall reaction time was longer for the O among Q's condition than the Q among O's condition and the target absent trials tended to show longer reaction times than target present trials.

For the 150, 180 and 210 msec presentation time conditions, as set size increased, reaction time appeared to increase only slightly, if at all. As shown in Figures 13-15, it is extremely difficult to support a case that these results indicate that the stimuli were searched via a serial processor. The reaction time patterns simply do not reveal serial search patterns (this issue is discussed in greater detail in the reaction time slope section). Neither the accuracy or reaction time patterns replicate findings found in Experiment 1. Since it is possible that all items were not fully processed due to the brief stimulus duration, it is probably inappropriate to identify serial search processes from the reaction time patterns.

For presentation times of 330 and 360 msec, the reaction time patterns maintain the same pattern as found in the 150, 180 and 210 msec conditions. Based on the accuracy results, this was expected because these presentation times do not allow enough time for processing to occur on set sizes above three items.

The 390, 420 and 450 msec presentation time conditions begin to show a trend towards results found in Experiment 1. Reaction time appeared to increase as a function of set size. However, based on results from the 420 msec condition, the trend does not appear to be a stable phenomenon. An explanation for this findings is that above 390 msec, only five items can be effectively scanned (i.e., the average presentation time required is 505 msec), but it is possible that some participants were able to effectively scan a few trials with seven items. Overall, these findings were consistent with earlier results.

The 750 and 1000 msec presentation time conditions replicate the reaction time results found in Experiment 1, albeit at a slightly reduced levels. This finding was expected because these presentation times provided a long enough stimulus exposure time to allow all nine items to be scanned. This resulted in few errors across set sizes, so reaction times obtained at each set size were meaningful. Thus, processing inferences can be made from reaction times at these presentation times.

The reaction time data for Experiment 2 illustrate the limitations of using brief presentation time in visual search experiments. A pre-attentive task, such as locating a Q among O's is not affected by presentation time. The results of Experiment 2 support that this task can be accomplished through parallel processing with presentation times as low as 150 msec. On the other hand, presentation time appears to have an substantial effect on the identification of serial search processes for attentive tasks, such as locating an O among Q's. Searches on these stimuli depend on the number of items able to be processed in the limited presentation time given. Since this restriction applies to visual searches using brief presentation times and not to response-terminated presentation conditions, inferences to the type of processing used are problematic.

Analysis of Reaction Time Intercepts

A regression line was computed to the data as a function of reaction time by set size. The mean reaction time intercepts from correct trials for the Q among O's condition are illustrated in Figure 23. Individual intercepts are presented for target present and target absent trials. No overall intercept differences were found across presentation time. Similarly, for the O among Q's condition, no overall differences were found across presentation time. The mean reaction time intercepts from correct trials for this condition are illustrated in Figure 24. Individual intercepts are presented for target present and target absent trials. Additionally, no overall differences were found across presentation time. For both the Q among Os' and O among Q's condition, target absent trials tended have higher reaction time intercepts than target present trials. This trend was consistent across presentation times.

Insert Figures 23-24 about here

Analysis of Reaction Time Slopes

Similar to Experiment 1, a regression line was computed to the data as a function of reaction time by set size. For each presentation time, a best fitting regression line was computed. The slopes from these regression equations are presented on Table 2. Slopes for the Q among O's condition remain relatively low (i.e., slopes of around 10 msec/item or less). This further supports the conclusion that presentation time does not affect pre-attentive stimuli. Hence, inferences can be made to parallel processing at presentation times as low as 150 msec.

Insert Table 2 about here

The effect of presentation time can be seen in the reaction time slopes in the O among Q's condition. As discussed previously, the only presentation times which theoretically allowed enough processing time to complete the full nine item search were the 750 and 1000 msec conditions. All other conditions might not allow sufficient time for thorough processing. Thus, only the 750 and 1000 msec conditions were expected to replicate findings in Experiment 1. Although the slopes in the 750 and 1000 msec conditions tend to be lower than those found in Experiment 1, the target present to target absent slope ratios are similar. The slope ratio for the 750 msec condition was 1.79, which was similar to the 1.75 found in Experiment 1. The 1000 msec condition had a lower slope ratio of 1.34, but a similar pattern was found.

The target-present and target-absent slopes of the O among Q's condition by presentation time are illustrated in Figure 25. The figure also presents the slopes found in the Experiment 1. As shown in the figure, only the 750 and 1000 msec presentation times have slope ratios that resemble those ratios found in the response-terminated presentation time of Experiment 1. Comparing both the accuracy and reaction time data found for the 750 and 1000 msec presentation times to the accuracy and reaction time data for the response-terminated presentation time data, similarities among the three presentation times are found. Although, the 750 and 1000 msec conditions show slightly lower accuracy rates and reaction time slopes than findings in the response-terminated condition, the findings are close enough to argue that similar processing occurred for the three presentation time conditions. Thus, the 750 and 1000 msec presentation times produced results consistent with those of a serial self-terminating search.

Insert Figure 25 about here

However, no support is found to suggest that a serial search was conducted for the other presentation times. The slopes for these presentation times do not resemble the slopes found during response-terminated presentation times. Based on this data and on the accuracy data, it is not possible to identify type of processing at these presentation times.

Based on previous results, the average presentation time necessary for effective processing of nine and seven items is 656 and 510 msec, respectively. Theoretically, none of these conditions allow enough time for effective processing. The results found that only the 390 and 450 msec conditions exhibit target present to target absent slope ratios close to those found in the 750, 1000 msec and response-terminated presentation time conditions.

The brief presentation times (150, 180, 210, 330, 360, and 420 msec) show target present to target absent slope ratios that do not replicate findings found in Experiment 1. Theoretically, the target absent slopes should be larger than the target present slopes to infer serial self-terminating processes. At these presentation times, the actual slope ratios are often below 1. Assuming no intercept differences, this does not replicate findings in Experiment 1 or any found in visual search experiments.

A scatter plot of the target absent slopes by participant for each presentation time obtained in the O among Q's condition is illustrated in Figure 26. Data from the response-terminated condition of Experiment 1 are included in the figure for reference. The presentation time conditions are presented along the x-axis as a continuous variable. In order for the response-terminated condition data to be presented along this continuum, the mean response time was used. The mean was computed from trials of the largest set size condition (9 item) and where the target was absent from the display. This produced an appropriate estimate of the average presentation time necessary to complete the task. The largest set size condition was used because this accounted for trials where resources were taxed the most. Target-absent trials were selected because these trials involve a complete search of the display; whereas, target-present trials only account for, on average, the time required to search only half of the items in the display. A regression line between slope and presentation time was computed to determine the relationship between slope and presentation time. The regression line indicates that as presentation time increases, the slopes increase. The regression equation for target absent trials is slope = 5.777 + 0.056 per msec of presentation time. Almost 42% of the variance in the data is accounted for in the regression, $\underline{R}^2 = 0.418$. Hence, the regression line accounts for a large portion of the variance of the data. This figure further illustrates the effect presentation time has on visual search tasks. Thus, reaction time slope patterns from presentation times under 750 msec do not replicate those slope patterns from response-terminated presentation times.

Insert Figure 26 about here

A scatter plot of the target present slopes by participant for each presentation time obtained in the O among Q's condition is illustrated in Figure 27. Data from the response-terminated condition of Experiment 1 are included in the figure for reference. A similar pattern is found with the target present slopes. As shown in the figure, as presentation time increases, the slopes increase at a level comparable to the lower response-terminated slopes. A regression between slope and presentation time was computed. The regression equation for target absent trials is slope = 13.841 + 0.025 per msec of presentation time, $\underline{R}^2 = 0.145$.

Insert Figure 27 about here

Analysis of Miss and False Alarm Rates

Accuracy data demonstrated the effect of presentation time on the O among Q's condition. As discussed earlier, the extremely high error rates found at very brief presentation times made it difficult to assess reaction time patterns. It was hypothesized that errors were due to participant's inability to effectively perform the task given the brief stimulus exposure time. To further examine the types of errors made, miss and false alarm rates were computed. A miss is defined as an incorrect response when the target was present in the display. On these trials, participants' responses indicated the target was absent when, in fact, it really was present. A false alarm is defined as an incorrect response when the target was absent from the display. On these trials, participants' responses indicated that the target was present when, in fact, it was really absent.

Miss and false alarm data for the O among Q's condition were partitioned by set size in order to assess differences as set size increased. Miss and false alarm rates by presentation time for set sizes of one, three, five, seven, and nine items are depicted in Figures 28 through 33, respectively. For a set size of one item, little difference between miss and false alarm rates were found as presentation time changed. These low miss and false alarm rates suggest that participants were able to effectively scan the display at all presentation times. For a set size of three items, miss and false alarm rates at the 150 and

180 msec presentation times were above 20%. As presentation time increased to 210 msec, the misses and false alarm rate began to decrease. At presentation times above 210 msec, miss and false alarm rates remained relatively low. As discussed previously, the change in accuracy may be associated with the optimal presentation time required to search three items. What is interesting is that the miss and false alarm rates follow an almost identical pattern across presentation time conditions. Similar patterns between miss and false alarm rates were found for set sizes of five and seven items. Paradoxically, the miss and false alarm patterns abruptly depart from each other at set size of nine items. Careful examination of the data reveals that the false alarm rates do not substantially deviate from the pattern found with a set size of seven items. Thus, it is the miss rates that change. Miss rates were elevated for a set size of nine items compared to the other set sizes. It is as if participants became more conservative on trials with nine items. On these trials they tended to make more negative responses than positive. Surprisingly, this elevated miss rate (above 20%) is also found with the response-terminated presentation conditions.

Insert Figures 28-32 about here

Miss and false alarm rates for the Q among O's condition were not computed because the high accuracy rates for both target present and target absent conditions denote little differences across presentation time as set size increased.

CHAPTER V

GENERAL DISCUSSION

This thesis assessed the effect of brief presentation time on visual search tasks. The findings for response-terminated presentation conditions were not found with shorter presentation times. Currently, researchers studying hemispheric specialization have attempted to use visual search tasks to infer serial and parallel search processes. However, questions surface concerning the ability of participants to perform the task with enough precision to infer underlying search processes.

Experiment 1 served as the baseline condition. Task and stimuli similar to those by Treisman and Souther (1985) were used. Experiment 2 was similar to Experiment 1 except that presentation time was manipulated. Based on the accuracy and reaction time data for the Q among O's condition, presentation time does not appear to affect inferences to parallel processing. This finding is supported at presentation times of 150 msec or greater. However, for the O among Q's condition, presentation time appears to have a substantial effect on the identification of serial search processes. Results from these experiments suggest that limited duration presentation times do not replicate findings by Treisman and her colleagues.

Usually, visual search experiments may be used to make inferences to serial and parallel processing because the high accuracy rates found at each set size suggest that participants are able to effectively complete the task. Results from Experiment 2 indicate that presentation time adversely affects task performance. Participants' inability to achieve performance levels much higher than chance is possibly due to insufficient presentation time. Assuming a serial search is performed, if the search is forced to end prematurely because the stimulus is removed, then there will be a limitation to the number of items that can effectively be searched. This makes interpretation of serial processes based on reaction time impossible. The dilemma that surfaces for researchers is how to assess mode of processing if the data are based on only partial processing. For example, participants might actually perform a serial search on a stimulus display, but you cannot determine what process was used because a response is made before all the items in the display have been scanned. Hence, only a few items in the display have been searched, but the remaining items were not scanned because of insufficient stimulus exposure time. The data obtained would then be based on only a partial search of the display. However, inferences to serial and parallel search processes make the assumption that all items were searched in the display. These inferences can be made with response-terminated presentations because the stimulus is removed following completion of the search. This is not true for experiments where presentation time is limited. Thus, inferences to search processes are not valid when the effectiveness of the search is questioned.

Some researchers realize the inherent problems associated with limited presentation time. Palmer and Tzeng (1992) mistakenly substituted accuracy rate patterns for reaction time patterns in an attempt to identify serial and parallel search processes.

They argued that Treisman and her colleagues support this technique, but the author knows of no theoretical justification for using accuracy rates to determine underlying search processes. In fact, an examination of Treisman's work concludes that reaction time slopes are the key determinant for identifying serial and parallel search patterns used (see Treisman, 1991; Treisman & Gelade, 1980; Treisman & Gormican, 1988).

Treisman and Gormican (1988) performed and experiment using brief presentation time. Due to high error rates found, a transformation was performed on the reaction time data found in an attempt to correct for errors. They estimated the actual number of items scanned based on errors found and then computed an adjusted set size. The main problem with this technique is the assumption that all errors are due to presentation time. Thus, task specific errors which are independent of presentation time (e.g., task complexity, stimulus resolution, stimulus discriminability, and speed-accuracy trade-offs, etc.) are erroneously included in the transformation. Thus, another technique is necessary to determine the number of items processed in each display.

Average Scan Time Estimate

Results from the O among Q's condition of Experiment 2 suggest that for serial searches, limiting presentation time limits the number of items able to be scanned. Based on the item scan time derived from Experiment 1 and total number of items in the display, an average scan time estimate can be computed. This estimate is the average presentation time necessary for an effective search of all the items in the display. In Experiment 2, for each set size, the average scan time or presentation time necessary was computed. Accuracy rates and reaction time slopes were compared at each presentation time condition to this estimate. Accuracy, reaction time, and reaction time slope patterns found in Experiment 2 were predicted by this average scan time estimate. When the presentation time was below the average scan time necessary, accuracy measures indicated that inadequate searches had occurred. This made inferences to mode of processing by reaction time measures invalid. Alternatively, when the presentation time was above the average scan time necessary, accuracy measures indicated that efficient searches had occurred, and thus, reaction time patterns allowed for inferences to serial and parallel processing.

These results supported the hypothesis that a response was made when the stimulus was removed. Differences in accuracy as presentation time varied, as well as, anecdotal comments suggested that participants made responses based entirely on the processing performed while the stimulus was available. For example, if the estimated presentation time required to effectively search a three item display was 250 msec, then a presentation times of 200 msec would show poor performance on trials with three items or more, because a response would be made based on only partial processing. Conversely, a presentation time of 300 msec would be show improved performance on trials with three items or less, because this presentation time allowed sufficient stimulus exposure time for the system to complete the search. Hence, inferences to serial or parallel search processes are only applicable to conditions where the presentation time was equal to or greater than the average scan time estimate.

Problems with the Current Study

Several inconsistencies were found in Experiment 1. Although, presentation time conditions of 750 and 1000 msec were above the average presentation time necessary for effective scans of nine items, the slopes found were lower than those found in Experiment 1. Since sufficient presentation time was provided to search all stimulus displays, there should be no difference among these three conditions. One explanation for this result might be that participants become more efficient when they know presentation time is limited. In response-terminated conditions, participants are able to take as much time as needed during each search to make a response; whereas, the participants in the 750 and 1000 msec conditions cannot afford this luxury. In order to make sure that target is found before the stimulus is removed, it would be an advantage to increase the scan time per item required. If participants did improve their scan rate then one would expect to find a speed-accuracy trade off. Comparing the accuracy rates among these conditions finds support for this explanation. On average, the performance found for the 750 and 1000 msec presentation times were approximately 3% worse than the performance found in the response-terminated condition. Thus, the lower slopes found in the 750 and 1000 msec conditions could be due to a speed-accuracy trade-off.

The large discrepancy between the miss and false alarm rate patterns from a set size of seven to nine was not expected. As discussed previously, the false alarm rate did not change substantially from a set size of seven to nine items. Miss rates almost doubled from a set size of seven to nine items. Two possible stimulus explanations were tested. Even though the placement of items in the display was random, it was possible that the nine item trials contained targets placed in outermost regions of the display. This would make it more difficult to identify the target and could explain the miss rates found. The second possibility was that the target for the nine item trials might be surrounded by many distractors; thereby, reducing target discriminability. To test these possible explanations, the stimuli with set sizes of seven were compared with the stimuli with a set size of nine. A careful review of the target placement found no differences between the two set sizes. In fact, on about two-thirds of the stimuli, a target in the seven item display matched the location of a target in a nine item display[8]. The other stimuli contained targets that did not constitute a direct match. However, the distance from the target to the center of the display remained equitable for the remaining stimuli. Thus, target placement cannot explain the miss rate found.

The second possible explanation is that the distractors in the nine item set size might have reduced target discriminability. The creation of each stimuli involved randomly placing distractors and/or a target in a 12 by 6 position grid. This made grouping of distractors rare. A careful review of distractor placement did not find any noticeable difference in grouping between set sizes of seven and nine. Hence, the apparent cause of why participants were made more misses when presented with nine item displays than with displays of seven items is unexplained.

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[8] For example, if the target for a seven item display was located in the upper right of the display, then a similar target was found in the same upper region of the display for a nine item display. A match was defined as with a position or two of each other.

Areas of Future Research

These experiments only examined one of the two procedural differences between typical visual search studies and hemispheric specialization experiments. Stimulus placement in these two experiments was limited to foveal projections. Hemispheric specialization experiments present the stimulus to either the right or left visual field. In order to assess possible differences between foveal and peripheral presentations, future research manipulating stimulus presentation is necessary. However, it is recommended that all hemispheric specialization experiments perform a foveal presentation condition to act as a baseline for comparisons found between the two hemispheres.

The presentation time effect found in Experiment 2 could be further examined by using a response delay following the removal of the stimulus. The O among Q's condition yielded results that supported the notion that participants made responses based on the processing up to the point when the stimulus was removed. While the visual information was removed, it is possible that participants responded too quickly. Assuming that the search continued after the stimulus was removed, then it is possible that better performance could be obtained if participants were forced to wait for a response cue before making a response.

Finally, there is some speculation that alternative techniques exist to better infer serial and parallel searches. These techniques should be examined for their applicability to visual search tasks using brief presentation times. Townsend (1990) outlines a number of promising methods to assess serial and parallel processing. For example, one method suggests the use of redundant targets. Another suggests analyzing the effect having a second response has on serial or parallel processes. Another technique assumes partial processing by identifying processes that capitalize on the similarity and confusion between target and distractor. These techniques might not be affected of brief presentation time, so serial and parallel processes can be determined in hemispheric specialization paradigms (see Townsend, 1990 for a more thorough review of the techniques).

