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# CAPACITY REQUIREMENTS FOR AUTOMATIC RESPONDING IN AUDITION AND VISION: EFFECTS OF CUEING AND CONCURRENT MEMORY SEARCH

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CAPACITY REQUIREMENTS FOR AUTOMATIC RESPONDING

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AND CONCURRENT MEMORY SEARCH

A DISSERTATION

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# CHAPTER 1

## INTRODUCTION

Theories of attention and information processing may be characterized as two-stage (Broadbent, 1958; Norman, 1968) or dual-process (Kahneman, 1973; LaBerge, 1973; Posner & Snyder, 1975a) approaches. These theories emphasize the capacity-limited aspect of attention, compared with stages or processes which appear relatively unlimited in information processing capacity. Contemporary dual-process theories distinguish between controlled (effortful or conscious) processing and automatic (unconscious) processing (Hasher & Zacks, 1979; LaBerge, 1973, 1981; Logan, 1978a, 1979; Posner, 1978; Posner & Snyder, 1975b; Shiffrin & Schneider, 1977).

Posner (1978) and LaBerge (1981) identified three fundamental properties of automatic processing. Other characteristics have been reported, but may be subsumed under one of these three properties. Automatic processing is 1) unlimited in capacity (parallel in nature, unaffected by task load, highly efficient, used in well-developed skilled behaviors, does not require attention, nor interferes with concurrent cognitive activity) 2) unavoidable when enabled (not under subject control, not influenced by the intentions of the subject, hard to suppress, modify or ignore) and 3) does not involve awareness. In contrast, controlled processing is 1) limited in capacity (serial in nature, affected by task load, requiring slow and deliberate attentional processing) 2) under the direct control of the subject (easily set-up and modified) and 3) usually involves awareness (although Shiffrin and Schneider distinguish between controlled processes that are "veiled" from awareness and those that are "unveiled").

Shiffrin and Schneider (1977) posit two types of automatic processes: actional and informational. Actional processes contain routines for directing internal operations, whereas informational processes do not. Actional processes include automatic detection, described as an automatic attention-getting response (Schneider & Fisk, 1982), and automatic responding, which entails the performance of skilled motor behavior (e.g., automatic button-pressing to test stimuli). Recently, Shiffrin and Schneider (1984) have added a third classification of automatic processes - automatic classification, in which a category code is generated automatically for each target detected. All of these types of automatic processing provide efficient and accurate assessment of habitually encountered information.

Key components in the development of automatic processing include consistent mapping (CM) of responses to stimuli and extensive practice (Fisk & Schneider, 1983; Kristofferson, 1972b; Ross, 1970; Welford, 1968). Under CM conditions, stimulus items used as targets never appear as distractors across trials, and vice versa. As a function of practice, the subject forms a strong association between specific stimulus-response pairings and processing becomes automatic. These effects are typically observed in the function relating response latency to set size, which becomes relatively flat after CM practice (Egeth, Jonides, & Wall, 1972; Kristofferson, 1972a; Neisser, 1974). Under varied mapping (VM) conditions, each item from the stimulus pool is used as both a target and distractor over trials. This inconsistent situation precludes the mapping of specific responses to certain stimuli, regardless of the amount of practice, and the subject is forced to use a controlled mode of processing. A varied mapping procedure produces response latency curves that are linear across set size levels (Sternberg, 1966; Atkinson, Holmgren, & Juola, 1969), even after extensive practice (Burrows & Murdock, 1969; Kristofferson, 1972a).

The primary purpose of the present series of experiments was to examine carefully the unlimited capacity nature of automatic processing. Ryan (1983) has argued that the automatic/controlled processing dichotomy is based largely on this property. In particular, interest was in the effects of task load on automatic responding. A single-presentation memory search paradigm was used with reaction time (RT) as the main dependent measure. Following acquisition of automaticity in the memory search task (Experiment 1), the capacity requirements for automatic responding were investigated using two different approaches. In Experiment 2, subjects were provided a cue indicating the spatial position of a possible target on each trial. It was hypothesized that cueing would reduce the capacity demands for automatic performance. During the second phase of the experiment, the memory set was removed on each trial to investigate possible cueing effects associated with the presentation of the memory set. In Experiment 3, subjects performed between-modality dual memory search: one of the tasks was automated while the other was unpracticed. It was predicted that systematic increases in load between and within tasks would produce corresponding deficits in automatic responding. Confirmation of these hypotheses would suggest that the capacity requirements for automatic responding vary as a function of load. This outcome would support a distributional model of attention outlined in the general discussion section.

A second goal was to test the cross-modal generalizability of automatic/controlled processing theory. Shiffrin and Schneider (1977) consider their theory to be quite general, applying to both the auditory and visual modalities. These theorists argue that their model accounts for data obtained in auditory studies of selective attention. This issue was explored in the present study by comparing findings from auditory and visual memory search. In Experiment 1, one group of subjects developed automatic responding to auditory targets while a different group of subjects acquired automatic responding to visual targets. Cross-modal comparisons were conducted throughout the report. Converging evidence from both modalities should also help distinguish peripheral processes, which tend to be modality-specific, from the "unified central system" (Posner, 1978), which is relatively independent of modality input. The construction of auditory and visual versions of the single-presentation memory search paradigm also permits between-modality dual memory search in Experiment 3. The report continues with a review of the literature relevant to the goals of each experiment.

Developing Automatic Responding to Auditory and Visual Targets

Visual and auditory analogues of a single-presentation memory search paradigm were developed such that subjects were required to indicate the presence or absence of any memory set item during the test period on each trial. Memory and test set size were varied systematically and response latency was the principle dependent variable.

The visual memory search paradigm used in the present study was isomorphic to that used by Briggs and Johnsen (1973) and Schneider and Shiffrin (1977, Experiment 2). As many as 4 items were presented in a 4-character display which appeared during the test period. Letters served as targets and numbers as distractors.

Unfortunately, comparable paradigms in audition are rare in the attention and search literature. Moray and his colleagues (Moray, 1975; Ostry, Moray, & Marks, 1976; Underwood, 1974) have conducted extensive research on auditory target detection processes in dichotic listening situations. After extensive training under CM conditions, subjects are able to detect targets from two channels as well as from a single channel. In these experiments the dependent measure was detection accuracy. An investigation of automatic responding requires the measurement of reaction time as well.

Recently, Poltrock, Lansman and Hunt (1982) measured latency of response to auditory targets using a successive-presentation memory search paradigm. Their research represented an effort to generalize automatic/controlled processing theory to the auditory modality. Subjects were presented pairs of letters dichotically. Memory set size varied at 1 and 3 letters. One group of subjects conducted VM search while another group performed CM search. Each subject heard 9600 presentations: 1280 of these contained a target, requiring a key press response. The effect of memory set size diminished with practice for the CM group, but not for the VM group. Furthermore, when the assignment of target and distractor items were reversed for the CM group, performance was poorer than for VM subjects during their first session of CM search. These results were interpreted as evidence for automatic target detection in audition.

The paradigm devised by Poltrock et al. (1982) differs from the single-presentation task in at least two important respects. In Poltrock et *al.*'s task, responses were not given on negative presentations. This is a constraint of the successive-presentation design. Test frames are presented at a very rapid rate, in a sequence, precluding separate, overt responses to each frame. In the single-presentation task, responses are required for both positive and negative trials.

In addition, test set size is not easily varied in the paradigm used by Poltrock et *al.* Test set size might be altered using one versus two input channels, with single items presented on each channel, but does not permit variations in set size higher than two. In regard to this point, Poltrock et *al.* state that "frame size has no exact counterpart in auditory detection" (p. 38). Shiffrin (1976) has made a similar comment. Certainly, the simultaneous presentation of separate acoustical signals in the test environment corresponds with simultaneous exposure of visual items during the test frame. However, when multiple acoustical signals are presented concurrently, interaction effects are produced, making discrimination between component signals difficult. This problem does not arise with visual signals that are separated spatially.

Charleston and Boyer (1983) and Boyer and Charleston (1983) have provided evidence of the feasibility of an auditory version of the single-presentation memory search paradigm. Pure tones served as stimuli. One, two or four tones were presented simultaneously during the memory and test periods. Each subject was seated in a sound-attenuating chamber facing a rectangular array of four speakers. Overtone effects were minimized by presenting each tone from a separate speaker location and selecting frequencies that did not constitute harmonic multiples. Under these conditions, the tones were discriminable. In the Charleston and Boyer study, the best performing subject received 4680 trials of practice in CM auditory search. The best performing subject in Boyer and Charleston's experiment was given 4320 trials of training in CM memory search. Although low error rates indicated the feasibility of the paradigm, no evidence for automatic processing was obtained across all load levels in either study.

The use of pure tones as stimuli in these two studies may have hindered the development of automaticity. Subjects did not possess semantic labels for the pure tones prior to the investigation, whereas subjects in related visual studies have such labels for letters and digits. This reasoning led Charleston, Mergler and Boyer (1984, Experiment 1) to conduct another experiment using the Charleston and Boyer paradigm with vowel sounds as stimuli. Vowels have some pre-experimental associations (they are ubiquitous in everyday speech) while allowing precise control over temporal parameters of the stimuli. After 5520 trials of CM practice, again no evidence for automatic processing was found.

In a subsequent investigation by Boyer, Charleston and Mergler (1984), data were obtained that indicated automatic detection of auditory targets. However, a strong categorical distinction between target and distractor ensembles was utilized. Low frequency pure tones were used as targets and high frequency pure tones as distractors. The effect of the categorical distinction was so marked that RT curves were statistically flat over set size levels during the first two sessions of practice.

The auditory memory search paradigm used in the present report was similar to the one originally developed by Charleston and Boyer. A categorical distinction was established between target and distractor pure tones. However, this categorical difference was less dramatic than in the Boyer, Charleston and Mergler study. Consequently, the task was more difficult. It was expected that automatic responding would develop as a function of extensive CM training.

## Effects of Cueing on Automatic Responding

That cued items are processed more speedily than non-cued items in search tasks is a robust finding (LaBerge, VanGelder & Yellot, 1970; Posner & Snyder, 1975a). For instance, Smith and Blaha (1969) reported that cueing the location of a signal in a visual field altered d' measures. Apparently, cueing directs attention to a sub-field of the test environment, reducing interference from inputs outside the domain and enhancing perceptual sensitivity.