The results of these two experiments suggest that presentation time has an effect on visual search tasks. Although stimuli and tasks that are processed in parallel appear to work with presentation times of at least 150 msec, stimuli and tasks that are processed serially are adversely affected by brief presentation times. The findings in this study suggest that further experimentation is required on visual search tasks and stimuli before assessments of serial processing can be made with brief stimulus presentation times.

APPENDIX A

CONSENT FORM

I understand that I voluntarily agree to participate in a research project conducted by Gavin Lew, a graduate student at Loyola University Chicago. The research is being conducted in order to determine the effect of presentation time on visual search processes. The specific task I will perform requires me to look at a computer screen and for each trial, indicate whether the target was present or absent in the display. The experiment should take about 30 minutes to complete.

I acknowledge that Gavin Lew will explain the task to me and that I may withdraw from the experiment at any time without prejudice or penalty. I also do not give up any rights when I agree to participate in this study. I am aware that the information gathered is for research purposes only and will remain strictly confidential and anonymous.

I also understand that upon completion of the experiment, I will be given a description of the role my specific performance played on this project. The experimenter has offered to answer any questions I might have regarding this research procedure.

Thank you,

Gavin Lew

I have read and understand this statement

______________________________ _______________

Participant Signature Date

APPENDIX B

SUBJECT QUESTIONNAIRE

Name:__________________________ Instructor:______________________

Date:______________ Sex: M F Psychology Course Number: _______

Handedness: L R

Which hand do you use to: Write: L R

Eat: L R

Throw: L R

Familial Sinstrality (Name those in your family who are left-handed):

____

APPENDIX C

PARTICIPANT DEBRIEFING

Thank you for participating in this experiment to examine the effect of presentation time on visual search tasks. During the experiment, you were required to make target present/absent decisions on a display with a varying number of distractor items. The target is identified from a distractor by the absence or presence of a distinctive feature. As you may have noticed, the effect is rather robust. Hence, when you were asked to search for a single Q, the task was much easier than when I asked you to search for a single O. This effect if further magnified with larger set sizes. These results suggest that some targets are searched via a parallel processor while others are searched via a serial processor. Thus, when searching for the Q, it really did not matter how many distractors were on the display. Your reaction time for a set size of three was about the same for a set size of nine. However, this was not the case when you were asked to search for an O. The more distractors on the display, the harder the task became.

Based on these findings, researchers studying hemispheric specialization have used this procedure to model a parallel-serial processing mechanism to the right and left hemisphere. However, the procedures used for these studies differ from visual search studies along two dimensions: presentation time and stimulus placement. Hemispheric specialization studies use very brief presentation times (150-200 msec) and present the stimuli to either the left or right visual field; whereas, visual search studies to use response-terminated presentation times and the stimuli are presented to the fovea (center of the screen).

What I attempted to find out is whether participants can perform the task with very brief presentation times. The stimulus was in the center of the screen and not on the far left or right of the screen as in hemispheric specialization studies. Different groups of participants were given different presentation times (response-terminated to 1000 msec). I am examining the effect the length of presentation time has on these visual search experiments.

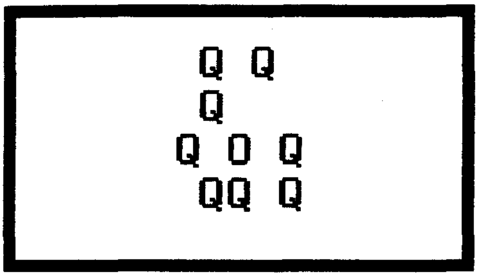
Again, thank you for your participation and feel free to stop by and ask any questions you may have.

....Gavin Lew

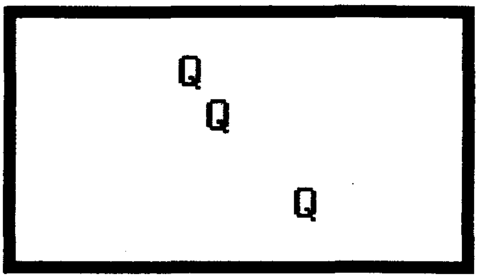
APPENDIX D

EXAMPLES OF STIMULI

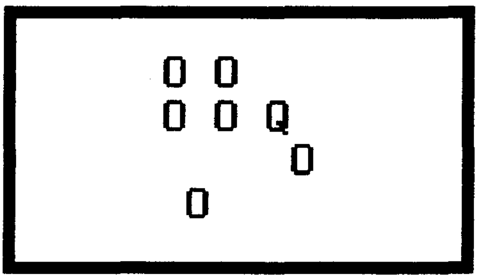
O among Q's Condition where the target is present and the set size is nine.



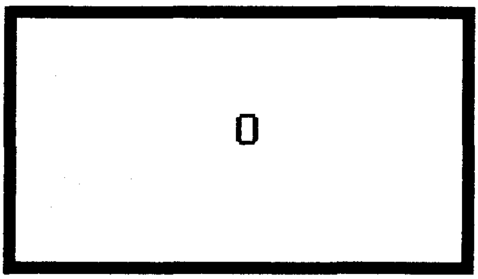
O among Q's Condition where the target is absent and the set size is three.



Q among O's Condition where the target is present and the set size is seven.



Q among O's Condition where the target is absent and the set size is one.



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VITA

The author, Gavin S. Lew, was born in Oakland, California.

In September, 1987, Mr. Lew entered the University of California at San Diego. In June, 1991, he received the degree of Bachelor of Arts with Distinction from the Department of Psychology. While attending the University of California at San Diego, he worked in various research laboratories, including the Scripps Clinic and Research Foundation, the University of California, San Diego Medical Center and Veterans Administration Hospital in La Jolla, California. Between 1991 and 1992, Mr. Lew actively participated in research at the University of California, San Francisco Medical Center.

In August, 1992, Mr. Lew was admitted to the doctoral program and was granted an assistantship at Loyola University Chicago.

Figure Caption

Figure 1. Mean accuracy rate found with a response-terminated presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

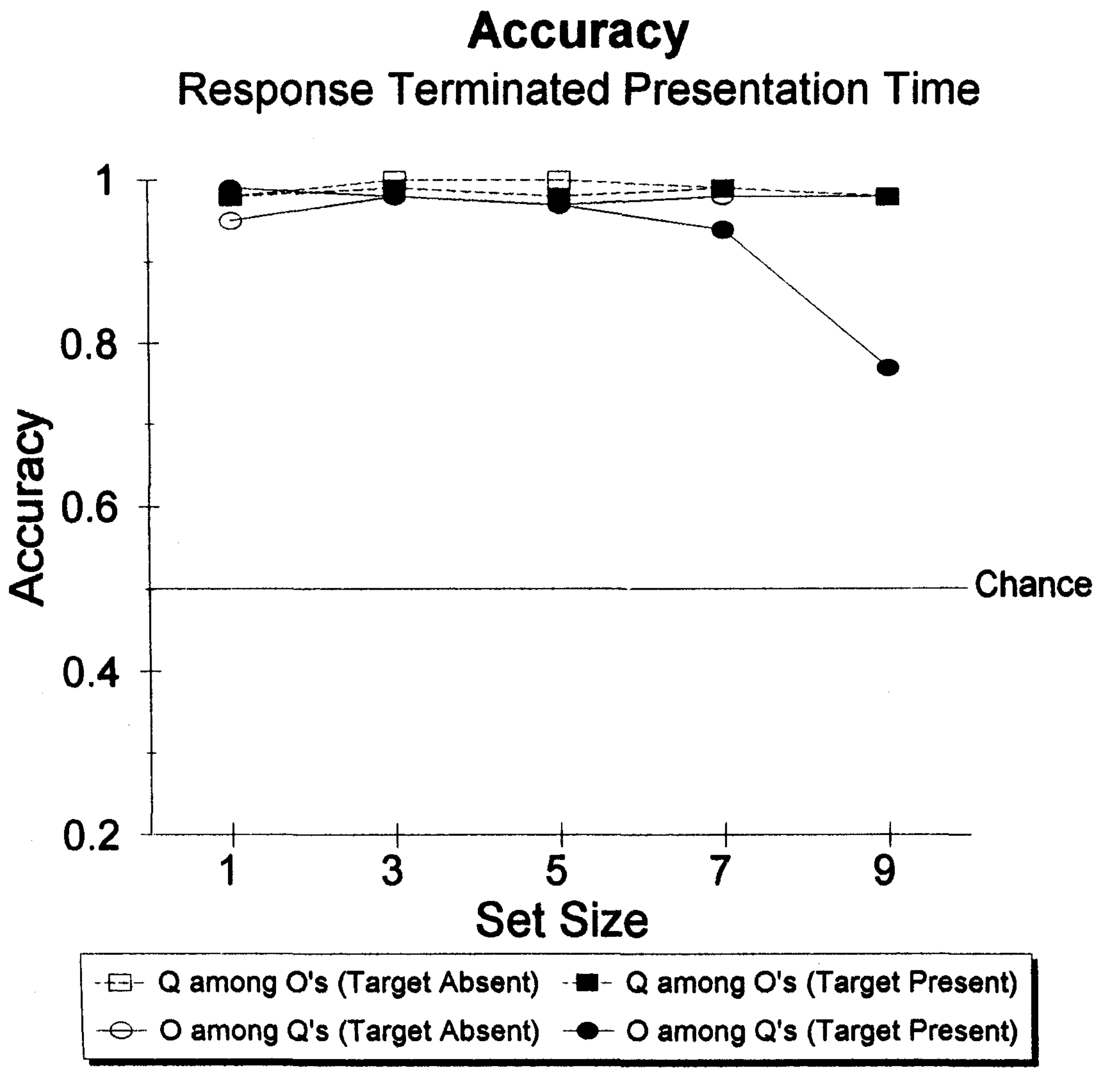

Accuracy
Response Terminated Presentation Time
1
0.8
0.6
0.4
0.2
Accuracy
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 2. Mean reaction time from correct trials with a response-terminated presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

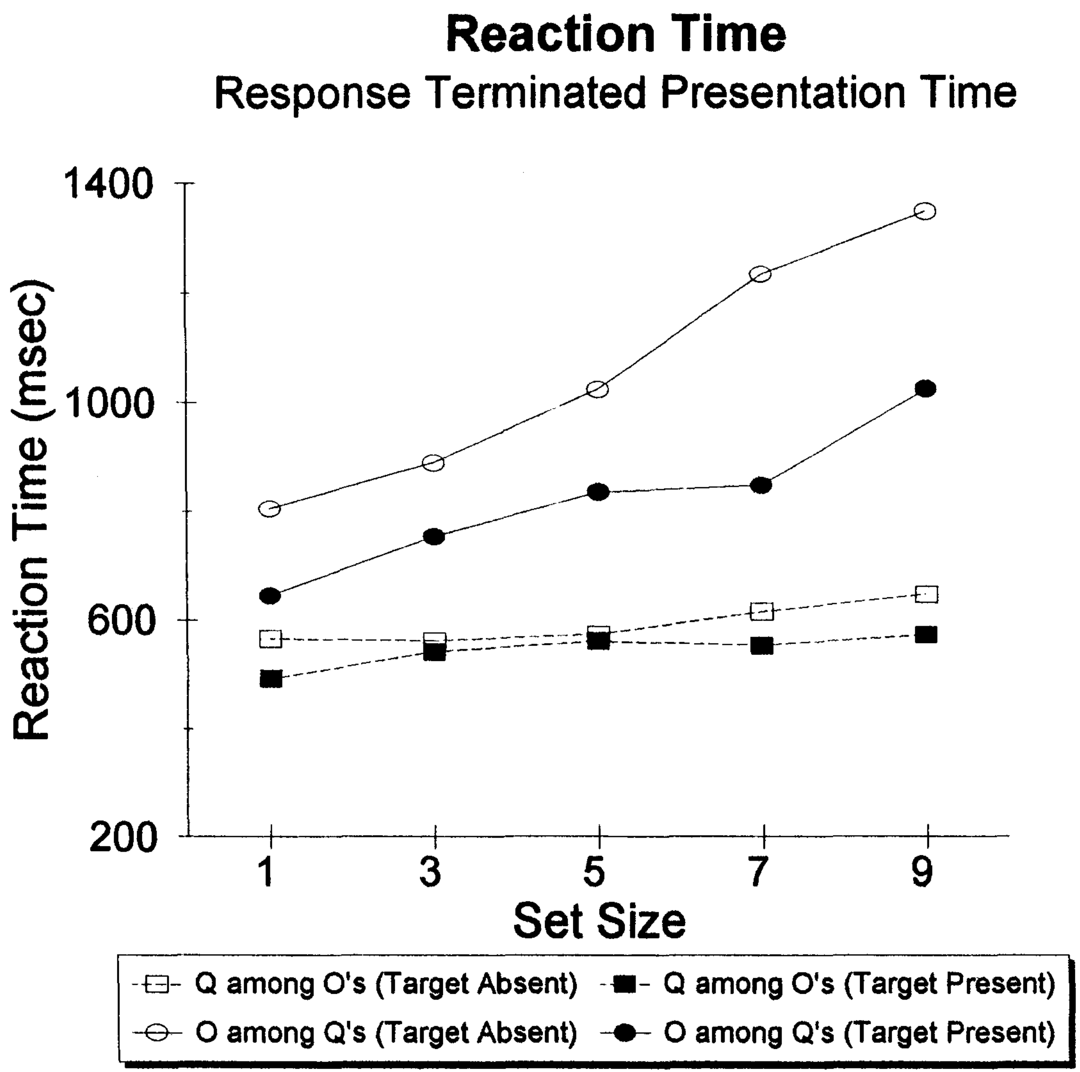
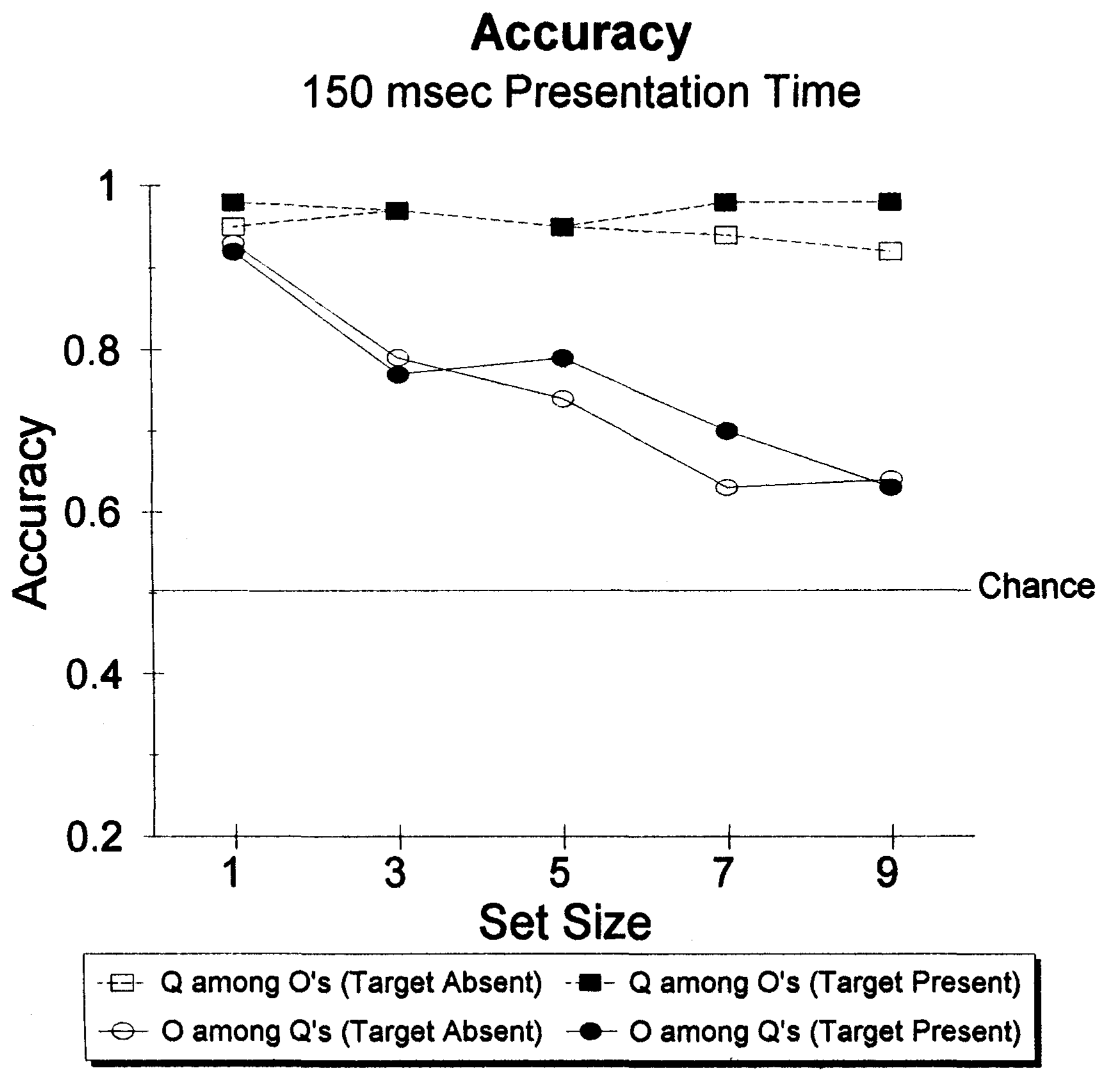

Reaction Time
Response Terminated Presentation Time
Reaction Time (msec)
1400
1000
600
200
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 3. Mean accuracy rate with a 150 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.