Processes which have become automatic are purportedly unaffected by attentionally-controlled processing, and consequently cueing. Indeed, one important property of automaticity identified earlier is its unavoidable nature (i.e., automatic processes are not under direct subject control).

A commonly-cited example is the Stroop phenomenon (Stroop, 1935). In the Stroop task, both the physical and semantic codes associated with each stimulus item are encoded automatically. When these dimensions are incongruous, interference in reporting only one of these codes is observed.

In the cueing literature, however, some experiments have demonstrated that cueing does influence automatic processing. Kahneman and Henik (1979) had subjects perform a Stroop color-naming task. During each trial, the visual display contained a square and circle, both within the central fixation field. Subjects were cued to search the circle first, naming the ink color of the printed word within. When conflicting physical and semantic codes appeared in the same location (e.g., the printed word "red" in blue ink within the circle), greater interference was observed than when the conflicting codes were presented from different spatial locations (e.g., the printed word "red" in black ink within the circle and a blue color within the adjacent square). These results are inconsistent with automaticity theory, which posits that the two dimensions are encoded automatically, in parallel, regardless of spatial location within the central fixation area. Accordingly, equal amounts of interference should have been produced under each condition.

A similar cueing procedure was utilized by Francolini and Egeth (1980). Subjects were instructed to count the number of items presented in red ink among items appearing in black ink. All items were arranged in a circular pattern. The color red was cued. Stroop interference was obtained when subjects counted two red "3"s among black "A"s in the display. Counting two red "A"s against black "3"s created no interference.

Deficits would be expected in both conditions according to theoretical accounts of early-stage processing.

These results can be explained by feature integration theory (Treisman & Gelade, 1980). The theory posits that individual features are processed in parallel at an early stage of analysis, but must be conjoined by focal attention during this stage to form percepts or objects. During environmental search, attention precedes processing of Stroop items because of information provided by the cue. Focal attention conjoins features in the cued location (producing interference if the cues conflict), while features in non-cued locations do not unitize. It seems, then, that benefits from cueing involve both automatic activation and conscious attention (Posner & Snyder, 1975a).

Automatic/controlled processing theory does imply that controlled processing can help automatic performance if the two processes are independent and the slowest automatic process has a shorter duration than the fastest controlled process (Schneider & Fisk, 1982). However, automatic responding would not seem to satisfy these criteria. When an entire input-output processing sequence becomes automatic, a direct link between automatic detection and automatic response execution should be formed, bypassing the central capacity system. Shiffrin and Schneider's (1977) model (p. 162) allows for automatic actional sequences which are not routed through the controlled processing system. Also, Schneider and Fisk (1982) state that "to the extent that automatic processes activate other automatic processes, there is no fixed upper bound to how complex a process can be carried out without attention" (p. 275). Automatic responding develops on the basis of a cascade of component automatic processes. Indeed, this is perhaps the characterization of automatism held by the layperson.

In memory search studies, CM foils (targets) that appear on the to-be-ignored diagonal of a visual display are detected automatically (Shiffrin & Schneider, 1977). Also, Schneider and Fisk (1982) found that under dual task conditions, in which CM and VM search were performed concurrently, automatic detection of CM targets declined compared with single task performance. These researchers attributed the deficit to subjects' attempts to help automatic target detection by "wasting" attentionally-controlled resources on the task. The deficits in performance disappeared when this strategy was abandoned. These studies suggest that information provided by a cue, which directs attentionally-controlled mechanisms, should not benefit automatic responding to targets.

In summary, the effects of cueing on automatic processing in memory search tasks are not clear. To help clarify this issue, the second experiment of this report provided subjects a cue indicating the spatial position of a possible target prior to each trial. Responding was automatic; therefore information provided by the cue should not benefit performance. It was hypothesized, however, that automatic responding does require small degrees of central capacity, and that the cue would noticeably reduce the amount of resources needed to perform the automated task.

## Effects of Dual Task Manipulations on Automatic Responding

The ability to do two things simultaneously is at the heart of the notion of automaticity (LaBerge, 1981). Dual task experiments have been used to measure cognitive capacity since the beginning of modern psychology

(Wundt, 1912) and some contemporary theorists believe that an understanding of the nature of dual task capacity and its concomitant patterns of interference remain key elements in attempts to develop a theory of attention (Posner, 1982).

The ability to time-share between tasks also has important practical applications to the study of man-machine interactions (e.g., the design of cockpits or simulators). Findings from dual task studies allow researchers to determine the optimal allocation of functions across tasks in human engineering situations.

Generally, dual task studies demonstrate that processing information from a primary task causes a delay or loss of information from a concurrent secondary task. Models of dual task interference identify the source of interference as a single channel (Welford, 1981), or a central processor (Posner, 1978), or a bottleneck (Pashler, 1984), or a limited pool of central resources for all cognitive processing (Kahneman, 1973), or limitations in multiple resources used for different cognitive operations (Wickens, 1980). The common feature of all these models is a stage of analysis that permits only sequential processing, or parallel processing that strains the resources available, causing a deficit in dual task performance.

A primary attribute of automatic processing is that it can operate in parallel with other processes without resource cost (Shiffrin & Schneider, 1984). Costs may be observed when the attentional system is utilized, in which case interference with another controlled process may result if their joint demands for resources exceed the limits of the system. Automatic responding circumvents the central attention mechanism, according to automatic/controlled processing theory. Dual task experiments may provide a more powerful test of this hypothesis than single task studies (Schneider & Fisk, 1982). Because automatic responding is an unlimited capacity and parallel process, no performance deficits would be expected under dual task manipulations (Logan, 1978).

There is evidence that after prolonged CM practice subjects can perform two tasks almost as well as one (Allport, 1980). In order to be confident that one or both tasks do not require processing capacity, at least two conditions must be met: 1) dual task performance must be comparable to single task baseline measures (Kantowitz, 1974; Ogden, Martin & Paap, 1980) and 2) the possibility of attention-switching or time-sharing between tasks must be ruled out (LaBerge, 1981). To meet the latter criteria in studies of automatic responding, it is necessary to measure both RT and accuracy, because these are known to trade off in a very sensitive manner (Banks & Atkinson, 1974; Parchella & Pew, 1968). The present concurrent memory search experiment attempted to make untenable the possibility of time-sharing between tasks by using discrete tasks (i.e., response latency was measured as well as accuracy), time-locking the presentation of test periods between tasks, and requiring an overt response in each task (not merely measuring accuracy of post-trial reports).

The following review of the relevant dual task literature will be restricted to studies in which processing in at least one of the tasks was automatic (for a general overview of dual task techniques see Posner, 1978). In most dual task paradigms, separate tasks are performed within the same modality. Dichotic listening experiments, in which information must be processed from one or two channels simultaneously, comprise the bulk of within-modality dual task studies in audition. It was pointed out earlier that evidence from dichotic listening experiments suggests that two targets can be detected as well as one after lengthy CM practice (Moray, 1975). However, there is much controversy as to whether time-sharing between channels can be eliminated as a possible explanation of the data. In addition, these studies usually measure detection accuracy, not response latency. Thus, the effects of dual tasks on automatic responding cannot be inferred.

A within-modality dual task experiment in vision was recently conducted by Schneider and Fisk (1982). A multiple-frame visual memory search paradigm was used. Following acquisition of automatic detection for CM targets, subjects performed CM automatic detection on one diagonal and VM controlled search on the other diagonal of 4-character displays. No more than one target appeared on each trial. A response was required for targets presented on either diagonal. Detection accuracy was the dependent variable. Findings indicated that accuracy levels under dual search were comparable to those obtained under single search when subjects were instructed to expend maximum effort in controlled VM search. These results were interpreted as evidence that controlled and automatic processing could be combined without resource cost.

In Experiment 2a of Schneider and Fisk's report, concurrent CM detection and VM search did produce interference. These authors attributed the performance deficit to subjects "wasting" attentional resources searching for CM targets. The results also may have been due to procedural instructions given to subjects and the design of the character display. Attending to only one diagonal (VM) while essentially ignoring the other

(CM) may be problematic when the configuration of elements contained in the display subtend no more than 2 deg of visual angle. This is an important concern when devising within-modality dual task paradigms which explore the parameters of automatic processing. Subjects must be able to encode all inputs in parallel while focusing attention on only a subset of the stimulus field.

It should also be noted that the design of Schneider and Fisk's experiment deviates from conventional dual task paradigms in that two separate targets, each requiring a different response, never appeared on any trial. Schneider and Fisk addressed this point, stating that interest was in automatic detection, not automatic responding, and that dual task interference does occur when two simultaneous targets are presented. However, none of the studies cited in support of their statement tested automatic responding, such that RT was observed for two different tasks and responding to targets in at least one task was automatic (Duncan, 1980; Moray, 1975; Schneider & Shiffrin, 1977, Experiment 3). If the automatic process is detection, then the presentation of two simultaneous targets activates only one call for attention. Hence, one of the targets passes unnoticed. In automatic responding, the attentional mechanism is circumvented. In this case, responding to two targets should not produce dual task interference.

A between-modality dual task paradigm requiring overt responses to two simultaneous targets should help resolve some of these difficulties by effectively eliminating stimulus competition. Response competition might persist, but using disparate response modalities would minimize response interference between tasks. McLeod (1977) has argued that compatibility of input-output codes are critical in dual task studies. If compatible stimulus-response loops are utilized (e.g., vocal responses to auditory stimuli) response competition diminishes. Although this reduction can be quite substantial (McLeod, 1977), some residual amount of interference is often observed (Posner & Cohen, 1980). Interference would be further reduced if the input-output modes for each task drew upon different pools of resources (Wickens, 1980).

Research suggests that the locus of dual task interference is not early stage processing (Posner & Bois, 1971; Shaffer & LaBerge, 1979), or response execution, but probably the decision or response selection stage (Duncan, 1980; Ostry, Moray & Marks, 1976; Pashler, 1984). Recall that none of these studies trained subjects in automatic target responding. If responding is automatic, the response selection stage should be bypassed. Even if some small degree of interference was observed in an automated task, the amount should remain constant across load levels.