Accuracy
150 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 4. Mean accuracy rate with a 180 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

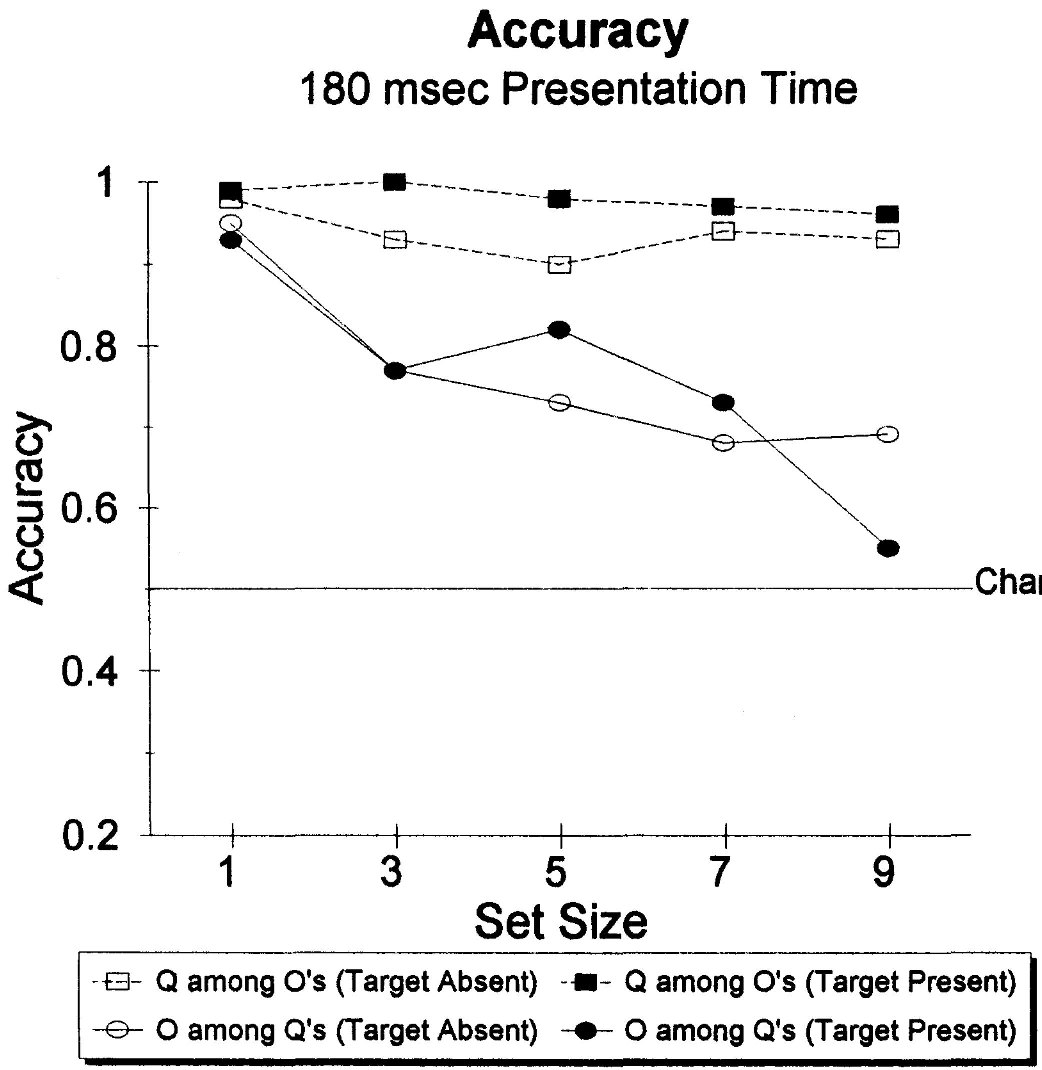

Accuracy
180 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 5. Mean accuracy rate with a 210 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

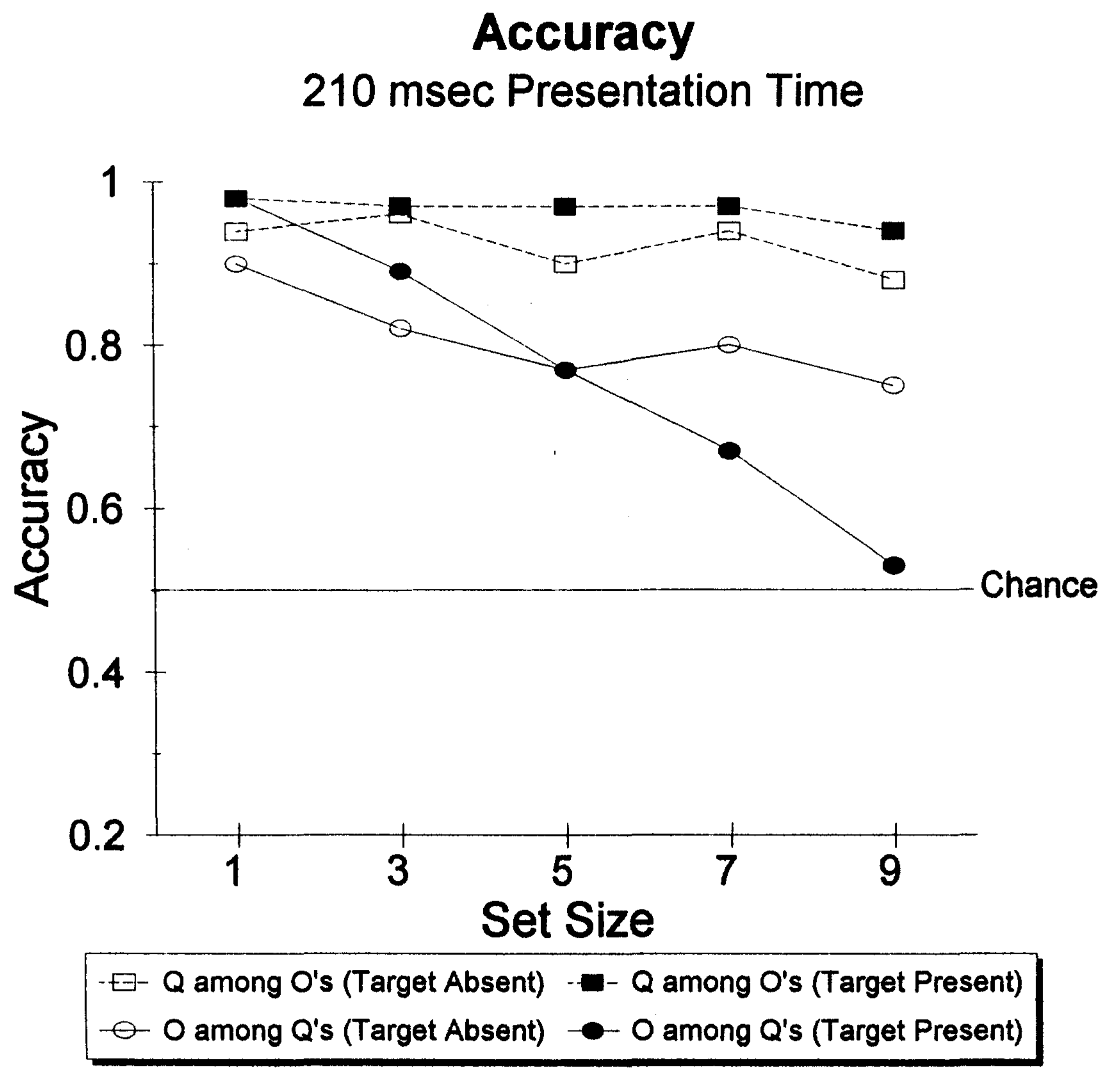

Accuracy
210 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 6. Mean accuracy rate with a 330 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

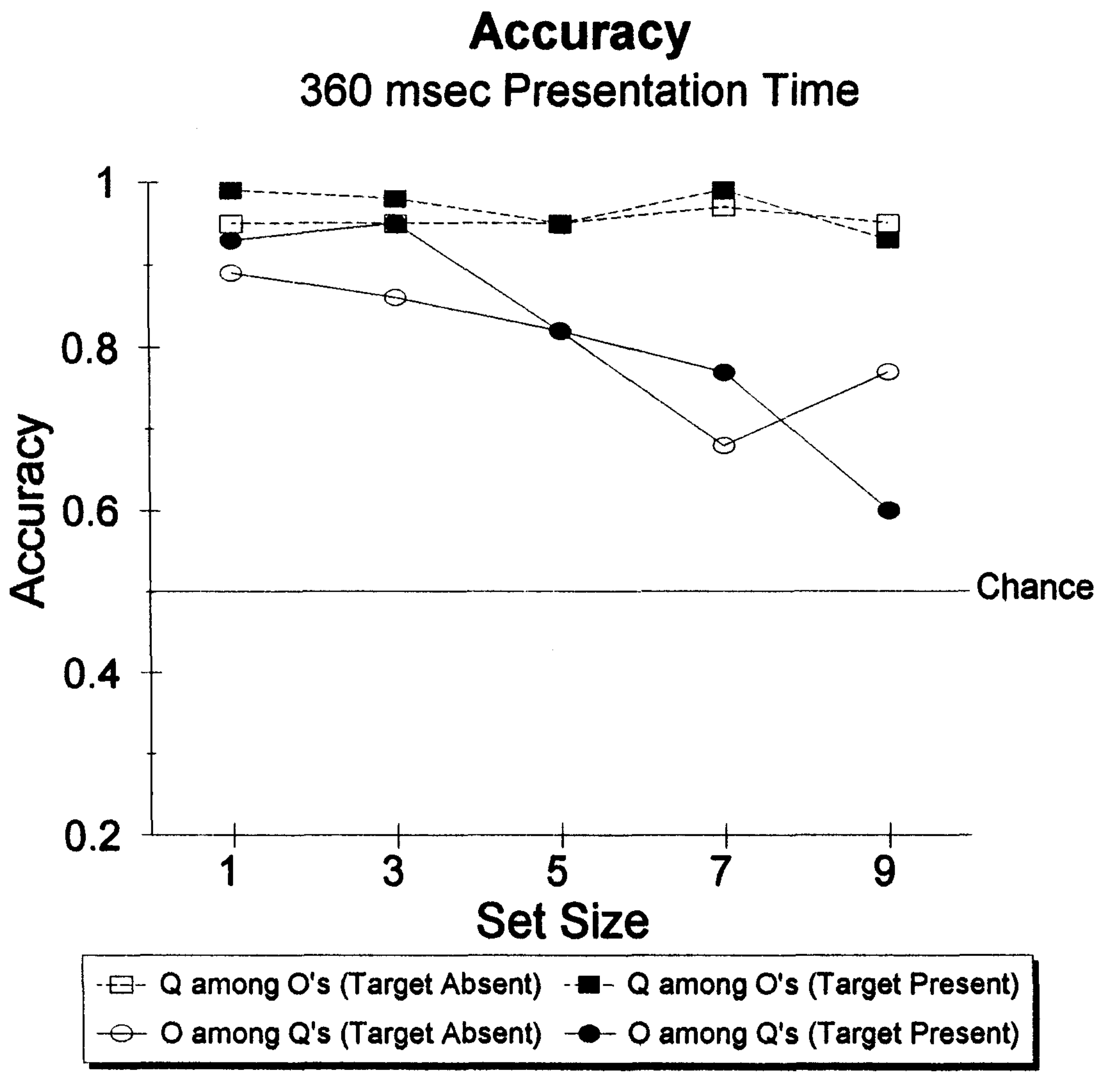

Accuracy
360 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 7. Mean accuracy rate with a 360 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

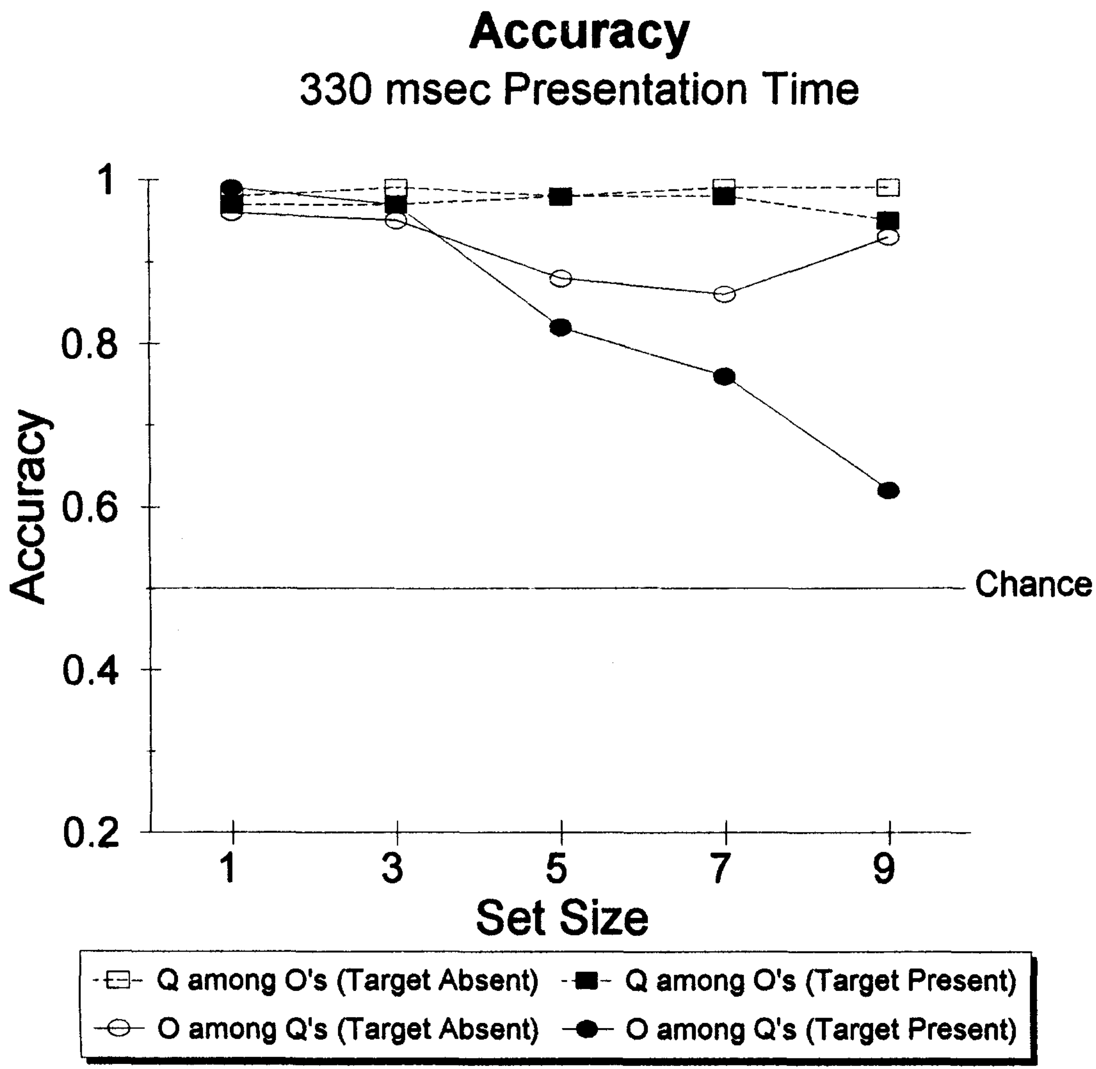

Accuracy
330 msec Presentation Time
1
0.8
0.6
0.4
0.2
Accuracy
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 8. Mean accuracy rate with a 390 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