These considerations led Charleston, Mergler & Boyer (1984, Experiment 2) to develop a 2-response between-modality dual task paradigm with both RT and accuracy as the dependent variables. First, subjects received 5520 trials of CM training in auditory search. A single vowel was presented during the memory period and 1, 2 or 3 vowels were heard simultaneously during the test period. During the final session of practice, the latency function accelerated substantially over test set sizes 1 and 2, but was flat across set sizes 2 and 3. Thus, responding was not completely automatic across all set size levels. During the dual task phase, subjects performed concurrently the auditory search task and a similar visual search task in which a single digit appeared during the memory and test periods. Vocal responses were given for auditory stimuli and manual responses for visual stimuli to reduce stimulus-response competition. The auditory and visual trials overlapped completely to control for attention-switching between tasks.

Dual search resulted in significant performance deficits compared with single task measures. However, performance curves in both tasks remained relatively flat across test set sizes 2 and 3 in the auditory task. It was concluded that even if a relatively automatic process does not require greater degrees of central capacity with increases in load, complex interference effects associated with enabling and perhaps monitoring operations do occur.

Experiment 3 of the present series represented an improvement upon the Charleston et al. dual search paradigm. First, subjects acquired automatic responding prior to the dual task phase. This was a consequence of a categorical distinction imposed between CM target and distractor items in the present study. Also, memory set size, as well as test set size, were varied, allowing a comparison between memory and environmental search. In addition, load levels changed systematically in both the automated secondary task and the unpracticed primary task. These manipulations provided a more sensitive measure of the capacity demands associated with automatic responding than was possible in the Charleston et al. study. Finally, cross-modal comparisons were conducted between automatic auditory and visual target responding under dual task conditions.

# CHAPTER II

## EXPERIMENT 1

Subjects received extensive practice in CM memory search during Experiment 1 to allow the development of automatic target responding. This permitted a systematic investigation of the capacity requirements for automatic responding in Experiments 2 and 3. A single-presentation memory search paradigm was used. One group of subjects received training in auditory memory search while another group of subjects received practice in visual memory search. To facilitate the acquisition of automatic target responding, a categorical distinction between targets and distractors was established. In the visual memory search task, letters were used as targets and digits as distractors. In the auditory task, targets consisted of low frequency pure tones and distractors included high frequency pure tones.

### Method

#### Subjects

Eight undergraduate volunteers were tested in Experiment 1 and received course credit for their participation. All subjects had 20/20 vision, normal hearing (20 dB hearing threshold level or below at all test frequencies) and were right-handed. Two male and two female subjects were randomly assigned to perform auditory memory search and two male and two female subjects conducted visual memory search.

Stimuli

Auditory. Auditory stimuli consisted of pure tones and white noise. A categorical distinction between targets and distractors was used to facilitate the development of automatic target responding. The memory ensemble included low frequency tones at 210 Hz, 260 Hz, 310 Hz and 360 Hz. The ensemble of high frequency distractor tones included 590 Hz, 690 Hz, 830 Hz, 990 Hz and 1175 Hz. The sound pressure level (SPLs) of auditory stimuli were measured from the position of the center of the subject's head using a Quest 215 sound level meter. Each tone was produced at approximately 61 dB SPL and the white noise was presented at 50 dB SPL. SPL measurements for the pure tones were compared to normative data (Fletcher & Munson, 1933) and were found to be within ±5 dB of the equiloudness contour. This finding confirmed subjects' reports that the tones sounded subjectively equal in loudness. Simultaneous presentation of multiple tones produces some degree of tonal interaction. As the amount of interaction increases, discrimination between tones becomes more difficult. Tonal interaction effects were minimized in the present study by selecting frequencies that did not constitute harmonic multiples of each other (which reduces overtone effects) and separating tones spatially (i.e., each tone was presented from a separate speaker) (Broadbent, 1954).

The auditory trial sequence is illustrated in Figure 1a. It consisted of 1) the memory period, during which 1, 2 or 4 tones were presented for 250 ms 2) a white noise mask from all four speakers for 750 ms 3) the test period, during which 1, 2 or 4 tones were presented for 250 ms and 4) a white noise mask from all four speakers for 1.75 s. Tones were always presented simultaneously, each from a separate and random speaker position. Intertrial intervals (ITIs) were 2 s in duration. Thus, the total duration of each trial was 5 s.

Visual. Visual stimuli included printed letters, digits, random dot masks and pattern masks. As with auditory stimuli, targets and distractors were categorically distinct to accelerate the acquisition of automatic responding. The memory ensemble consisted of the uppercase letters A, E, H and M; distractors included the digits 0, 2, 3, 5 and 9. Physical distinctiveness between the target and distractor categories was enhanced by selecting angular letters that were either symmetric or opened to the right, and digits having curvature that were either symmetric or opened to the left.

The format for visual trials is depicted in Figure 1b and is isomorphic in all relevant task parameters to the format for auditory trials. The visual trial sequence consisted of 1) the memory period, during which 1, 2 or 4 letters appeared simultaneously in a linear manner in the center of the screen for 250 ms 2) a pattern mask for 750 ms 3) the test period, during which 4 visual items (a single letter, digits or random dot masks) appeared in a square configuration centered around a fixation point for 250 ms and 4) a pattern mask for 1.75 s. ITIs were 2 s. During the test period, a random dot mask appeared in any position not occupied by a letter or digit.

Each letter and digit subtended .43 deg of visual angle in width (.5 cm on the projection screen) and .61 deg of visual angle in height

(.7 cm on the screen). Random dot masks were composed of ten randomly placed dots within a rectangular form slightly larger than the size of a single letter or digit. All stimuli presented during the memory and test periods subtended no more than 1.74 deg of visual angle (2 cm on the screen), falling easily within the foveal field of the subject. Pattern masks were composed of letter fragments positioned at all angles and had a density of 40%. The square pattern masks subtended 3 deg of visual angle (3.5 cm on the screen), effectively masking all positions during the memory and test periods. Letters, digits, random dot masks and pattern masks appeared as black figure on white ground. Luminance was measured from the surface of the screen using a GE 214 light meter with 10-15% variability in accuracy. Memory and test period slides were presented at approximately 70-75 lumens and pattern masks were shown at approximately 45 lumens. Ambient luminance was roughly seven lumens when visual stimuli were not presented.

Design

The design and procedure for auditory and visual trials were identical unless otherwise stated. A completely within-subjects repeated measures design was used. Two independent variables were manipulated: memory/test set size and trial type.

Memory set size (the number of items presented during the memory period, denoted *M*) and test set size (the number of items presented during the test period, denoted *T*) were varied at the following levels: *M*=1 *T*=1; *M*=1 *T*=2; *M*=1 *T*=4; *M*=2 *T*=1; *M*=4 *T*=1. Systematic variations in memory set size, while holding test set size constant at *T*=1, constituted memory search. Auditory and visual search (herafter referred to as modality search) involved systematic changes in test set size while memory set size remained at $\underline{M}$=1.

The trial type variable consisted of positive and negative trials. On positive trials, one of the items presented during the memory period was presented during the test period. On negative trials, none of the memory set items matched any presented during the test period.

The dependent variables were RT and error rate. RT was measured from the onset of the test period until a response was given by the subject. Error rate represented the percent of incorrect responses for a block of trials.

Three blocks of 64 trials were constructed for each of the five memory/test set size conditions. Half of the trials in each block were positive and half were negative. Each of the four memory ensemble elements or their combinations appeared equally often during the memory and test periods in each block. The spatial position of targets during test periods varied randomly with the constraint that each target appear with equal frequency in each of the four possible positions. Distractors for test periods were chosen at random and without replacement for each trial. All trials within a block were presented in random order such that positive and negative trials were presented equally often in subblocks of eight trials.

Subjects received 15 sessions of practice on consecutive days of the week. During each session, five blocks of trials representing each of the five memory/test set size conditions, and an additional sixth block, were given. The three different blocks for each memory/test set size condition were administered repeatedly, without replacement, across sessions. The sixth block of trials was selected at random such that each of the five memory/test set sizes was given three times over the 15 sessions. Thus, each subject received 1152 trials of practice at each memory/test set size, totalling 5760 trials for the entire experiment. Each block of trials was less than 5.5 minutes in duration. Blocks were separated by brief rest periods so that each session lasted approximately 1 hour.

Procedure

Subjects were run individually. The nature of the experimental task was explained, but the purpose of the experiment was not conveyed. Subjects were instructed to indicate the presence or absence of any memory set items appearing during the test period for each trial. For the auditory task, the verbal response "yes" was given for positive trials and the verbal response "no" was given for negative trials. Manual responses were required for the visual task. Positive responses were indicated by pressing a button with the middle finger of the right hand; negative responses were signalled by pressing a different button with the index finger of the same hand. Subjects were encouraged to respond quickly and accurately throughout the experiment. Verbal feedback was given for incorrect responses. For each block of trials, the first two trials were considered practice. These data were not included in any of the statistical analyses below. Prior to the first session, subjects received 8 practice trials at $\underline{M}$=1 $\underline{T}$=1.

Apparatus

Auditory stimuli were presented using a Teac 3340 4-channel tape recorder with simul-sync. The signal on each channel of the tape recorder was transmitted to a separate speaker using 2 stereo amplifiers. Recording and playback speed were set at 7.5 ips. Four speakers 20 cm in diameter, each contained in a separate enclosure, were mounted in a rectangular pattern to the inner wall of a sound attenuation booth. The horizontal distance between the center of the speakers was .7 m, the vertical distance was .6 m. The spatial dimensions of the booth were 1.11 m X 1.11 m X 2 m. The subject was seated in the booth facing the speaker array such that the subject's head was centered in the middle of the rectangular configuration of speakers. The distance between the subject's ears and the vertical plane of the speaker battery was approximately .5 m. The acoustical signal(s) occurring at the onset of each auditory trial activated a sound actuated relay connected to a Gerbrands G1271 digital millisecond clock/counter accurate to within $\pm$ 1 ms. Verbal responses given by the subject were monitored using a Sure 5755 omnidirectional microphone connected to a Gerbrands G1341 voice operated relay which stopped the clock.

For constructing auditory trials, a Lafayette 15010 tone generator, a B & K E-3108 sine/square wave generator, a Lafayette 1432(15013) white noise simulator and 2 stereo cassette decks were used to record pure tones and white noise onto separate tracks of the 4-channel tape recorder. The sequence and duration of stimuli recorded onto the tape machine were controlled using a series of contact closures connected to a Gerbrands 300-6T 6-channel digital millisecond timer and a Gerbrands G1159 tachistoscope logic interface.

Visual stimuli were front-projected onto a 5.5 cm X 5.5 cm white screen using a Gerbrands G1177 3-field projection tachistoscope with timer. The electronic shutters had a rise time of 2 ms and a fall time of 2 ms or less. The projection screen was fixed over an opening in the wall of the sound attenuation booth on which the speaker array was mounted. The screen was positioned approximately in the center of the speaker configuration and at the eye level of the subject. The distance between the eyes of the subject and the screen was approximately 66 cm. A Lafayette 54030 digital stop clock accurate to within $\pm$ 1 ms was activated at the onset of each trial by the Gerbrands tachistoscope logic. Manual responses given by the subject triggered a Gerbrands G1360 reaction time apparatus which stopped the clock and indicated whether the response was positive or negative. The subject responded by pressing one of two small momentary push buttons secured to an armboard attached to the right armrest of the subject's chair. The buttons were positioned 2.25 cm apart, as measured from the center of each button.

## Results and Discussion

Mean reaction time and error rate were calculated for each condition for each subject. Data were analyzed using a repeated measures analysis of variance (ANOVA). Factors included trial type, memory/test set size and practice (Session 1 vs. Session 15). Data for Session 1 were averaged across the first two sessions of the experiment to provide a stable estimate of mean performance. Similarly, data for Session 15 were averaged over the last two sessions of practice. All three-way ANOVAs presented below were 2 (trial type) X 5 (set size) X 2 (sessions). RT for both auditory and visual memory search are presented in Figure 2. Error rates appear in Table 1. Summary ANOVA tables for all analyses in Experiment 1 are included in Appendix A.

### Auditory Memory Search Results

RT scores were analyzed using a three-way ANOVA. No significant difference in RT was found between positive and negative trials,

$F$ (1, 3)=.04, $p$>.05, $MSe$=6909. Although RT decreased over all set size levels from Session 1 to Session 15, this difference was not significant, $F$ (1, 3)=5.37, $p$>.05, $MSe$=77784. RT varied significantly over set size levels, $F$ (4, 12)=3.80, $p$<.05, $MSe$=2418. The trial type X set size interaction was significant, $F$ (4, 12)=4.05, $p$<.05, $MSe$=2418. No other interaction term was significant. A one-way ANOVA with set size as the factor was conducted on data for Session 15, collapsing across trial type. No significant difference was obtained, $F$ (4, 12)=1.45, $p$>.05, $MSe$=1282. The same analysis on data for Session 1 indicated a significant difference between set sizes, $F$ (4, 12)=3.46, $p$<.05, $MSe$=846.

A three-way ANOVA was applied to error rate scores. No significant difference was obtained between positive and negative trials, $F$ (1, 3)= .003, $p$>.05, $MSe$=4.65, and between Sessions 1 and 15, $F$ (1, 3)=2.82, $p$> .05, $MSe$=21.08, although error rate declined slightly with practice. Error rate varied significantly across set size levels, $F$ (4, 12)=6.12, $p$<.01, $MSe$=5.85. None of the interactions were significant. A one-way ANOVA indicated a significant difference in error rate over set size levels during Session 15, $F$ (4, 12)=3.71, $p$<.05, $MSe$=1.13.

These results were interpreted as evidence of automatic responding in auditory memory search. RT performance did not vary significantly across set size levels during the final session of practice. Although error rate varied significantly as a function of set size during Session 15, errors did not exceed more than 6 percentage points at any set size level and were considered within an acceptable range of variation of automatic target responding (Schneider & Shiffrin, 1977).

Visual Memory Search Results

RT data were analyzed using a three-way ANOVA. Responses on positive trials were significantly faster than responses on negative trials, $F(1, 3)=10.09$, $p<.05$, $MSe=1515$. A significant improvement in RT performance was obtained between Sessions 1 and 15, $F(1, 3)=16.13$, $p<.05$, $MSe=10840$. Response latency did not vary significantly over set size levels, $F(4, 12)=2.33$, $p>.05$, $MSe=952$. The only interaction to reach significance was the set size X sessions term, $F(4, 12)=3.28$, $p<.05$, $MSe=377$. RT data for Session 15 were combined over positive and negative trials and analyzed using a one-way ANOVA with set size as the factor. No significant difference was found, $F(4, 12)=3.07$, $p>.05$, $MSe=271$. An identical analysis revealed no significant difference in RT across set sizes for Session 1, $F(4, 12)=2.34$, $p>.05$, $MSe=391$.

A three-way ANOVA was performed on error rate scores. No significant difference in error rate was obtained over set size levels, $F(4, 12)=1.06$, $p>.05$, $MSe=18.19$, and between sessions, $F(1, 3)=.89$, $p>.05$, $MSe=19.15$. Error rate for positive trials was significantly higher than error rate for negative trials, $F(1, 3)=19.28$, $p<.05$, $MSe=4.05$. The trial type X session interaction was the only significant interaction term, $F(4, 12)=16.87$, $p<.05$, $MSe=1.25$. A one-way ANOVA performed on error rate data for Session 15 indicated no significant differences between set size levels, $F(4, 12)=1.87$, $p>.05$, $MSe=3.04$.

RT and error rate performance curves were statistically flat across set size levels during the final session of training. Again, error rate did not vary more than 7 percentage points at any set size level. These findings are interpreted as evidence of automatic responding to visual targets.

General Results

Responses in the auditory memory search task were slower than responses in the visual task during the first and final sessions of the experiment. These results would not have been predicted based upon findings in simple reaction time studies. Simple reaction time to an auditory stimulus is usually faster than simple reaction time to a visual stimulus (Kling & Riggs, 1971).

Visual inspection of Figure 2 suggests that memory search was slightly slower than modality search in the auditory task. The visual task shows no apparent difference between memory and modality search. This cross-modal difference may have been due to the use of pure tones in the auditory task. Even after extensive practice, retention of pure tones in short-term memory (STM) may be more difficult than retaining letters.

The degree of interaction between set size and sessions of practice has been used to evaluate whether processing is automatic (Logan, 1978, 1979; Poltrock, Lansman, & Hunt 1982). Initial differences in performance across set size levels are expected to diminish as a function of CM practice, producing an interaction between these effects. In the present experiment, a significant set size X session interaction was obtained only in the visual task. However, performance curves for Sessions 1 and 15 appear roughly parallel for both auditory and visual memory search. Subjects undoubtedly learned the target-distractor dichotomy quickly, resulting in relatively flat performance curves during the first session. Similar results have been found in related studies when only the first probe items are considered (Banks & Fariello, 1974; Burrows & Okada, 1975). Subjects capitalize on pre-experimentally learned categorical differences between target and distractor items early in training.

Poltrock, et _al_. (1982) also obtained results in this direction. Response latency for subjects trained in CM memory search was consistently faster than for subjects receiving practice in VM memory search during Session 1. Furthermore, the memory set size effect was smaller in the CM group. Schneider and Fisk (1982, Experiment 1) found higher accuracy levels during CM training compared with VM training at the beginning of their investigation. Overall, these findings confirm those of Boyer, Charleston, and Mergler (1984), where statistically flat performance functions were observed across load levels during the first two sessions of practice. In their study, subjects were informed about the categorical distinction between targets and distractors prior to the experiment.

It was assumed that after 5760 trials of practice in the present experiment, performance curves reached asymptote. Although the response latency functions do not have a zero slope, this goal is rarely achieved in memory search studies (Logan, 1978; Ryan, 1983; Shiffrin & Schneider, 1984). The results of the present experiment are comparable to those in related memory search studies which found evidence for automatic processing (Poltrock, et _al_., 1982; Schneider & Shiffrin, 1977, Experiment 2).

# CHAPTER III

## EXPERIMENT 2

There were two objectives of Experiment 2: to test the effects of target cueing and removal of the memory set on automatic responding. The same subjects and experimental tasks used in Experiment 1 were used in Experiment 2. During the target cueing phase of Experiment 2, subjects were provided a spatial cue prior to the onset of each trial indicating the location of a possible target during the test period. Although cueing should reduce the amount of information to be processed when performing modality search, performance should not improve according to theoretical accounts of automaticity because inputs are processed automatically and in parallel. However, it was predicted that information regarding the location of a possible target would benefit performance by reducing the cognitive capacity required to execute automatic response processes.

At the completion of Experiment 1, responding to targets had become automatic. Therefore, the inclusion or exclusion of the memory set on each trial should not affect performance if automaticity theory is correct. However, the presence of the memory set may provide a cue for the subset of possible targets on each trial, reducing the capacity required for automatic responding. This hypothesis was tested during the memory set absent phase of Experiment 2 by removing the memory set on each trial. These data were compared with performance at *M*=1 *T*=1 and *M*=4 *T*=1 during Session 15 of Experiment 1.

## General Method

The same subjects, stimuli and apparatus used in Experiment 1 were used in two phases of Experiment 2. The design and procedure were identical for both experiments except as described below. The same blocks of auditory and visual trials used in the first experiment were also used in Experiment 2. The following description applies to both the auditory and visual tasks unless otherwise noted.

In Experiment 2, subjects received trials in the same modality as in Experiment 1. Experiment 2 began the day following completion of the first experiment. The target-cueing phase was administered before the memory set absent phase, and both were given in a single session.

## Target Cueing

### Method

Prior to the onset of each trial, subjects were given a verbal cue specifying the spatial position of a possible target during the memory period. Targets were never presented in non-cued positions. Verbal cues included the instructions "upper left," "upper right," "lower left" and "lower right." These cues referred to the spatial position of possible targets with respect to the fixation dot on visual trials and the subject's head on auditory trials. Subjects were informed that a verbal cue indicating the position of a possible target would be provided prior to each trial, and that the experimental task was otherwise unchanged. Subjects were also instructed to maintain the same postural orientation toward auditory or visual stimuli as during the first experiment.