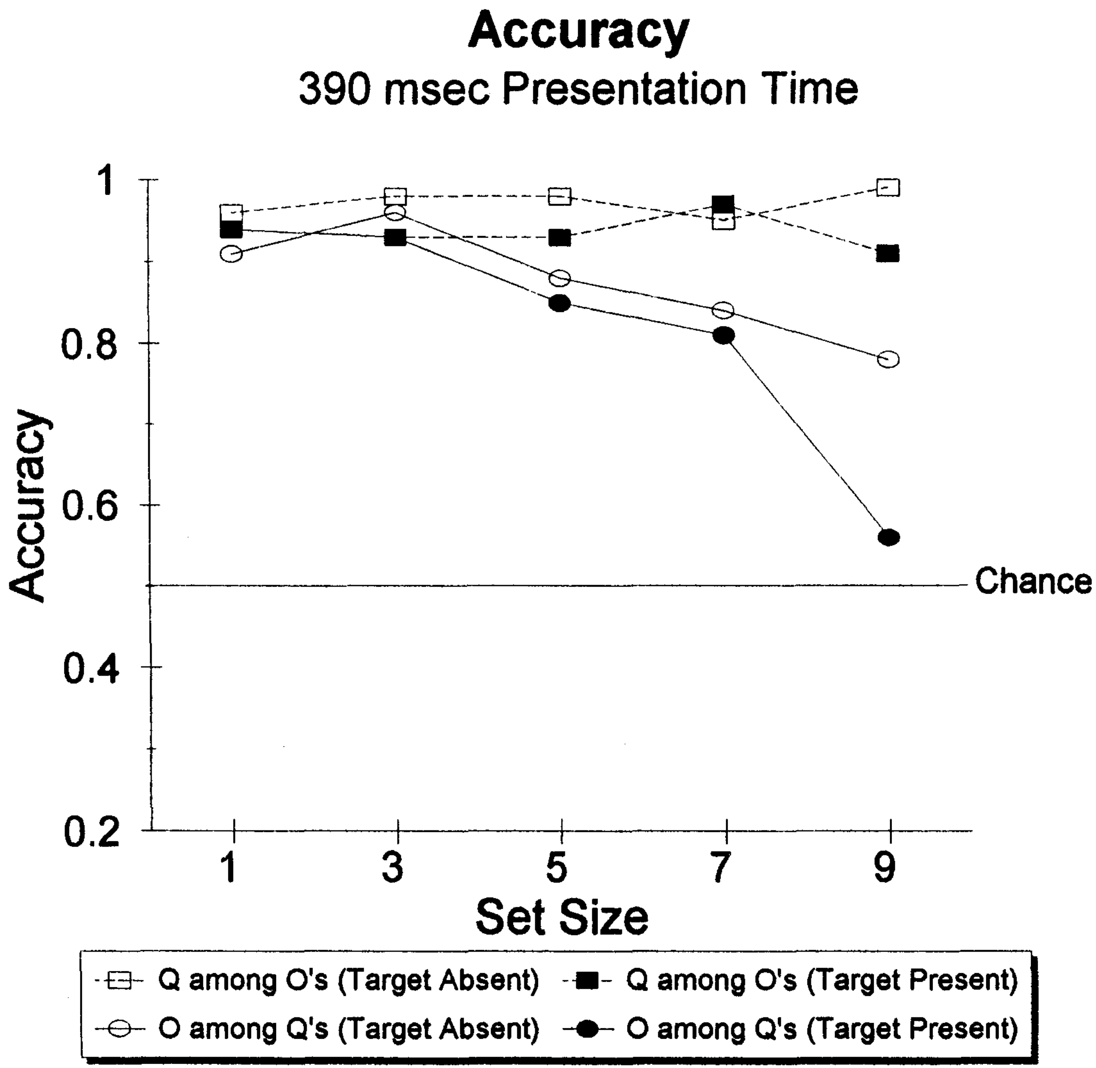
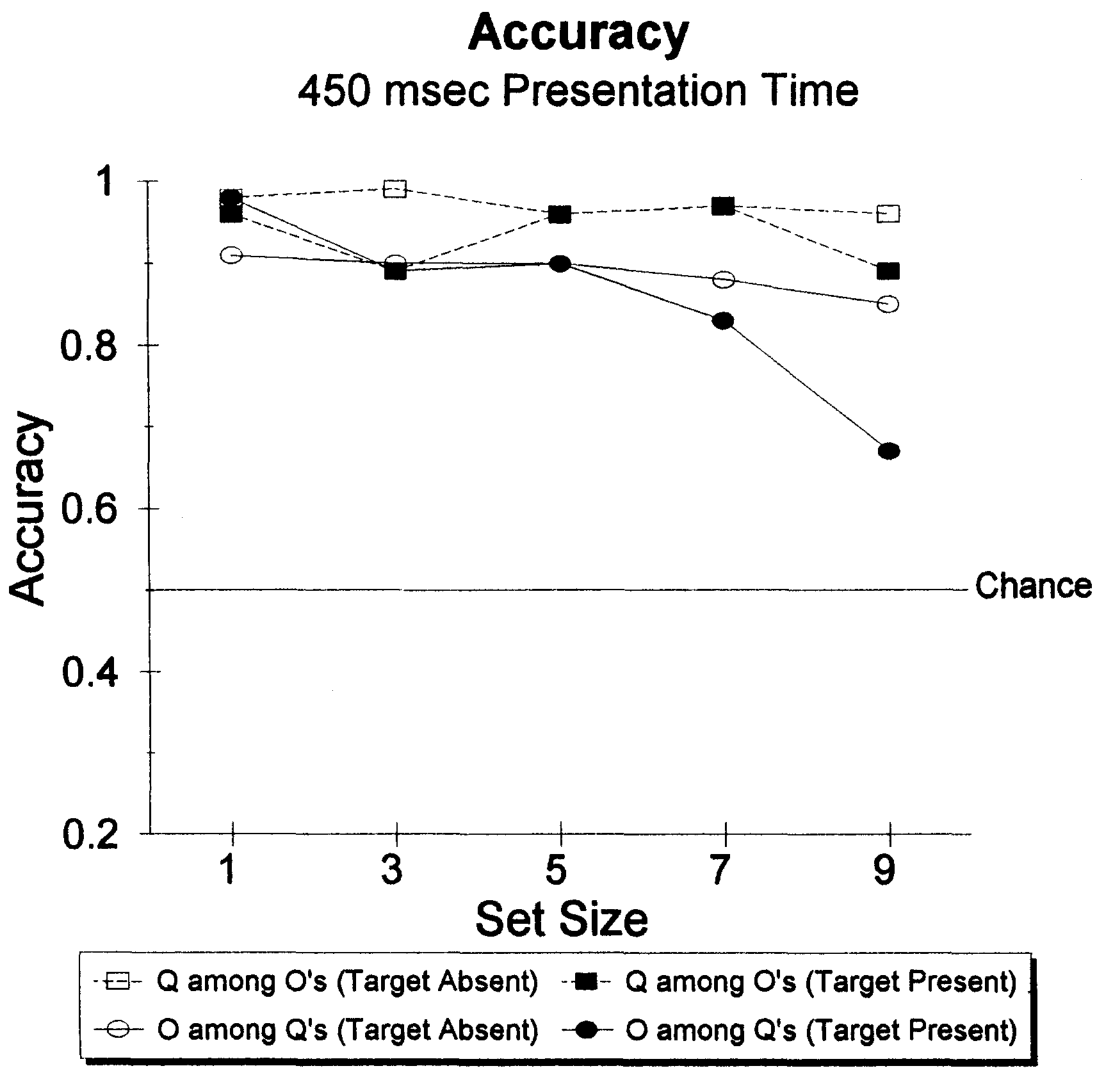

Accuracy
390 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
1
3
5
7
9
Set Size
Chance
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 9. Mean accuracy rate with a 420 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.



Accuracy
450 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 10. Mean accuracy rate with a 450 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

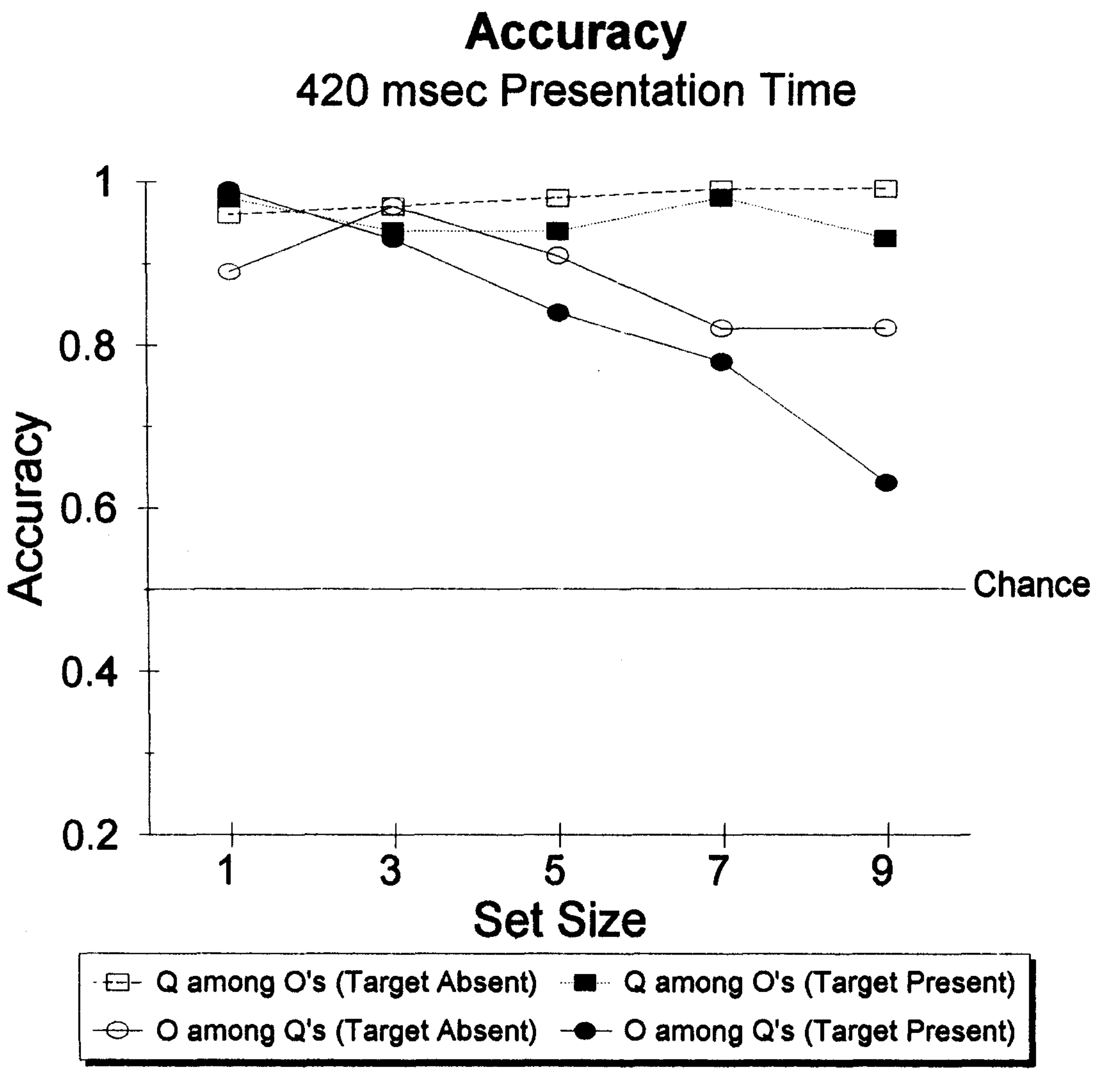

Accuracy
420 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 11. Mean accuracy rate with a 750 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

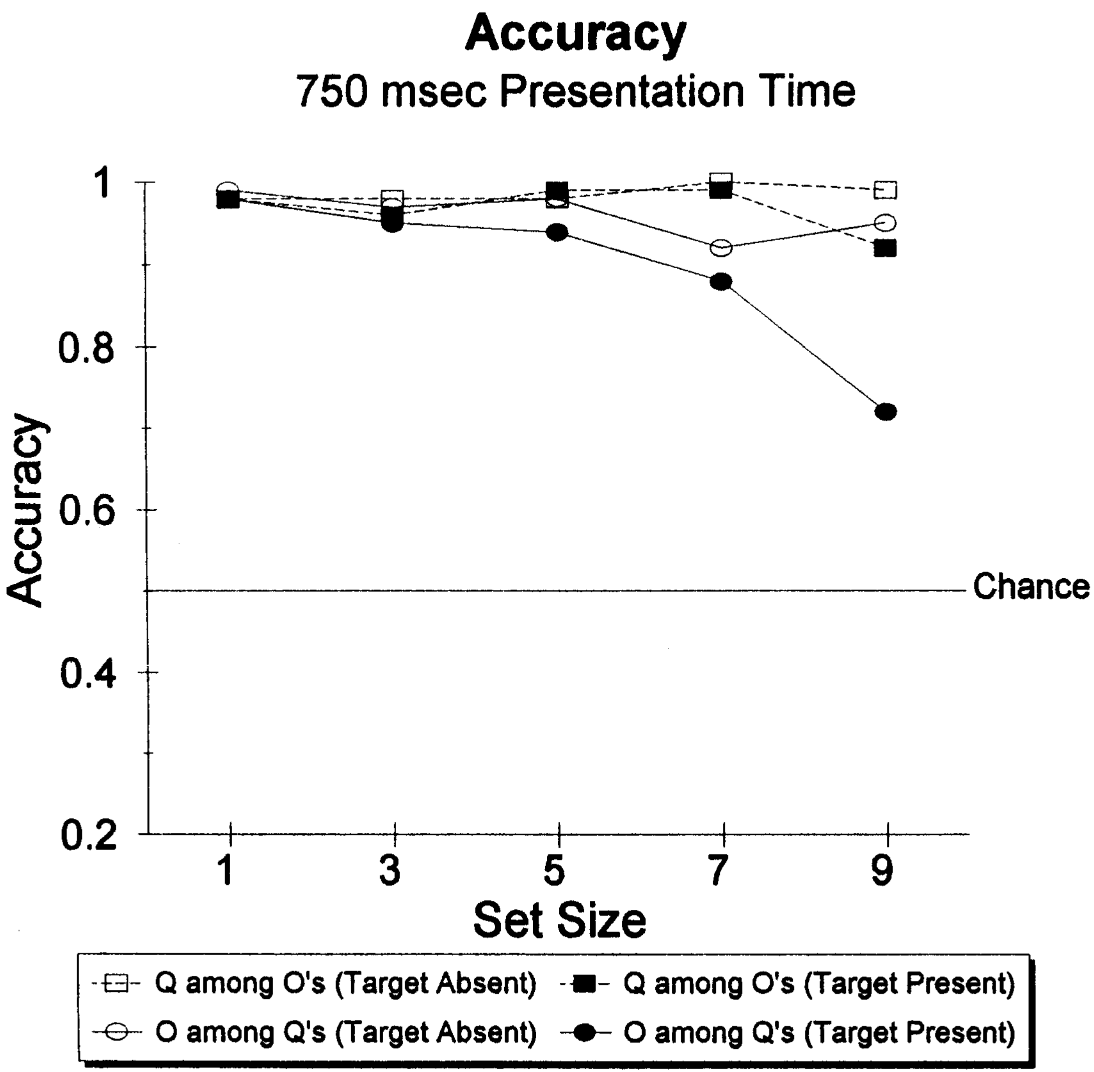

Accuracy
750 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 12. Mean accuracy rate with a 1000 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

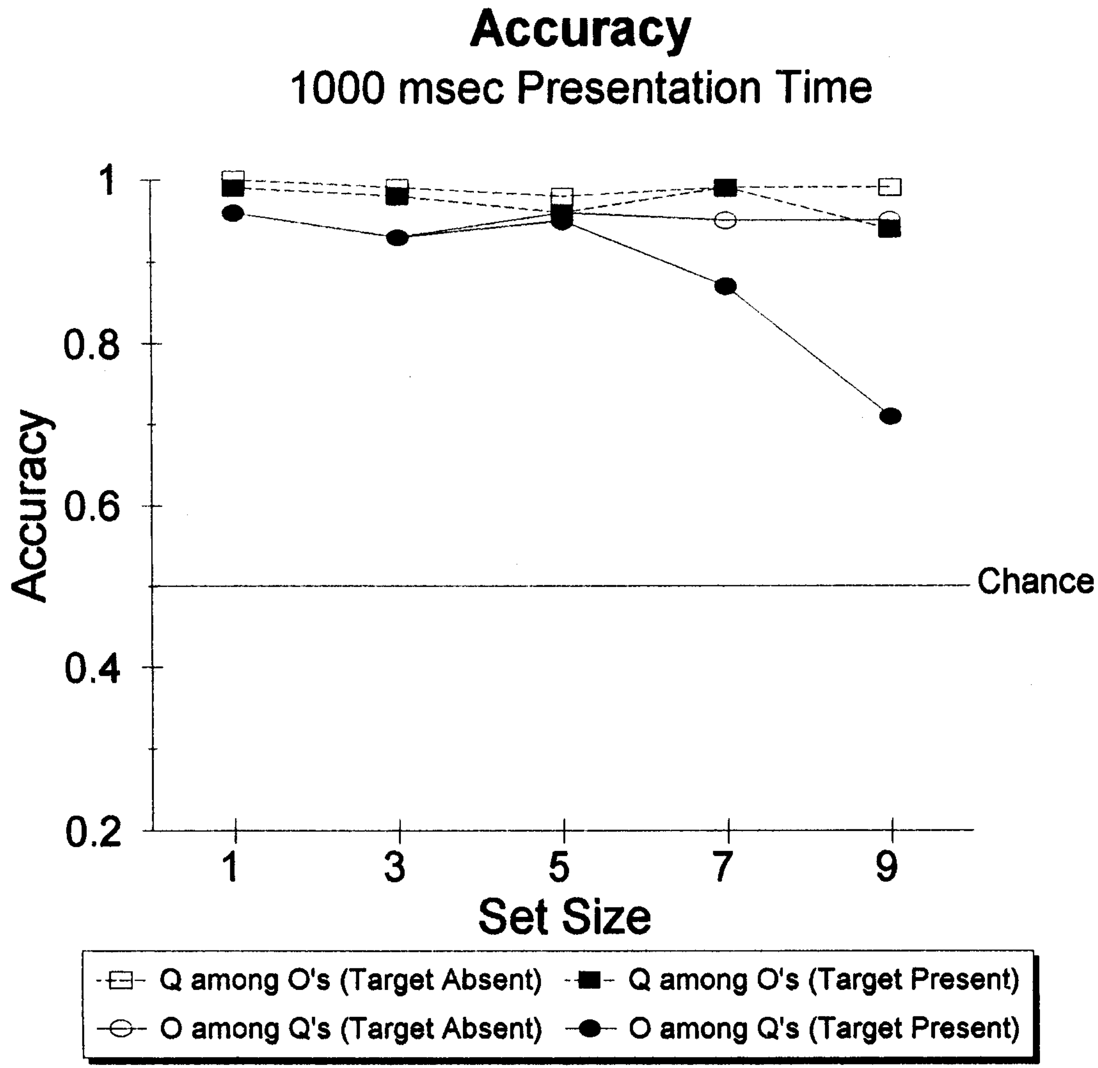

Accuracy
1000 msec Presentation Time
Accuracy
1
0.8
0.6
0.4
0.2
Chance
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 13. Mean reaction time from correct trials with a 150 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

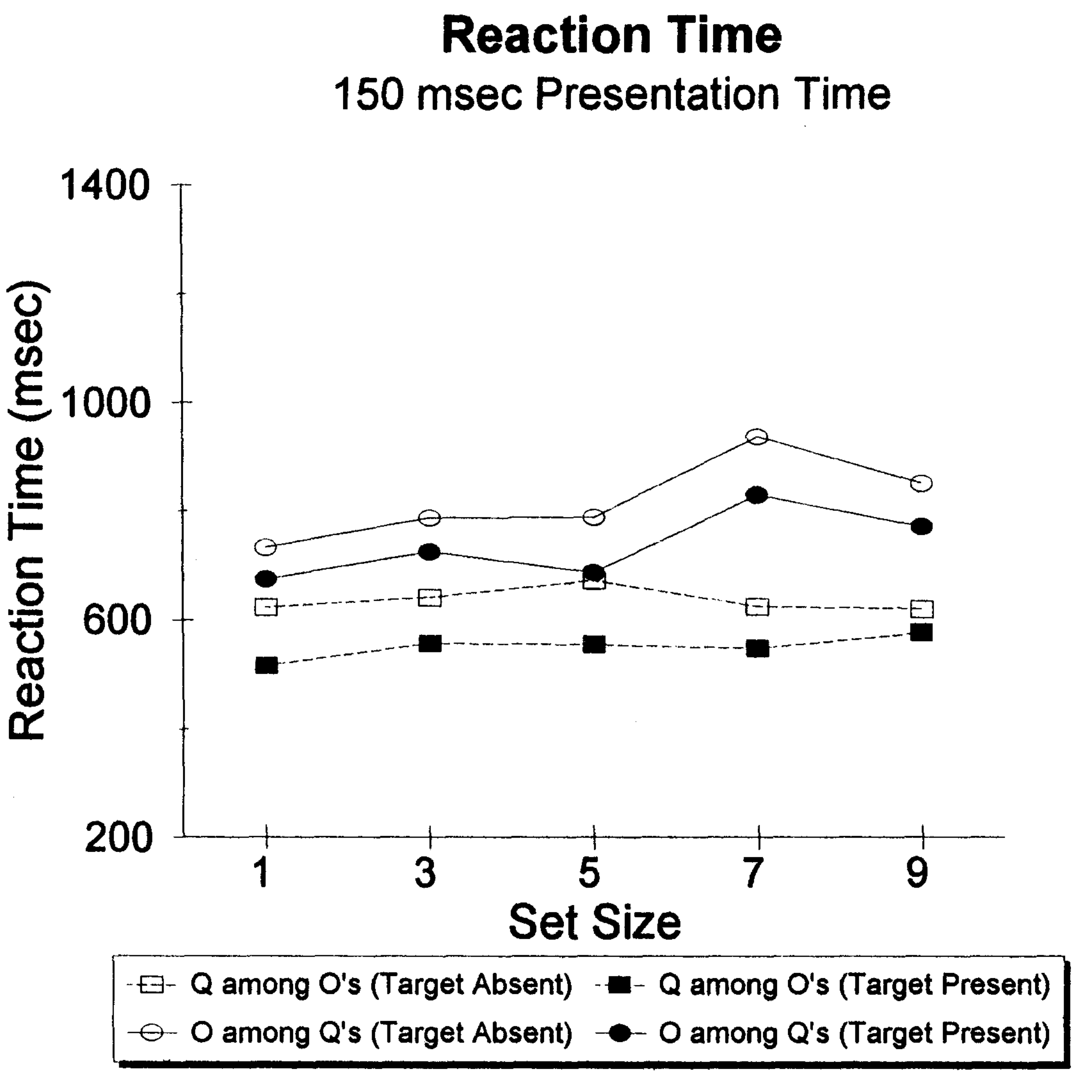

Reaction Time
150 msec Presentation Time
1400
1000
600
200
Reaction Time (msec)
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 14. Mean reaction time from correct trials with a 180 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

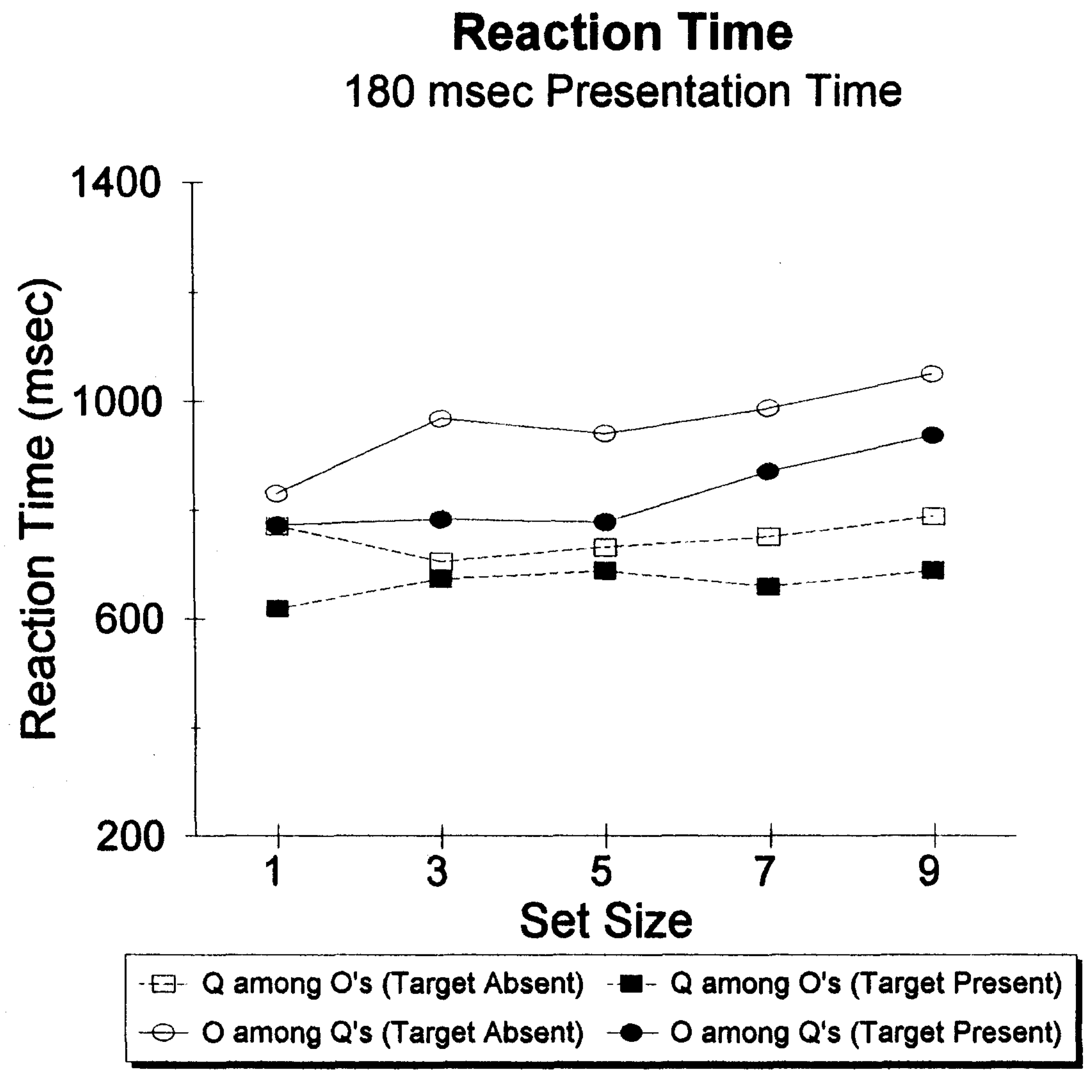

Reaction Time
180 msec Presentation Time
1400
1000
600
200
Reaction Time (msec)
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

<u>Figure 15</u>. Mean reaction time from correct trials with a 210 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

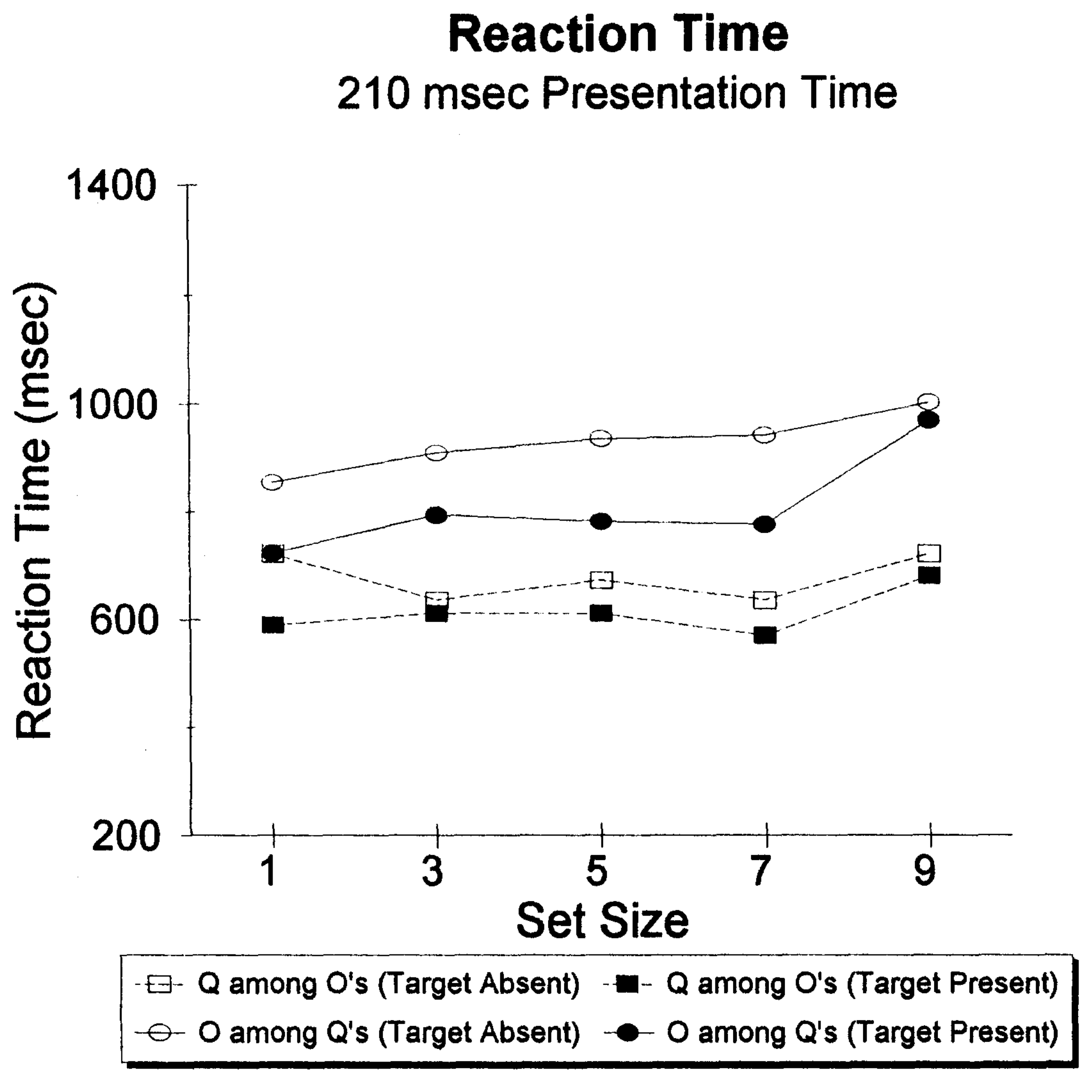

Reaction Time
210 msec Presentation Time
Reaction Time (msec)
1400
1000
600
200
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

<u>Figure 16</u>. Mean reaction time from correct trials with a 330 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

Reaction Time

330 msec Presentation Time

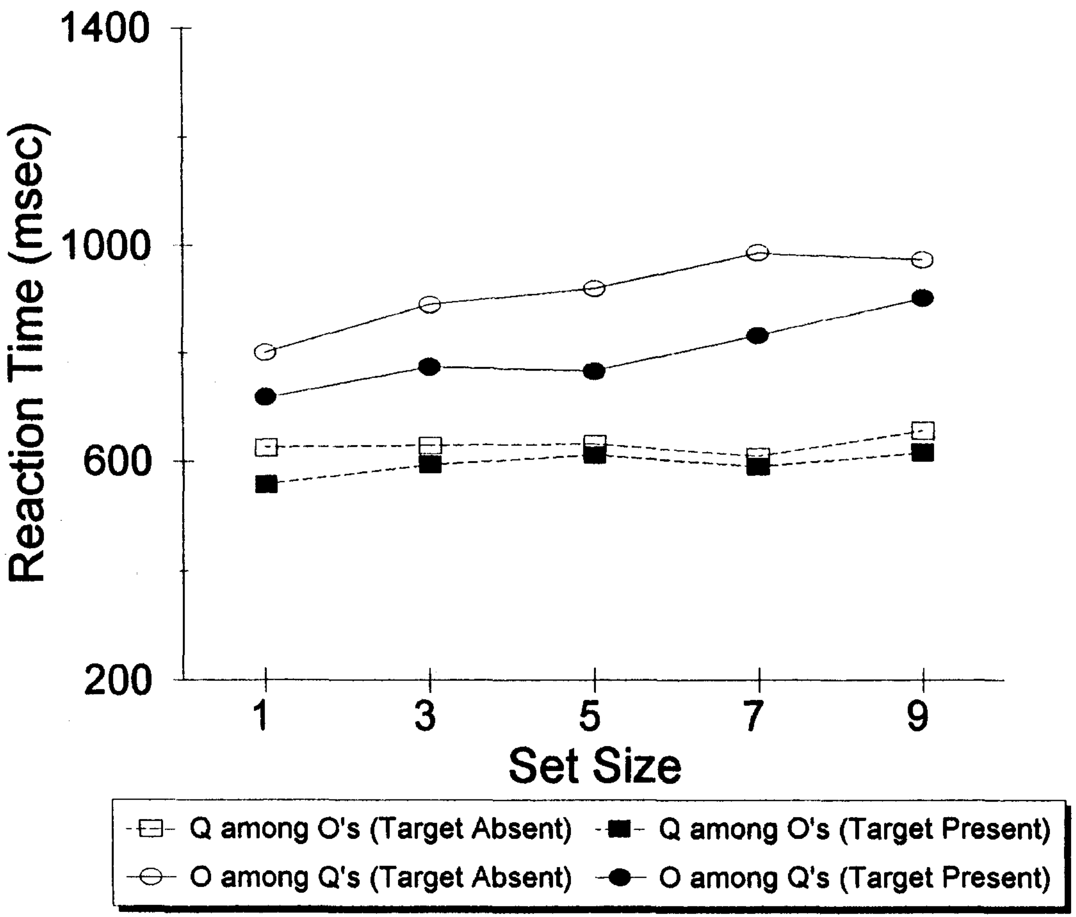


Figure Caption

Figure 17. Mean reaction time from correct trials with a 360 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

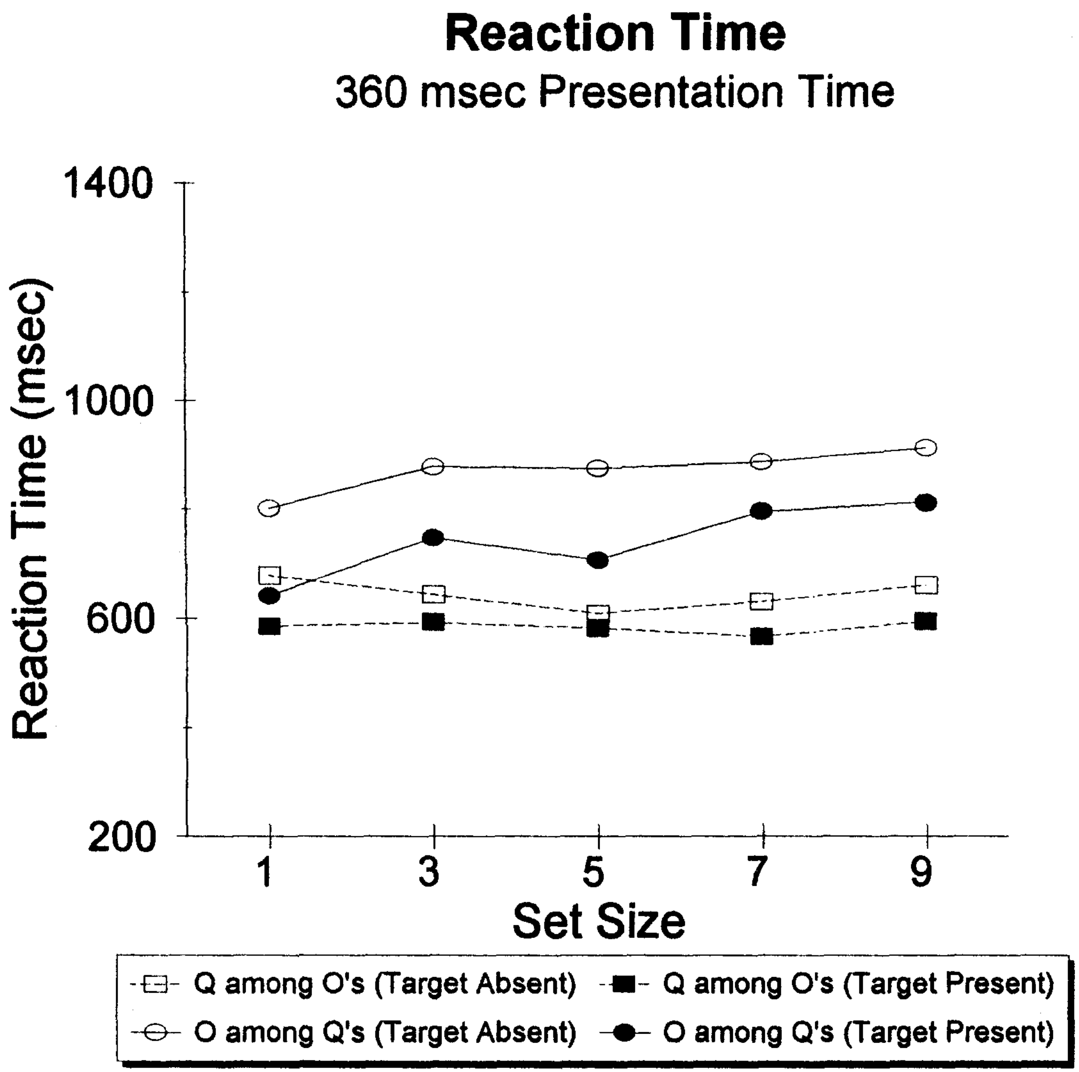

Reaction Time
360 msec Presentation Time
Reaction Time (msec)
1400
1000
600
200
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 18. Mean reaction time from correct trials with a 390 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