Only the M=1 T=1, M=1 T=2 and M=1 T=4 conditions were tested because interest was in the effects of target cueing on load associated with automatic modality search. Subjects received four blocks of 64 trials. The first and fourth block administered were at T=1; the second and third block were at T=2 and T=4, respectively. Data for the T=1 condition were averaged over the first and fourth blocks. As stated in the design section of Experiment 1, each target was presented in each position during the test period with equal frequency in each block of trials.

Results and Discussion

MRT and error rate were calculated for each experimental condition for each subject, and were analyzed using repeated measures ANOVA. Test set size and target cue versus no target cue were input as factors. The target cue condition included data from the target cueing phase of Experiment 2. The no target cue condition consisted of an average of the modality search data from Session 15, Experiment 1 and Session 1, Experiment 3 to control for practice effects. (During Session 1 of Experiment 3, subjects performed the same modality task as in Experiment 1.) All two-way ANOVAs were 3(test set size) X 2(target cue versus no target cue). RT and error rate for modality search are presented in Figure 3 and Table 2, respectively. Summary ANOVA tables are given in Appendix B.

RT results for auditory search were evaluated using a two-way ANOVA. RT was significantly faster under the target cue condition compared with the no target cue condition, $F$ (1, 3)=10.76, $p<.05$, $MSe$=600. No significant difference was obtained between test set size levels, $F$ (2, 6)=2.88, $p>.05$, $MSe$=64. The interaction was not significant.

Error rate for auditory search was also analyzed using a two-way ANOVA. Neither of the main effects nor their interaction were significant: the test set size effect was not significant, $F$ (2, 6)=.28, $p$>.05, $MSe$= 4.63; error rate did not vary significantly over the target cue and no target cue conditions, $F$ (1, 3)=.09, $p$>.05, $MSe$=4.38.

In visual search, cueing targets resulted in significantly faster RTs than not cueing targets, $F$ (1, 3)=39.35, $p$<.01, $MSe$=168. RT varied significantly as a function of test set size, $F$ (2, 6)=8.60, $p$<.05, $MSe$=96. No significant difference was found for the interaction term.

Error rate for visual search did not change significantly under the target cue and no target cue manipulations, $F$ (1, 3)=5.58, $p$>.05, $MSe$= 3.61. No significant difference was obtained for the main effect of test set size, $F$ (2, 6)=3.20, $p$>.05, $MSe$=3.79. The interaction term was not significant.

In summary, the results indicated that cueing the spatial position of possible CM targets improved performance, even though responding was automatic. Error rate in each task remained unchanged by the cueing manipulation.

It is noteworthy that all subjects reported that the target cue was unhelpful. Generally, subjects perceived no change in their performance. One subject (in the visual group) even claimed that the cue was deleterious to performance of the task. In fact, performance improved for this subject under cue conditions.

It might be argued that presentation of the cue prior to each trial somehow changed the experimental task. The introduction of a novel element into the task may have augmented the subject's arousal or expectation levels. Even if this were true, these kinds of processes should have either hindered or had no effect on automatic responding, according to the automatic processing framework.

## Memory Set Absent

### Method

In Experiment 1, subjects received a memory set for the possible subset of targets that might appear during the test period. During the memory set absent phase of Experiment 2, the memory set was removed to allow a comparison of the effects of a memory set versus no memory set on automatic target responding. On each trial, subjects performed the experimental task without the inclusion of the memory set. Subjects received one block of 64 trials at $T$=1. Subjects were informed prior to the experiment that no items would be presented during the memory period.

In order to remove the memory set on auditory trials, a series of normally-open contact closures were connected between the amplifiers and speakers. The acoustical signal occurring at the onset of each trial triggered a sound actuated relay connected to the Gerbrands 6-channel timer and logic interface. The contact closures were activated by the logic unit 250 ms after the trial began.

### Results and Discussion

MRT and error rate were calculated for each subject and combined across positive and negative trials. These data were compared with results from the $M$=1 $T$=1 and $M$=4 $T$=1 conditions for Session 15, Experiment 1. A one-way repeated measures ANOVA was performed on the data. Summary ANOVA tables appear in Appendix B. Results for the auditory and visual tasks are presented in Table 3.

A one-way ANOVA indicated no significant difference in RT for auditory memory search across set sizes, $F$ (2, 6)=1.31, $p$>.05, $MSe$=1384. Error rate did not vary significantly over memory set conditions, $F$ (2, 6)=4.94, $p$>.05, $MSe$=1.89.

In visual memory search, a one-way ANOVA revealed a significant difference in RT across memory set conditions, $F$ (2, 6)=5.90, $p$<.05, $MSe$=231. Mean pairs were tested using the Newman-Keuls method. The only significant difference was between $M$=1 $T$=1 and $M$=4 $T$=1, $q$ (3)=4.7. Error rate also changed significantly across levels, $F$ (2, 6)=6.66, $p$< .05, $MSe$=7.97. A Newman-Keuls test showed that the only significant comparison was between $M$=1 $T$=1 and the memory set absent condition, $q$ (3)=5.13.

These findings suggest that the presentation or exclusion of the memory set had no effect on automatic target responding in the auditory task, supporting automaticity theory. In the visual task, RT was unaffected by the omission of the memory set, but error rate increased. These findings are considered further in the general discussion section.

# CHAPTER IV

## EXPERIMENT 3

In Experiment 3, subjects performed auditory and visual memory search concurrently. Varying levels of dual task performance were compared with single task baseline measures. For each subject, one of the tasks was automated and the other was unpracticed. Only the extreme load levels for memory and modality search were investigated in each task (i.e., *M*=4 *T*=1, *M*=1 *T*=1 and *M*=1 *T*=4). The sequence of each trial, including the duration of each period, were identical for the auditory and visual tasks. The onset of auditory and visual trials were time-locked. Thus, test periods for each trial were presented simultaneously. During the first session of Experiment 3, each subject's performance in the task previously automated in Experiment 1 was measured to detect any changes in performance attributable to Experiment 2.

The possible outcomes of Experiment 3 may be conceptualized along two dimensions in terms of load effects. Differences across set size levels might be observed in each performance curve for each of the tasks. These changes might be enhanced as load levels associated with the other task increase. However, in Session 1 of Experiment 1, performance curves were found to be statistically flat across all set size levels for visual memory search. In auditory memory search, performance curves across set sizes were not as marked as might be expected. These findings suggest that differences between set size levels might not be obtained, even as load from the other task increases.

The other load dimension corresponds with changes in performance in one task, collapsing across set size levels, with increases in load in the other task. Compared with single task measures, dual task manipulations might produce deficits in performance in the automated task, the unpracticed task, both tasks, or neither task. The degree of deterioration of performance under dual task conditions might be affected by the levels of load associated with the other task. The finding that performance curves do not change across load conditions would support the notion that automatic processing requires no central capacity. The occurrence of performance deficits would disconfirm this hypothesis. Moreover, the degree of increase in capacity required for automatic responding would be reflected in the magnitude of these performance deficits under different load levels.

## General Method

Experiment 3 was identical to Experiment 1 in all respects, except as indicated below. Throughout the following description of methodology for all phases of Experiment 3, the modality memory search task subjects performed in Experiment 1, for which automatic target responding was acquired, will be referred to as the secondary task. The other modality memory search task, in which subjects have not previously received practice, will be referred to as the primary task. To minimize interference resulting from concurrent performance of the auditory and visual tasks, the categorical distinction between targets and distractors for the auditory and visual paradigms used in Experiment 1 was also employed in Experiment 3. The same blocks of auditory and visual trials constructed for Experiment 1 were used in Experiment 3. During all phases of Experiment 3, subjects gave the same verbal and manual responses given in Experiment 1 for auditory and visual trials. To control the synchrony between the onset of auditory and visual trials under dual task conditions, the acoustical signal(s) from the 4-channel tape machine activated a sound actuated relay connected to the Gerbrands 6-channel timer and tachistoscope.

## Baseline Measures

### Secondary Task Performance

During Session 1 of Experiment 3, performance in the task previously automated in Experiment 1 was measured again for each subject. Each subject received a block of 64 trials at each of the five memory/test set sizes. An additional block of 64 trials was given at $M$=1 $T$=1. Data for this condition were averaged over the two blocks. All blocks were given in a single session.

RT results appear in Figure 4 as baseline data for the secondary task. Error rate is displayed in Table 4. Only data for the $M$=4 $T$=1, $M$=1 $T$=1 and $M$=1 $T$=4 conditions are shown. The data were collapsed across positive and negative trials. A one-way repeated measures ANOVA was used to analyze RT and error rate for the auditory and visual tasks.

Although RT appears relatively flat across set sizes in the auditory task, a significant difference was found, $F$ (2, 6)=29.18, $p$<.005, $MSe$= 100. Error rate did not vary significantly across set sizes, $F$ (2, 6)=

1.77, $p > .05$, $MSe = 25.11$. It is interesting to note that RT at all set size levels in the auditory task was consistently faster during the first session of Experiment 3 than during the final session of Experiment 1. According to automaticity theory, the development of automatic detection processes should preclude the possibility of obtaining consistently faster RTs during subsequent sessions. Because response latency did not vary by more than 50 ms over set sizes, the results are considered within an acceptable range for automatic responding (Schneider & Shiffrin, 1977, Experiment 2).

RT in the visual task showed no significant difference between set size levels, $F\ (2, 6) = 4.99$, $p > .05$, $MSe = 252$. Error rate was found to vary significantly over set sizes, $F\ (2, 6) = 5.65$, $p < .05$, $MSe = 2.89$. MRT in the visual task was almost identical between Session 15, Experiment 1 and Session 1, Experiment 3. Although significant, error rate did not vary by more than six percent across set sizes. Therefore, responding was interpreted to be automatic.

Primary Task Performance

Baseline measures were established for single task performance in the primary task during the second session of Experiment 3. Subjects previously trained in auditory target responding received practice in the visual memory search task. Subjects previously acquiring automatic responding to visual targets were given training in the auditory memory search task. The baseline session included eight practice trials followed by each of the five memory/test set size blocks. Again, the $M=1$ $T=1$ condition was given twice; data for this condition were averaged over the two blocks. Thus, each subject received six blocks of 64 trials.

Baseline results for the primary task are presented with dual task data in the following section and appear in Figure 4 and Table 4, because primary interest was in a comparison of single and dual task performance. Only data corresponding with the three extreme load levels are shown.

## Dual Tasks

### Method

Subjects were required to perform the auditory and visual tasks concurrently. Trial onset was synchronous between the two tasks. Therefore, presentation of the auditory and visual test periods, at which time the subject was able to make a comparison decision, was time-locked. The duration of each period for each task was identical to the format of trials in Experiment 1 (refer to Figure 1a and b). The ITI was 2 s, providing sufficient time for subjects to respond.

Dual task trials were given over two sessions. During the first session, subjects received six blocks of trials. For the primary task, memory and test set size equalled one for all six blocks. For the automated secondary task, all five memory/test set sizes were administered, and the *M*=1 *T*=1 block was given two times. Again, data for the *M*=1 *T*=1 condition were averaged over the two blocks. The first session permitted an investigation of the effects of load associated with memory and modality search in the automated secondary task under dual task conditions, when memory and test set size were held constant at *M*=1 *T*=1 for the primary task.

The second dual task session involved the presentation of three blocks at *M*=1 and *T*=4 in the primary task while the secondary task varied at *M*=1 *T*=1, *M*=1 *T*=4 and *M*=4 *T*=1. Another three blocks were given at _M_=4 and _T_=1 in the primary task and at _M_=1 _T_=1, _M_=1 _T_=4 and _M_=4 _T_=1 in the secondary task. The additional dual task manipulations given during the second session allowed an examination of the range of load effects on performance in the automated secondary task and in the primary task. (Load levels ranged from _M_=1 _T_=1 to _M_=1 _T_=4 in modality search and from _M_=1 _T_=1 to _M_=4 _T_=1 in memory search.) Both dual task sessions also provided a test of the prediction that memory search would be more immune to load effects than modality search.

Attention to the automated secondary task should not improve performance on that task according to theoretical accounts of automatic processing and may actually interfere (Schneider & Fisk, 1982). Therefore, subjects were instructed to allocate as much attention to the primary task as necessary to maintain performance in that task at baseline levels, even at the expense of deficits in performance in the secondary task. This is the usual procedure in dual task studies (Kahneman, 1973; Logan, 1978b; Posner & Bois, 1971). Quick and accurate responses in both tasks were encouraged frequently.

## Results and Discussion

RT and error rate for each task were analyzed using a 3(set size) X 4(single/dual tasks) repeated measures ANOVA. Summary tables are included in Appendix C. The results for the dual task phase are presented in Figure 4 and Table 4. RT for subjects previously trained to respond automatically to auditory targets appear in the upper panel and RT for subjects previously trained in visual target responding are shown in the lower panel. Response latency is plotted as a function of memory/test set size and single/dual task conditions. Data for positive and negative trials were combined. Performance in the automated secondary task is depicted on the left side of each graph. The right portion of each graph exhibits performance in the unpracticed primary task.

Results for Subjects Trained in Auditory Target Responding. A two-way ANOVA was performed on the RT data for the secondary auditory task. RT varied significantly across set sizes, $F$ (2, 6)=9.47, $p<.05$, $MSe$=1549. Response latency also varied significantly as a function of single/dual task conditions, $F$ (3, 9)=13.17, $p<.005$, $MSe$= 50785. The interaction term was not significant, $F$ (6, 18)=1.33, $p>.05$, $MSe$=1771. Data were collapsed across set size levels and the differences between means for the single/dual task conditions were tested using a Newman-Keuls test. Pairwise comparisons indicated that RT in the single task was significantly faster than at set size $M$=1 $T$=1 in the visual task, $q$ (2)=6.78, $p<.01$, at set size $M$=4 $T$=1 in the visual task, $q$ (3)=7.19, $p<.01$, and at set size $M$=1 $T$=4 in the visual task, $q$ (4)=7.66, $p<.01$. No other pairwise comparison was significant.

Error rate was also analyzed using a two-way ANOVA. The main effects of set size, $F$ (2, 6)=1.84, $p>.05$, $MSe$=14.52, and single/dual tasks, $F$ (3, 9)=2.51, $p>.05$, $MSe$=20.01, were not significant. Their interaction was not significant, $F$ (6, 18)=.93, $p>.05$, $MSe$=9.08.

RT in the primary visual task was evaluated using a two-way ANOVA. No significant differences were obtained between set sizes, $F$ (2, 6)= 3.83, $p>.05$, $MSe$=3630, single/dual tasks, $F$ (3, 9)=1.41, $p>.05$, $MSe$=1852, and for their interaction, $F$ (6, 18)=.53, $p>.05$, $MSe$=1142. The same analysis was applied to error rate scores. Again, error rate did not vary significantly across set sizes, $F$ (2, 6)=.91, $p>.05$, $MSe$=4.16.

Errors over single/dual tasks were not significantly different, $\underline{F}$ (3, 9)=.33, $\underline{p}$>.05, $\underline{MSe}$=3.06. The interaction between these two effects was not significant, $\underline{F}$ (6, 18)=.87, $\underline{p}$>.05, $\underline{MSe}$=5.09.

Single task performance in the unpracticed visual task was roughly equivalent to dual task performance and did not vary with changes in set size. This outcome permits the clearest interpretation of secondary task data (Kantowitz, 1974).

In general, the results for the secondary auditory task indicated that single task performance was significantly better than dual task performance. Changes in concurrent task load did not affect performance in the automated auditory task.

In the automated secondary task, the effects of concurrent task load did not interact with set size levels. The effects appeared to be additive. This result supports the notion that responding was automatic under single and dual task conditions. RT in the secondary task, however, was substantially slower under concurrent task manipulations compared with single task baseline performance. Certainly, responses in both the primary and secondary tasks were not simultaneous. Responses in the fastest auditory dual task condition (load level 11 in the visual task) were 443 ms slower, on the average, than responses during baseline. The degree of disruption of automatic responding in the auditory task was greater than would be expected if central operations are bypassed.

<u>Results for Subjects Trained in Visual Target Responding</u>. RT in the secondary visual task was analyzed using a two-way ANOVA. RT did not vary significantly across set sizes, $\underline{F}$ (2, 6)=1.57, $\underline{p}$>.05, $\underline{MSe}$=3326.

The effect of single/dual tasks was significant, $F$ (3, 9)=11.88, $p<.005$, $MSe=6282$. The interaction term was not significant, $F$ (6, 18)=1.68, $p>.05$, $MSe=2881$. A Newman-Keuls test was used to compare mean pairs, collapsing over set sizes. Results were similar to those found in the secondary auditory task for subjects trained in auditory target responding. Mean RT in the single task condition was significantly faster than at M=1 T=1 in the auditory task, $q$ (2)=5.34, $p<.01$, at $M=1$ $T=4$ in the auditory task, $q$ (3)=7.20, $p<.01$, and at $M=4$ $T=1$ in the auditory task, $q$ (4)=7.40, $p<.01$. RT at $M=1$ $T=1$ in the auditory task appears faster than at the higher set size levels, but these differences were not significant. None of the other pairwise comparisons differed significantly.

Error rate in the secondary visual task was evaluated using a two-way ANOVA. No significant differences in error rate were obtained across set sizes, $F$ (2, 6)=.20, $p>.05$, $MSe=12.19$, single/dual task conditions, $F$ (3, 9)=.61, $p>.05$, $MSe=10.17$, and for their interaction, $F$ (6, 18)= 1.54, $p>.05$, $MSe=7.00$.

A two-way ANOVA was used to analyze RT scores in the primary auditory task. Responses at $M=1$ $T=4$ and at $M=4$ $T=1$ seem to be slower than at $M=1$ $T=1$. However, RT did not vary significantly as a function of set size, $F$ (2, 6)=2.05, $p>.05$, $MSe=30055$. The single/dual task manipulation did not produce significantly different RT scores, $F$ (3, 9)=3.25, $p>.05$, $MSe=18555$. The interaction was not significant, $F$ (6, 18)=1.21, $p>.05$, $MSe=4267$.

Using a two-way ANOVA, error rate in the primary auditory task did not differ significantly as a function of set size, $F$ (2, 6)=1.87, $p>.05$, $MSe=137$, and single/dual task conditions, $F$ (3, 9)=.77, $p>.05$, *MSe*=43. The interaction was not significant, $F$ (6, 18)=.71, $p$>.05, *MSe*=21.

The overall findings for subjects trained in visual target responding mirror closely the pattern of results found for subjects trained in auditory target responding. Subjects trained to respond automatically to visual targets evidenced no significant variations between single task performance and the differing levels of dual task performance in the unpracticed auditory task. Set size levels did not produce significant differences in performance in the auditory task. Again, performance in the primary auditory task did not change significantly under concurrent task conditions, allowing the most straight-forward interpretation of results in the secondary visual task.

In the automated visual task, a substantial and significant difference was obtained between baseline and dual task measures. There was also a non-significant but noticeable improvement in visual dual task performance between load level 11 in the auditory task and the other load levels associated with that task. Differences in performance between set size levels under dual task conditions were not significant in the visual task.

As in auditory target responding, results for subjects trained in visual target responding showed additivity of concurrent task effects. Furthermore, the dual task performance deficit was significant and marked. The mean difference between response latency in the single task condition and the fastest dual task condition was 383 ms. Thus, response latency doubled under concurrent memory search. This finding is inconsistent with the current automatic responding framework.

# CHAPTER V

## GENERAL DISCUSSION

In Experiment 1, subjects acquired automatic responding to auditory or visual targets. Performance functions were statistically flat across set size levels during the final session of practice and assumed asymptotic after 5760 trials of CM training, thus meeting the currently used major criteria for automatic responding. In subsequent experiments, the capacity requirements for automatic responding were examined carefully.