Reaction Time

390 msec Presentation Time

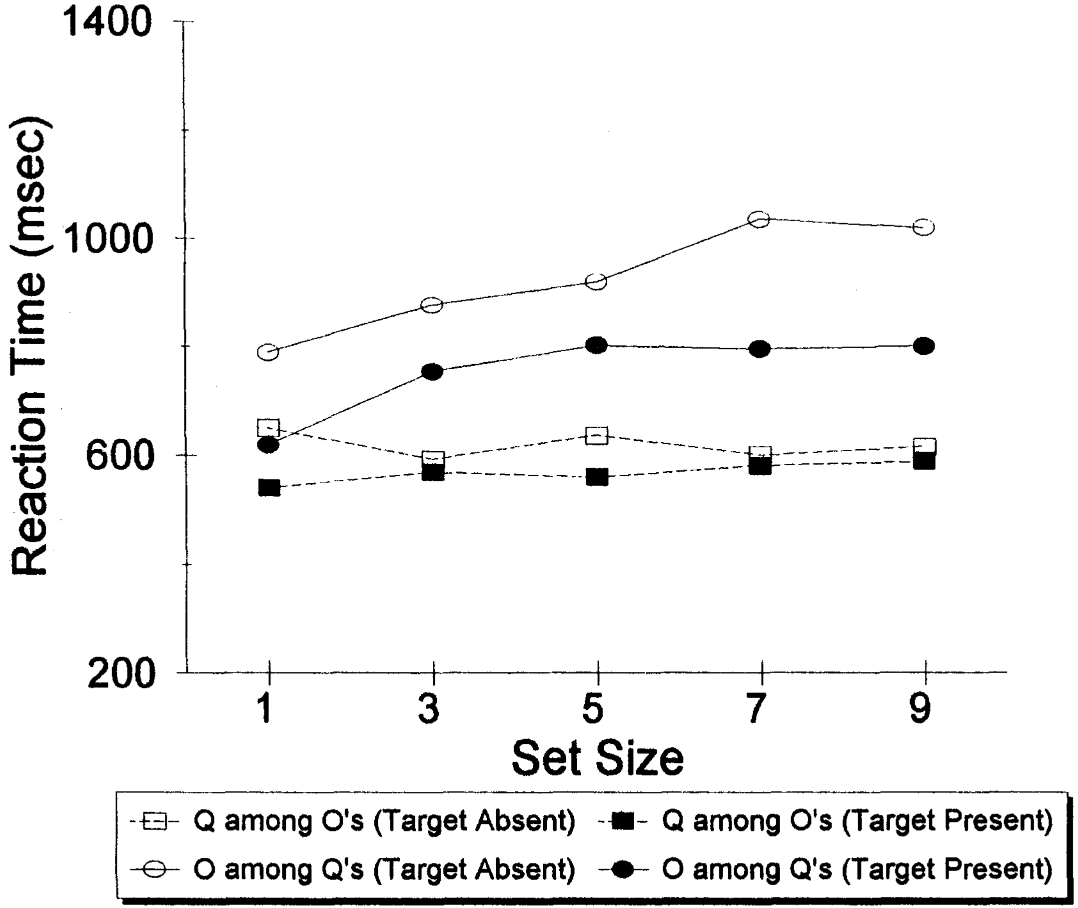
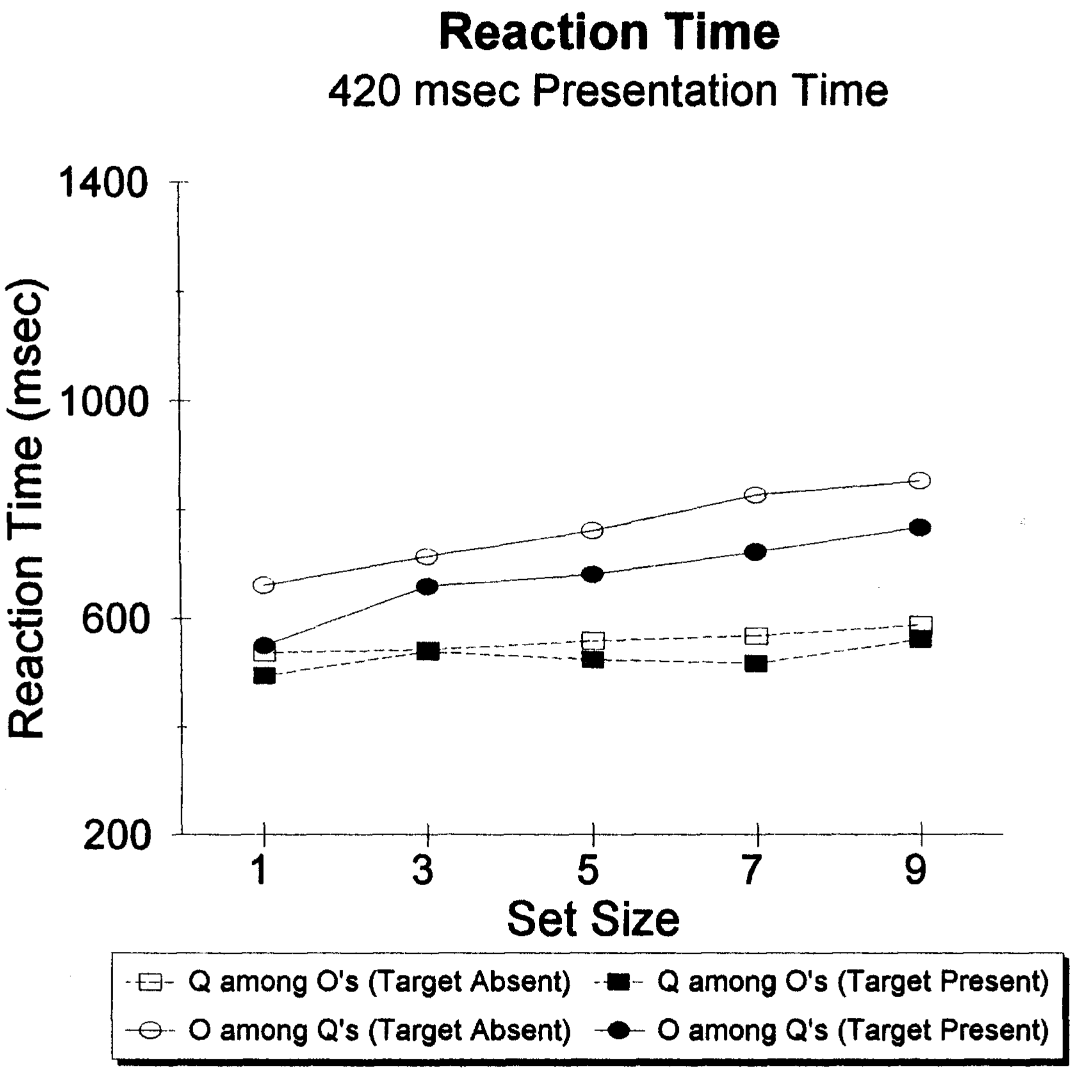


Figure Caption

Figure 19. Mean reaction time from correct trials with a 420 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.



Reaction Time
420 msec Presentation Time
Reaction Time (msec)
1400
1000
600
200
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 20. Mean reaction time from correct trials with a 450 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

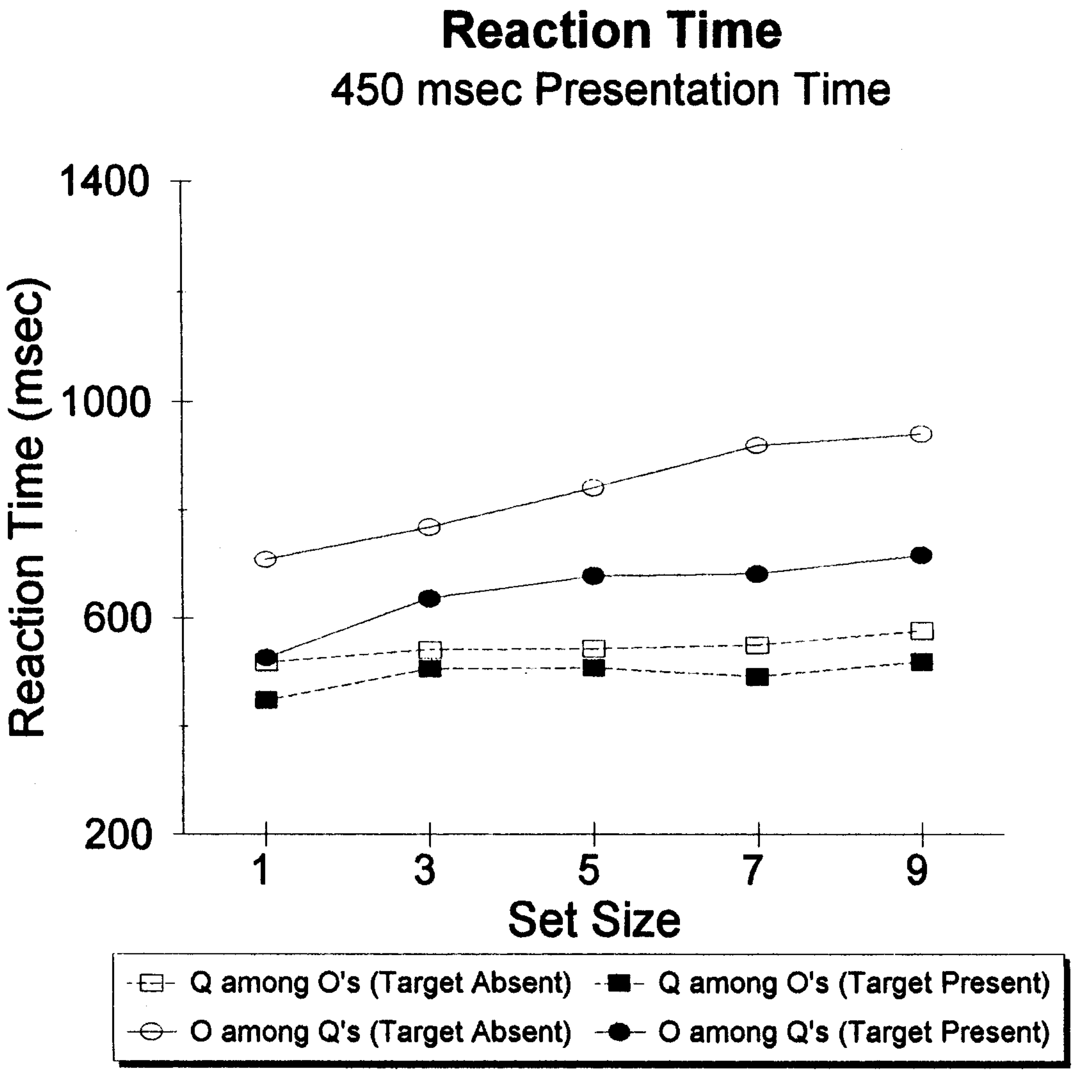

Reaction Time
450 msec Presentation Time
Reaction Time (msec)
1400
1000
600
200
1
3
5
7
9
Set Size
Q among O's (Target Absent)
Q among O's (Target Present)
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

Figure 21. Mean reaction time from correct trials with a 750 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

Reaction Time

750 msec Presentation Time

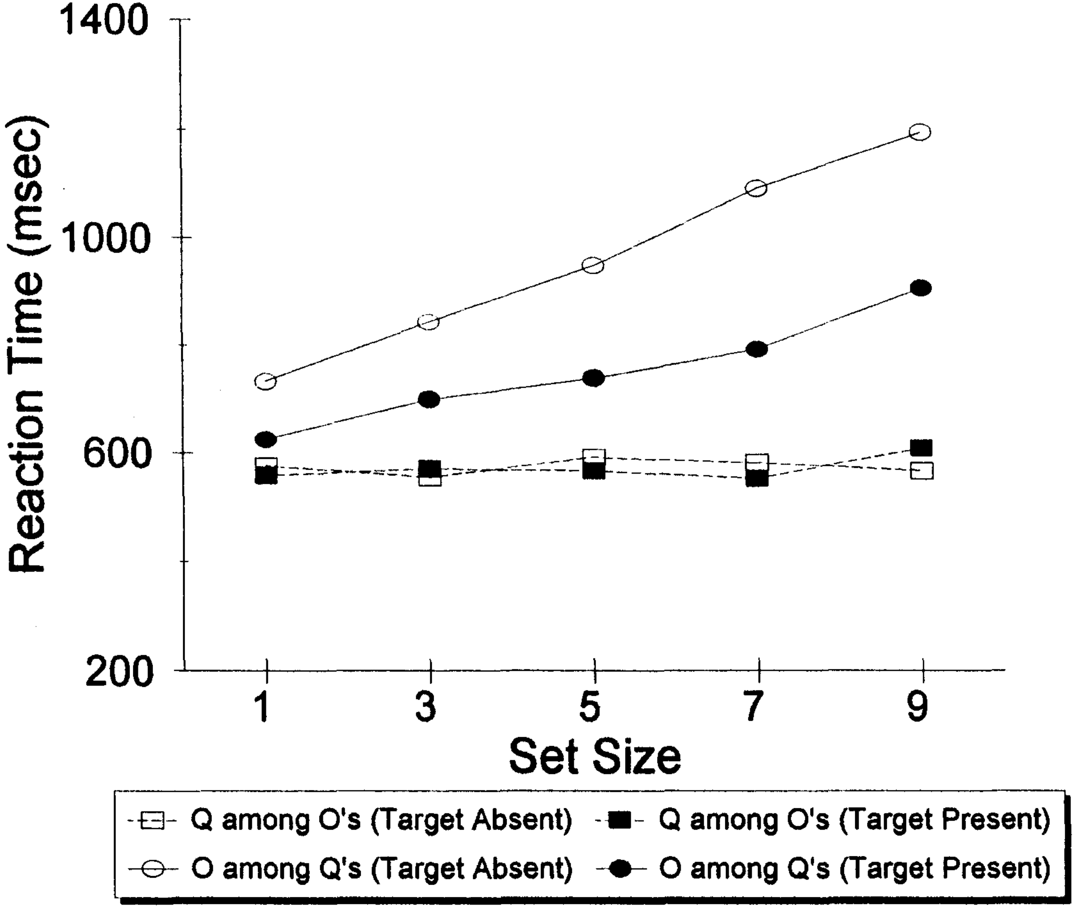


Figure Caption

Figure 22. Mean reaction time from correct trials with a 1000 msec presentation time as a function of the number of items in the display for both the Q among O's condition when the target was present and absent, and for the O among Q's condition where the target was present and absent.

Reaction Time

1000 msec Presentation Time

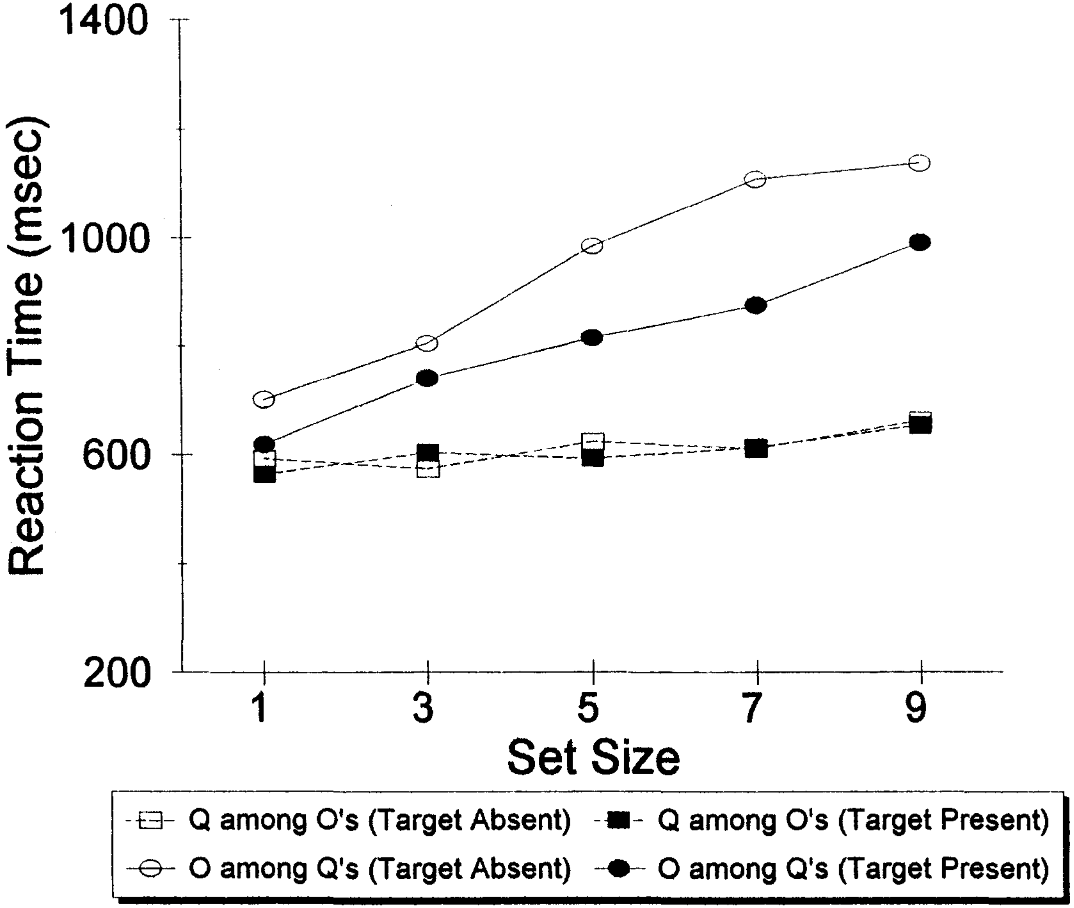


Figure Caption

<u>Figure 23</u>. Mean reaction time intercepts from correct trials by presentation time condition the Q among O's condition. Individual intercepts are presented for target present and target absent trials.

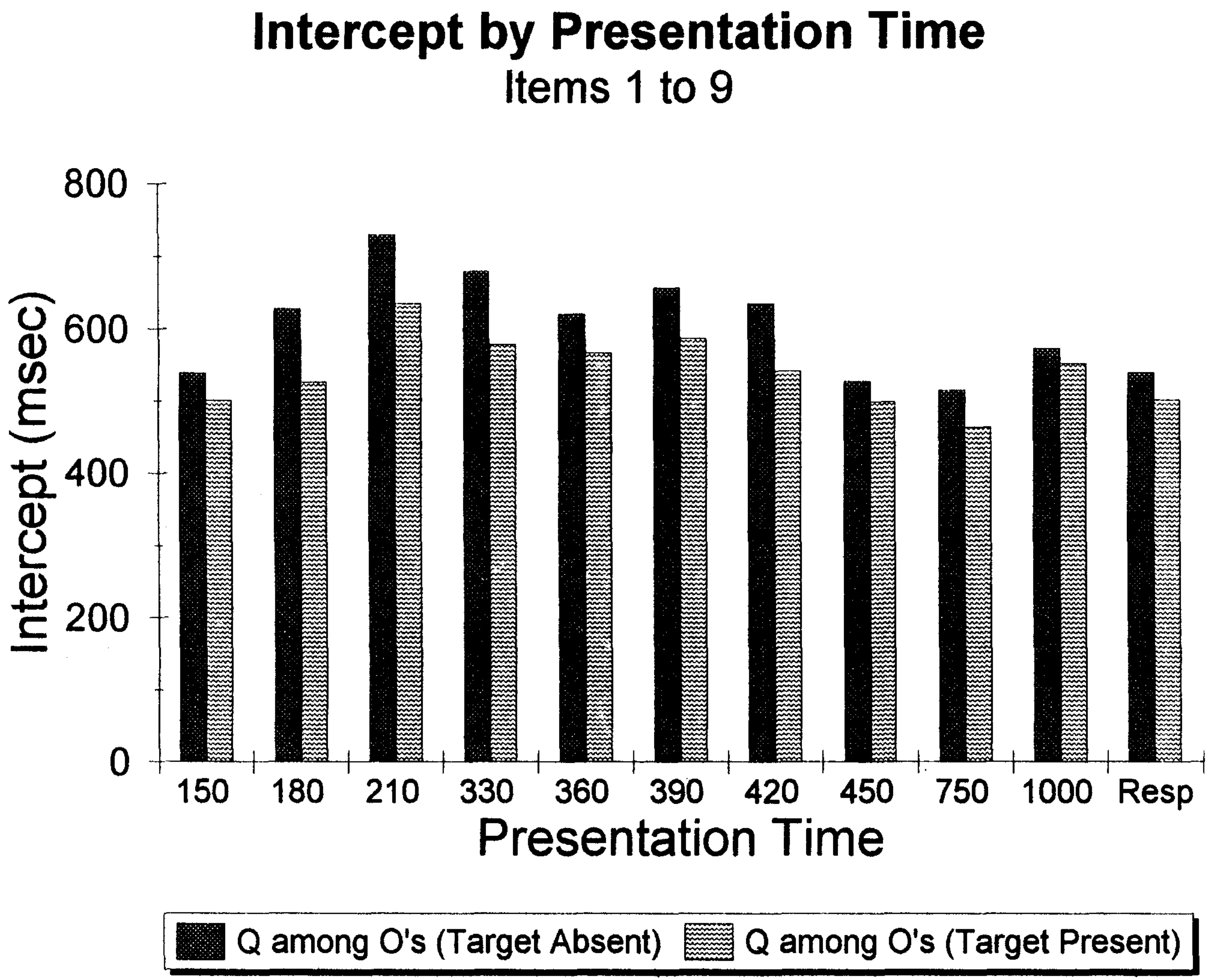

Intercept by Presentation Time
Items 1 to 9
Intercept (msec)
800
600
400
200
0
150
180
210
330
360
390
420
450
750
1000
Resp
Presentation Time
Q among O's (Target Absent)
Q among O's (Target Present)

Figure Caption

Figure 24. Mean slopes for target present and target absent trials for the O among Q's condition by presentation time.

Intercept by Presentation Time
Items 1 to 9

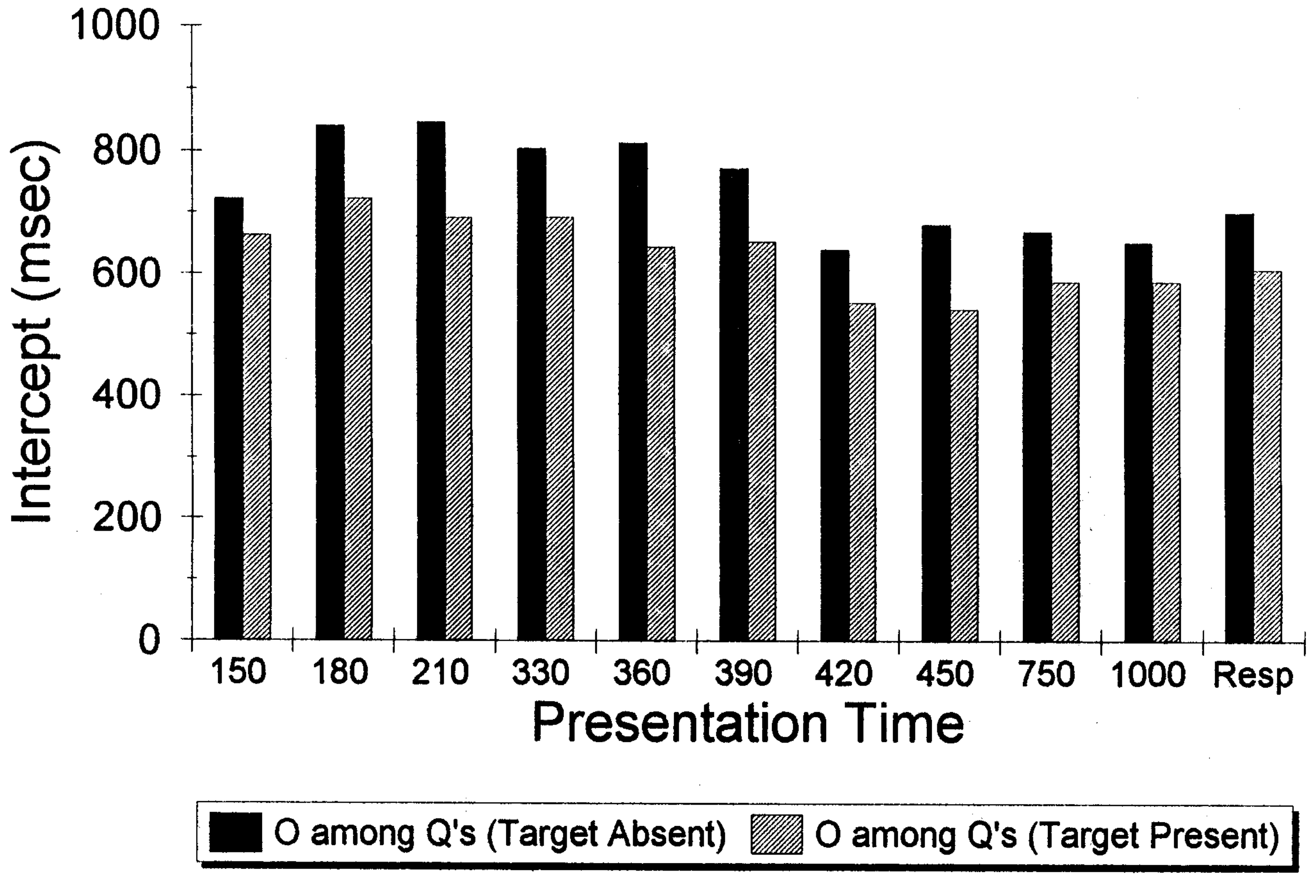


Figure Caption

<u>Figure 25</u>. Mean reaction time intercepts from correct trials by presentation time condition the O among Q's condition. Individual intercepts are presented for target present and target absent trials.

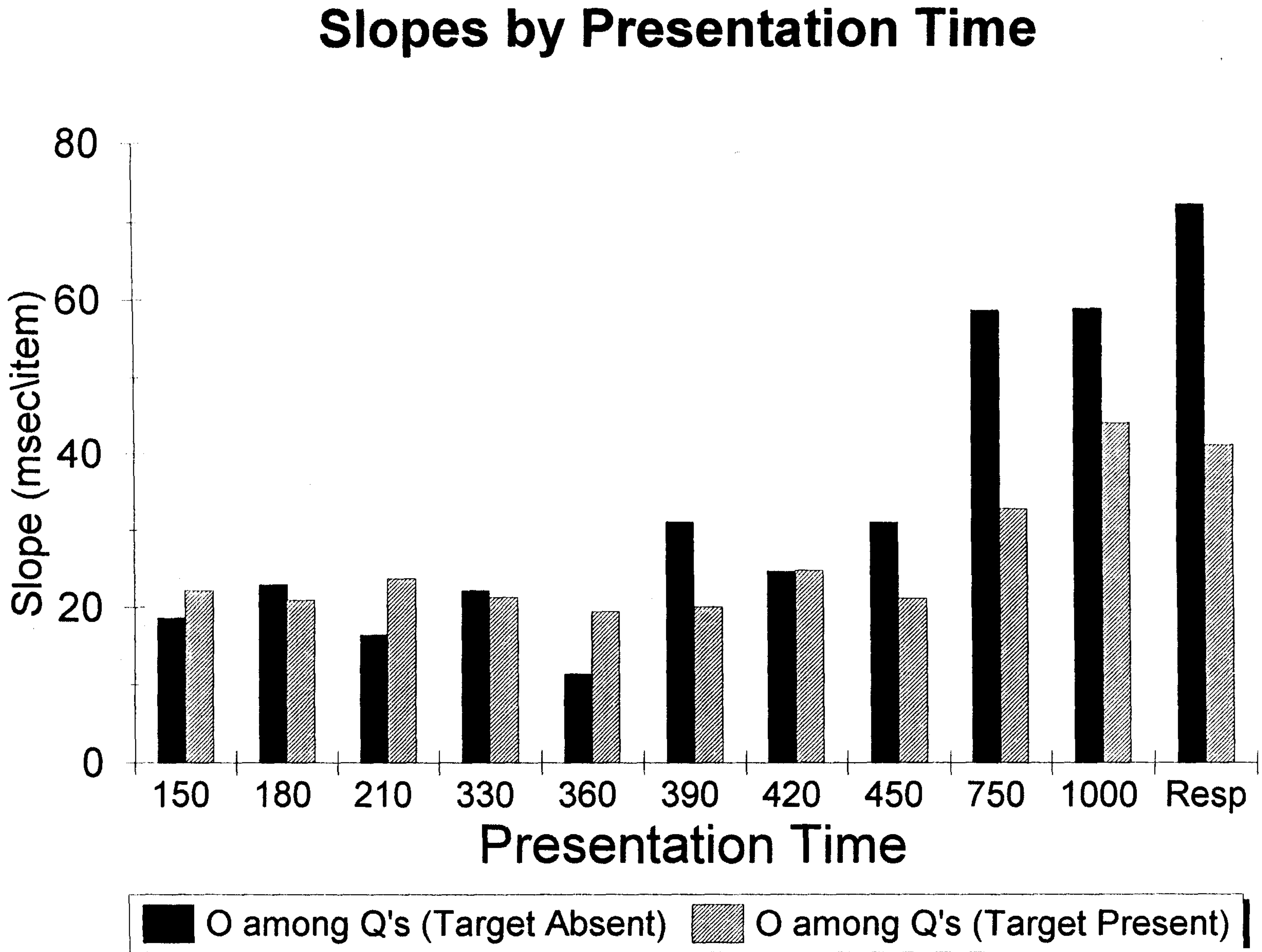

Slopes by Presentation Time
80
60
40
20
0
Slope (msec\item)
150
180
210
330
360
390
420
450
750
1000
Resp
Presentation Time
O among Q's (Target Absent)
O among Q's (Target Present)

Figure Caption

<u>Figure 26</u>. Scatter plot reaction time by set size slopes by presentation time for the O among Q's condition and target absent trials. For the response-terminated condition, the mean is substituted.

Scatterplot of Target Absent Slopes by Presentation Time

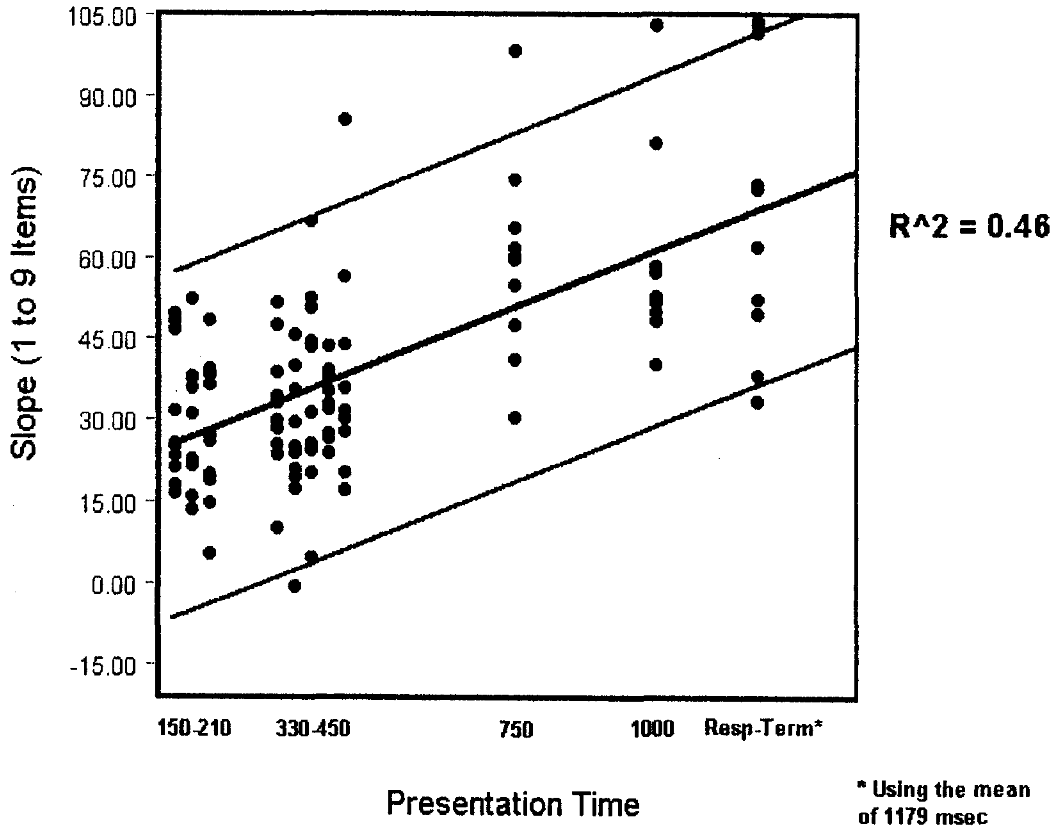


Figure Caption

Figure 27. Scatter plot reaction time by set size slopes by presentation time for the O among Q's condition and target present trials. For the response-terminated condition, the mean is substituted.

Scatterplot of Target Present Slopes by Presentation Time

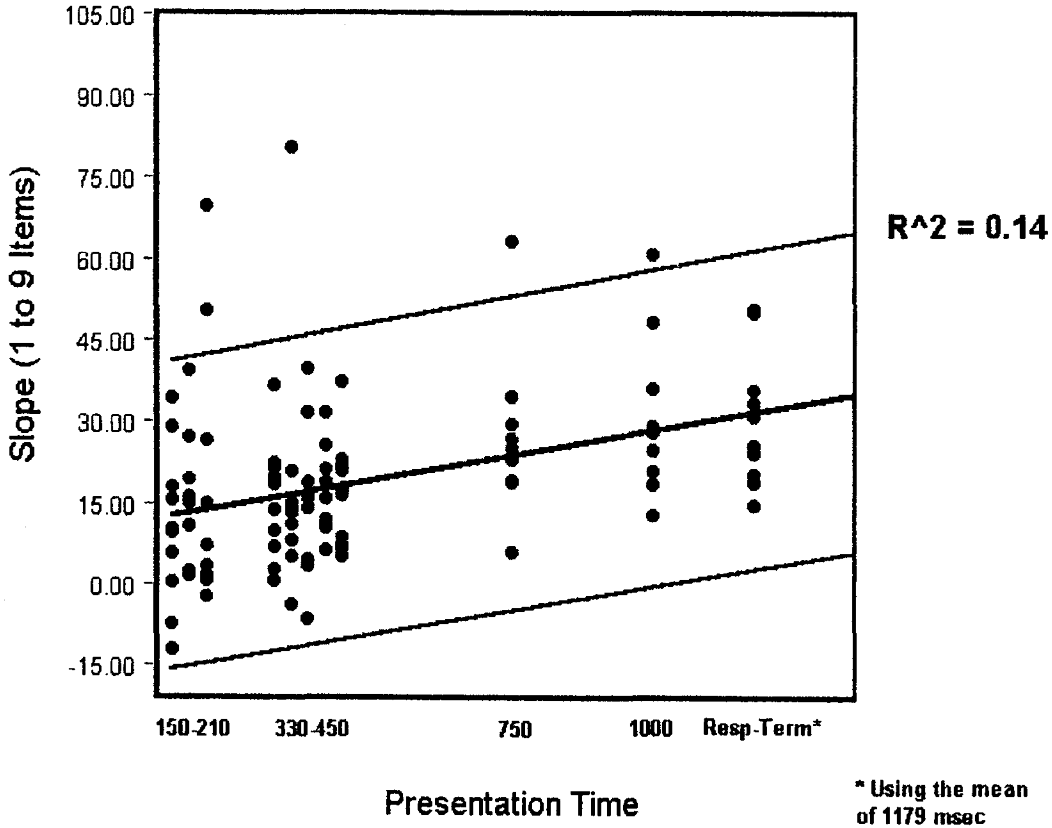


Figure Caption

Figure 28. Mean miss and false alarm rate for a set size of one item by presentation time for the O among Q's condition and target present trials.

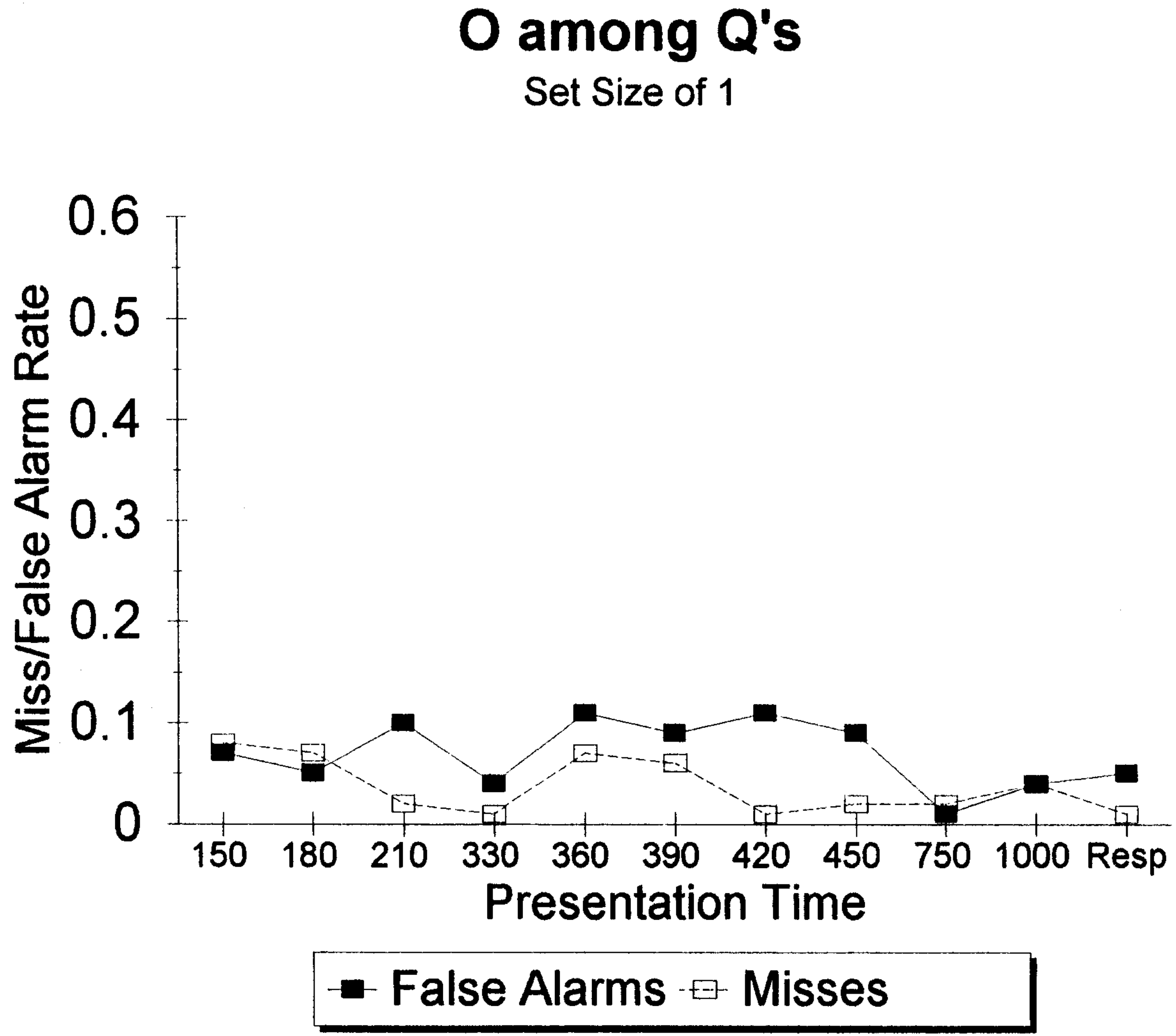

O among Q's
Set Size of 1
Miss/False Alarm Rate
0.6
0.5
0.4
0.3
0.2
0.1
0
150
180
210
330
360
390
420
450
750
1000
Resp
Presentation Time
False Alarms
Misses

Figure Caption

Figure 29. Mean miss and false alarm rate for a set size of three items by presentation time for the O among Q's condition and target present trials.