During the target cueing phase of Experiment 2, subjects were provided a cue prior to each trial indicating the spatial position of possible targets presented during the test period. RT results showed a significant improvement for both auditory and visual search under cueing conditions compared with non-cueing conditions. Error rate for both tasks was unaffected by cueing. It is argued that this attentionally-controlled processing manipulation benefited automatic responding.

During the memory set absent phase of Experiment 2, reliance on knowledge of the memory set rather than actual presentation of the memory set had no significant effect on response latency for both auditory and visual memory search. Error rate remained unchanged when the memory set was omitted compared with the presentation of four memory set items. Thus, maintenance of memory set items in short-term memory did not help automatic responding; targets automatically activated their representations in long-term memory. This outcome supports the automatic/controlled processing framework.

In Experiment 3, subjects performed single and dual memory search. The secondary task was previously automated and the primary task was unpracticed and in a different modality. The same pattern of results was observed for subjects trained in either modality. First, no changes in performance in the primary unpracticed task were obtained comparing single and concurrent memory search. This finding is not consistent with that of Charleston, Mergler and Boyer (1984, Experiment 2) in which performance in the unpracticed primary task was disrupted by performance in the highly-practiced secondary task. The set size effect for the primary task in the present study was also not significant. These results are not surprising because 1) subjects probably capitalized on the categorical distinction imposed between the target and distractor ensembles and 2) the extensive CM training subjects received previously undoubtedly produced strong transfer effects between the two modality tasks.

Second, the automated secondary task of Experiment 3 revealed a marked deterioration in RT performance under dual task conditions that was constant across load manipulations in the primary task during concurrent memory search. The set size effect in the secondary task was significant only in audition.

The interaction between set size and single/dual tasks was not significant in the automated secondary task for either modality. This finding indicates that dual task load effects were additive across set size. Thus, the search component of information processing was relatively immune to load effects. Similar results have been found in other dual task studies demonstrating that automatic processing is relatively cost-free (Logan, 1979; Schneider & Fisk, 1982). However, the substantial deficits in automatic responding under concurrent memory search compared with single task performance imply that the entire input-output processing sequence is not cost-free, and requires expenditure of central resources to execute well-developed skilled behaviors.

Together, the findings in Experiments 2 and 3 demonstrated that automatic responding requires central processing resources. These performance deficits in automatic responding caused by increases in processing load may be explained by 1) costs associated with automatic enabling, which sets-up an automatic process, and possibly 2) monitoring operations, which maintain enabling conditions (Schneider & Fisk, 1982). According to this account, enabling an automatic process requires attentional resources. Thus, automaticity theory and data from the present report suggest that automatic responding requires central resources, regardless of the amount of CM practice.

In the present study, strong evidence for the generalizability of automatic responding and its associated capacity requirements across the auditory and visual modalities was provided. In all three experiments, the pattern of results for each modality task were similar. The generalizability of automatic/controlled processing theory to audition was confirmed in Experiment 1, supporting the findings of Poltrock et al. (1982). Cross-modal comparisons in Experiments 2 and 3 indicated similar resource dependent and independent components of information processing. Automatic responding was facilitated by cueing and disrupted by concurrent memory search, and to a similar extent in each modality.

The term _automatic processing_ refers to a class of unlimited capacity processes. Researchers must be careful to clarify the type of automatic process under investigation or discussion, avoiding use of the generic term. For instance, in their 1977 articles, Shiffrin and Schneider examined _automatic detection_, which automatically activates calls for attention. The present study tested another type of automatic process -- _automatic responding_. A cascade of automatic processes are engaged in automatic responding, including stimulus encoding and perhaps response execution. However, the attentional system is not circumvented. These kinds of distinctions are crucial because different internal mechanisms may be utilized by different types of automatic processes.

Characterizing a particular type of mental process as "automatic" probably stems from the machine analogy. In a simple machine, the entire processing sequence, from input to output stages, is programmed. Processing is mechanical in nature: thinking or deliberation are not involved. Automatic responding in humans seems closest to this conceptualization of automatism.

In general, evidence for automatic processing often indicates that only certain components in the processing chain become automated. Distinct types of automatic processes have been delineated to account for these differences. Theorists must be cautious, however, not to propose new types of automatic components whenever an incongruity with the automatic/controlled processing framework is encountered. Such a strategy will eventually render the model unparsimonious, generating more confusion than clarification of the attention and search literature.

This problem is probably due in large part to the rigid, qualitative distinction originally imposed between automatic and controlled processing. The evidence suggests that a sharp distinction may not be appropriate (Ryan, 1983). For instance, automatic processing is purportedly unaffected by load. Yet, after prolonged CM practice zero-slope response curves are rarely obtained (Logan, 1978b; Shiffrin & Schneider, 1984). Such results indicate that small amounts of central resources are required in an automatic process. Some researchers accommodate this finding by describing automatic processing as drawing no or <u>little</u> central resources, as if there might be degrees of automaticity (Schneider & Fisk, 1982; Shiffrin & Schneider, 1977). Confusion arises when attention is strictly identified with controlled processing and not with automatic processing.

There is another problem with this operational definition of automatic processing. It was stated earlier that sometimes performance curves are relatively flat at the beginning of practice (Banks & Fariello, 1974; Boyer, Charleston & Mergler, 1984; Burrows & Okada, 1975). Similar results were found in Experiment 1 in the present study. Flat performance functions are supposed to be observed <u>after</u> CM practice. The criterion of asymptotic performance may be included in the operationalization of automaticity, but continual improvement in response latency has been demonstrated over extremely protracted training periods. For example, Mowbry and Rhoades (1959) found continuing practice effects following 45,000 trials in both two and four choice reaction time tasks.

The qualitative difference in results obtained under CM and VM conditions may be attributable to the type of experimental paradigm used to investigate attention and memory search. In the typical memory search paradigm, a maximum of 4 items are searched during the memory and test periods. The task is rather easy, and the slope of the RT function across set size decreases rapidly with practice. If, for instance, 30 items were presented during the test period, all within the foveal field, the task would become considerably more difficult. The ability to process 30 items as quickly as a single item seems implausible, but the ability to process 4 items as quickly as one does not. Yet, evidence of the latter case has led many researchers to conclude that processing of this kind is unlimited in capacity, having an effectively unlimited upper bound (Schneider & Fisk, 1982). However, a fast, serial search may appear parallel when only a small number of items are scanned. If a large number of items must be searched, the serial nature of the search process may become apparent. Logan (1978a) has suggested that subjects tend to use different search strategies with different array sizes. With smaller arrays (approximately 1 to 5 items) elements are scanned so quickly that an exhaustive search is most efficient. A self-terminating mode is employed with larger array sizes.

Boyer, Charleston and Mergler (1984) constructed RT tasks which corresponded to less complex variants of an auditory memory search paradigm. These tasks included simple RT to a single tone, single-response choice RT to one of two tones, two-response choice RT to two tones, and simple memory search (memory and test set size equalled one). Subjects received CM practice in each task. The results demonstrated that as task complexity increased, response latency also increased. Thus, the efficiency of information processing is contingent upon the experimental paradigm used, even if processing is automatic.

Ryan (1983) has recently criticized automatic/controlled processing theory. He maintains that a rigid distinction between automatic and controlled processing is not appropriate given the available evidence. It is further argued that Shiffrin and Schneider's use of attention as a defining property of controlled processing is at best unhelpful. In summary of Shiffrin and Schneider's model, he concludes that "there is no new and independent theory at all. We are left with the trivial redescription of the fact that ensemble size is sometimes an important variable in human performance... the explanatory force is illusory" (p. 177).

The continuity between controlled and automatic modes of processing is certainly acknowledged by theorists. Automatic processing develops from controlled processing as a function of practice in consistent situations. Performance curves show that the transition is gradual (Kristofferson, 1977; Poltrock et al., 1982). If there was a sudden qualitative change from a controlled to an automatic mode of processing, an abrupt transition should be observed in the function relating performance to practice.

Evidence for disparate modes of processing indicates that automatic and controlled processing are endpoints on an underlying continuum of information processing. Most researchers agree with this view (Hasher & Zacks, 1979). Indeed, Shiffrin and his colleagues have slackened their position on this issue and no longer advocate a sharp distinction between automatic and controlled processing (Schneider & Fisk, 1982; Shiffrin & Schneider, 1984).

The involvement of attention across cognitive operations, however, is not also conceptualized in terms of degrees. This is an important discrepancy in current theories of attention. Although modes of information processing may be placed on a quantitative dimension, attention continues to be equated with controlled processing. Accordingly, attention is considered to function in an all-or-none manner. This is perhaps a consequence of the belief that attention is an isolable, local processing system (Posner, 1982). It may also be due to a natural language distinction useful in discussing performance of skilled behavior in a relative manner (Ryan, 1983).

A distributional model of attention provides a more complete account of the findings in the attention and memory search literature (Boyer, Charleston & Mergler, 1984; Charleston, Mergler & Boyer, 1984). In this model, attention comprises processing resources having a focal center and increasingly peripheral levels. Resources can be committed flexibly across cognitive operations within an integrated processing system. The locus of concentrated processing resources constitutes the focus of attention and the information processing bottleneck. Automatic and controlled processing can be conducted in parallel, but must not exceed the resource limitations of the system. It is possible that processes which have become relatively automatic constitute extremely rapid serial processing, requiring only a minimal amount of attentional resources.

This framework is not new. Fitts and Posner (1967) established a similar model in the area of motor skills. In their model, the degree of automaticity is clearly related to the amount of learning that the subject has acquired in forming particular stimulus-response associations. The stronger the association becomes, the less drain there is on attentional resources. The quintessential point is that some amount of attention is necessary to perform any task. Even components of a task which appear automatic may demand a small quantity of attentional capacity.