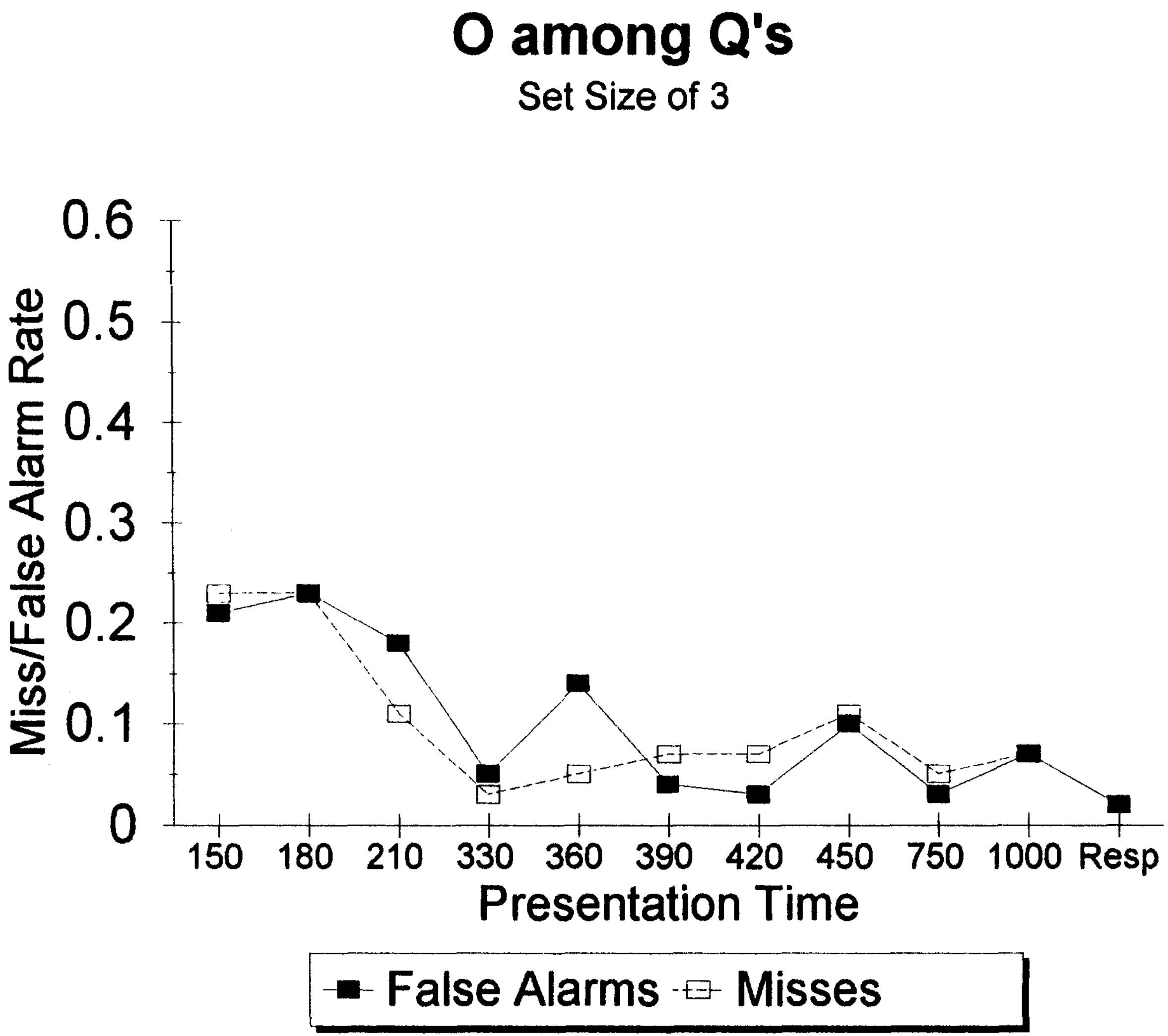
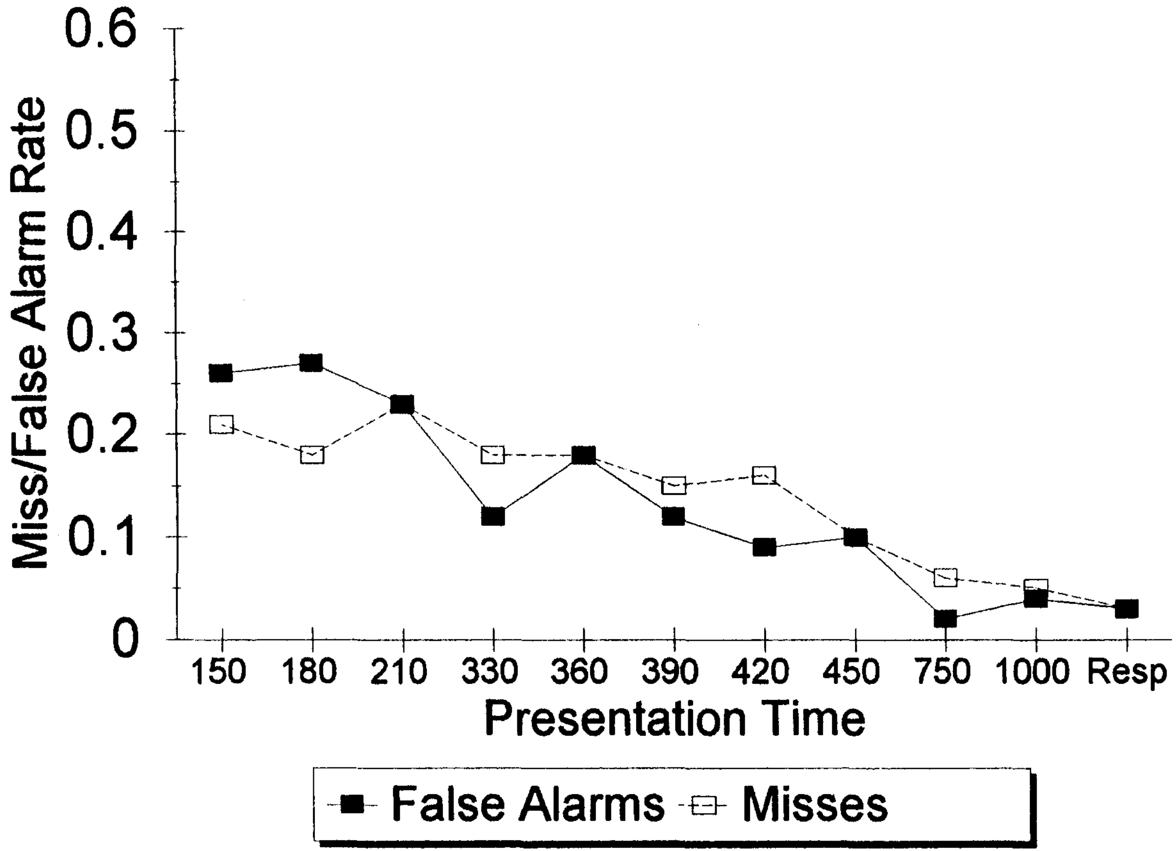

O among Q's
Set Size of 3
Miss/False Alarm Rate
0.6
0.5
0.4
0.3
0.2
0.1
0
150
180
210
330
360
390
420
450
750
1000
Resp
Presentation Time
False Alarms
Misses

Figure Caption

Figure 30. Mean miss and false alarm rate for a set size of five items by presentation time for the O among Q's condition and target present trials.

O among Q's

Set Size of 5



Figurc Caption

Figure 31. Mean miss and false alarm rate for a set size of seven items by presentation time for the O among Q's condition and target present trials.

O among Q's

Set Size of 7

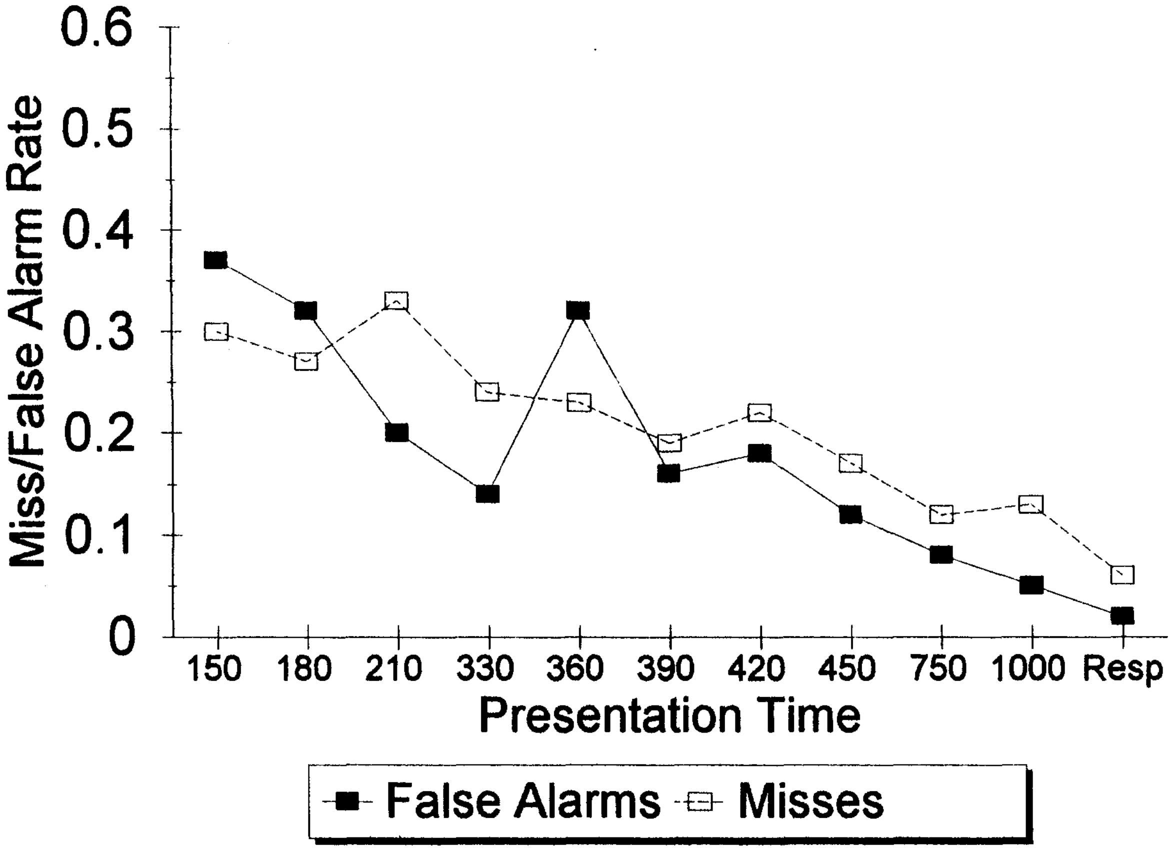


Figure Caption

Figure 32. Mean miss and false alarm rate for a set size of nine items by presentation time for the O among Q's condition and target present trials.

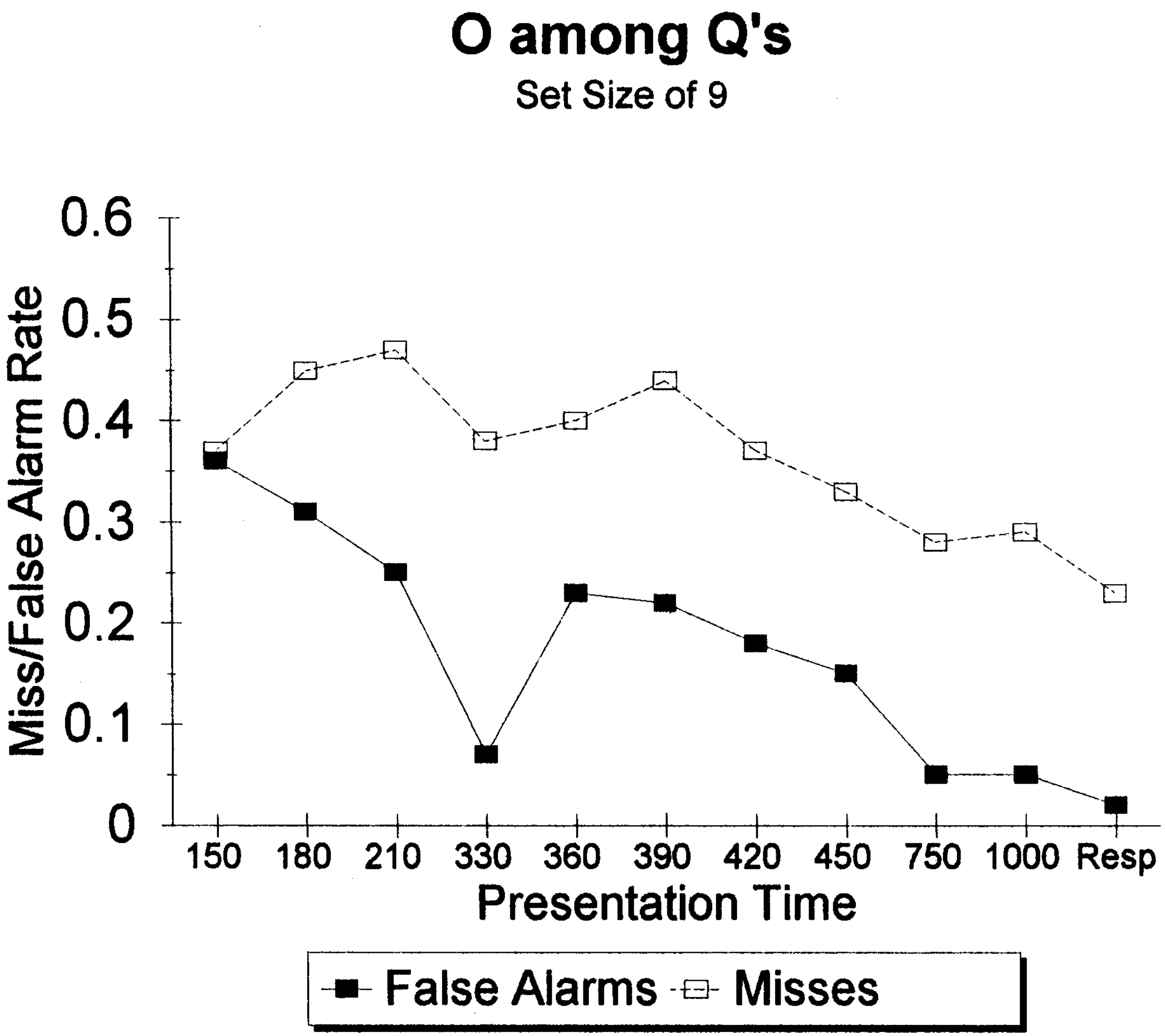

O among Q's
Set Size of 9
Miss/False Alarm Rate
0.6
0.5
0.4
0.3
0.2
0.1
0
150
180
210
330
360
390
420
450
750
1000
Resp
Presentation Time
False Alarms
Misses

Table 1. Reaction Time Slope Data for Target-present and Target-absent Trials by Condition.

Condition	Target	Slope (msec/item)	SD
Q among O's	Absent	72.09	35.53
	Present	41.03	16.52
O among Q's	Absent	11.21	10.54
	Present	8.52	6.03

Table 2. Reaction Time Slope Data (msec/item) from Set Size 1 to 9 Across All Presentation Times.

		Presentation Time (msec)										
Condition	Target	150	180	210	330	360	390	420	450	750	1000	Resp-Term
Q among O's	Absent	-1.6	3.9	-0.1	-0.1	-2.4	-3.1	6.3	6.2	6.3	0.4	11.2
	Present	10.3	6.2	6.9	6.9	-0.4	5.4	5.6	6.3	6.8	4.0	8.5
O among Q's	Absent	18.6	22.9	16.4	22.1	11.4	31.0	24.6	30.9	58.5	58.8	72.1
	Present	22.2	20.9	23.6	21.2	19.4	20.0	24.7	21.1	32.7	43.9	41.0

THESIS APPROVAL SHEET

The thesis submitted by Gavin S. Lew has been read and approved by the following committee:

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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the committee with reference to content and form.

The thesis is, therefore, accepted in partial fulfillment of the requirements for the degree of Master of Arts.

april 4, 1996
Date

Raymond H. Dye Jr
Director's Signature