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# APPENDIX A

## SUMMARY ANOVA TABLES FOR EXPERIMENT 1

Reaction Time for Auditory Subjects: Session 1 vs. 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU* | 3 | 332758.4375 | 110919.4375 | | |
| PN** | 1 | 252.0500 | 252.0500 | 0.0365 | 0.854 |
| SU PN | 3 | 20727.6367 | 6909.2109 | | |
| SS*** | 4 | 36782.9492 | 9195.7344 | 3.8028 | 0.032 |
| SU SS | 12 | 29017.5508 | 2418.1292 | | |
| SE**** | 1 | 417316.0000 | 417616.0000 | 5.3651 | 0.103 |
| SU SE | 3 | 233351.6875 | 77783.8750 | | |
| PN SS | 4 | 6344.4492 | 1586.1123 | 4.0532 | 0.026 |
| SU PN SS | 12 | 4695.8516 | 391.3208 | | |
| PN SE | 1 | 911.2500 | 911.2500 | 0.2604 | 0.645 |
| SU PN SE | 3 | 10499.6250 | 3499.8750 | | |
| SS SE | 4 | 1449.9375 | 362.4844 | 0.1981 | 0.933 |
| SU SS SE | 12 | 21959.3750 | 1829.9478 | | |
| PN SS SE | 4 | 2186.2383 | 546.5596 | 1.2608 | 0.338 |
| SU PN SS SE | 12 | 5201.8359 | 433.4863 | | |
| CORRECTION FACTOR | | 22031104.0500 | | | |

Reaction Time for Auditory Subjects: Session 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 201830.7500 | 67276.8750 | | |
| SS | 4 | 7432.6992 | 1858.1748 | 1.4496 | 0.277 |
| SU SS | 12 | 15381.7383 | 1281.8115 | | |
| CORRECTION FACTOR | | 4100556.8000 | | | |

Reaction Time for Auditory Subjects: Session 1

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 81000.3750 | 27000.1250 | | |
| SS | 4 | 11721.6992 | 2930.4248 | 3.4635 | 0.042 |
| SU SS | 12 | 10153.1133 | 846.0928 | | |
| CORRECTION FACTOR | | 7132956.8000 | | | |

*SU=Subjects
**PN=Positive vs. Negative Trials
***SS=Set Size(*M*=4 *T*=1 vs. *M*=2 *T*=1 vs. *M*=1 *T*=1 vs. *M*=1 *T*=2 vs. *M*=1 *T*=4)
****SE=Session 1 vs. Session 15

Error Rate for Auditory Subjects: Session 1 vs. 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 110.7375 | 36.9125 | | |
| PN | 1 | 0.0125 | 0.0125 | 0.0027 | 0.961 |
| SU PN | 3 | 13.9375 | 4.6458 | | |
| SS | 4 | 143.2000 | 35.8000 | 6.1197 | 0.007 |
| SU SS | 12 | 70.2000 | 5.8500 | | |
| SE | 1 | 59.5125 | 59.5125 | 2.8233 | 0.191 |
| SU SE | 3 | 63.2375 | 21.0792 | | |
| PN SS | 4 | 26.8000 | 6.7000 | 1.0177 | 0.438 |
| SU PN SS | 12 | 78.9998 | 6.5833 | | |
| PN SE | 1 | 4.5125 | 4.5125 | 0.9003 | 0.585 |
| SU PN SE | 3 | 15.0373 | 5.0124 | | |
| SS SE | 4 | 17.8000 | 4.4500 | 1.4355 | 0.281 |
| SU SS SE | 12 | 37.1999 | 3.1000 | | |
| PN SS SE | 4 | 6.7998 | 1.6999 | 0.4304 | 0.786 |
| SU PN SS SE | 12 | 47.3998 | 3.9500 | | |
| CORRECTION FACTOR | | 456.6125 | | | |

Error Rate for Auditory Subjects: Session 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 16.4000 | 5.4667 | | |
| SS | 4 | 16.8000 | 4.2000 | 3.7059 | 0.034 |
| SU SS | 12 | 13.6000 | 1.1333 | | |
| CORRECTION FACTOR | | 39.2000 | | | |

Reaction Time for Visual Subjects: Session 1 vs. 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 222392.0000 | 74130.6250 | | |
| PN | 1 | 15290.4492 | 15290.4492 | 10.0934 | 0.049 |
| SU PN | 3 | 4544.6758 | 1514.8918 | | |
| SS | 4 | 8881.1719 | 2220.2930 | 2.3311 | 0.115 |
| SU SS | 12 | 11429.8281 | 952.4856 | | |
| SE | 1 | 174844.9375 | 174844.9375 | 16.1289 | 0.026 |
| SU SE | 3 | 32521.3750 | 10840.4570 | | |
| PN SS | 4 | 563.4258 | 140.8564 | 0.5791 | 0.686 |
| SU PN SS | 12 | 2918.9492 | 243.2458 | | |
| PN SE | 1 | 9.7500 | 9.7500 | 0.0912 | 0.776 |
| SU PN SE | 3 | 320.6992 | 106.8997 | | |
| SS SE | 4 | 4952.8750 | 1238.2188 | 3.2827 | 0.049 |
| SU SS SE | 12 | 4526.2969 | 377.1914 | | |
| PN SS SE | 4 | 241.3242 | 60.3311 | 0.3071 | 0.868 |
| SU PN SS SE | 12 | 2357.6758 | 196.4730 | | |
| CORRECTION FACTOR | | 14632472.4500 | | | |

Reaction Time for Visual Subjects: Session 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 37936.1484 | 12645.3828 | | |
| SS | 4 | 3331.2998 | 832.8250 | 3.0721 | 0.058 |
| SU SS | 12 | 3253.0986 | 271.0916 | | |
| CORRECTION FACTOR | | 2905506.4500 | | | |

Reaction Time for Visual Subjects: Session 1

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 89588.9375 | 29862.9766 | | |
| SS | 4 | 3654.5000 | 913.6250 | 2.3355 | 0.114 |
| SU SS | 12 | 4694.3125 | 391.1926 | | |
| CORRECTION FACTOR | | 4507751.2500 | | | |

Error Rate for Visual Subjects: Session 1 vs. 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 652.3374 | 217.4458 | | |
| PN | 1 | 78.0125 | 78.0125 | 19.2823 | 0.020 |
| SU PN | 3 | 12.1374 | 4.0458 | | |
| SS | 4 | 76.8750 | 19.2188 | 1.0568 | 0.420 |
| SU SS | 12 | 218.2251 | 18.1854 | | |
| SE | 1 | 17.1125 | 17.1125 | 0.8938 | 0.584 |
| SU SE | 3 | 57.4376 | 19.1458 | | |
| PN SS | 4 | 36.4250 | 9.1063 | 1.7718 | 0.199 |
| SU PN SS | 12 | 61.6749 | 5.1396 | | |
| PN SE | 1 | 21.0125 | 21.0125 | 16.8663 | 0.024 |
| SU PN SE | 3 | 3.7375 | 1.2458 | | |
| SS SE | 4 | 17.0750 | 4.2688 | 1.0119 | 0.441 |
| SU SS SE | 12 | 50.6249 | 4.2187 | | |
| PN SS SE | 4 | 38.4250 | 9.6062 | 2.9501 | 0.065 |
| SU PN SS SE | 12 | 39.0748 | 3.2562 | | |
| CORRECTION FACTOR | | 1402.8125 | | | |

Error Rate for Visual Subjects: Session 15

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 121.7500 | 40.5833 | | |
| SS | 4 | 22.7000 | 5.6750 | 1.8658 | 0.181 |
| SU SS | 12 | 36.5000 | 3.0417 | | |
| CORRECTION FACTOR | | 252.0500 | | | |

# APPENDIX B

## SUMMARY ANOVA TABLES FOR EXPERIMENT 2

Reaction Time for Auditory Subjects: Target Cueing

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU* | 3 | 234496.8125 | 78165.5625 | | |
| SS** | 2 | 369.0833 | 184.5416 | 2.8841 | 0.132 |
| SU SS | 6 | 383.9167 | 63.9861 | | |
| SE*** | 1 | 6468.1641 | 6468.1641 | 10.7753 | 0.045 |
| SU SE | 3 | 1800.8359 | 600.2786 | | |
| SS SE | 2 | 391.0820 | 195.5410 | 1.9956 | 0.216 |
| SU SS SE | 6 | 587.9153 | 97.9859 | | |
| CORRECTION FACTOR | | 3983720.1667 | | | |

Error Rate for Auditory Subjects: Target Cueing

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 39.1250 | 13.0417 | | |
| SS | 2 | 2.5833 | 1.2917 | 0.2793 | 0.767 |
| SU SS | 6 | 27.7500 | 4.6250 | | |
| SE | 1 | 0.3750 | 0.3750 | 0.0857 | 0.782 |
| SU SE | 3 | 13.1250 | 4.3750 | | |
| SS SE | 2 | 10.7500 | 5.3750 | 1.9846 | 0.218 |
| SU SS SE | 6 | 16.2500 | 2.7083 | | |
| CORRECTION FACTOR | | 35.0417 | | | |

*SU=Subjects
**SS=Set Size($\underline{M}$=4 $\underline{T}$=1 vs. $\underline{M}$=1 $\underline{T}$=1 vs. $\underline{M}$=1 $\underline{T}$=4)
***SE=Session 15, Experiment 1 and Session 1, Experiment 3 vs. Target Cueing, Experiment 2

Reaction Time for Visual Subjects: Target Cueing

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 47109.8320 | 15703.2773 | | |
| SS | 2 | 1658.5833 | 829.2915 | 8.6024 | 0.018 |
| SU SS | 6 | 578.4167 | 96.4028 | | |
| SE | 1 | 6600.1641 | 6600.1641 | 39.3517 | 0.007 |
| SU SE | 3 | 503.1680 | 167.7227 | | |
| SS SE | 2 | 558.0820 | 279.0410 | 3.8974 | 0.082 |
| SU SS SE | 6 | 429.5833 | 71.5972 | | |
| CORRECTION FACTOR | | 3120488.1667 | | | |

Error Rate for Visual Subjects: Target Cueing

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 39.0000 | 13.0000 | | |
| SS | 2 | 24.2500 | 12.1250 | 3.1978 | 0.113 |
| SU SS | 6 | 22.7500 | 3.7917 | | |
| SE | 1 | 20.1667 | 20.1667 | 5.5846 | 0.098 |
| SU SE | 3 | 10.8333 | 3.6111 | | |
| SS SE | 2 | 3.5833 | 1.7917 | 0.4230 | 0.676 |
| SU SS SE | 6 | 25.4167 | 4.2361 | | |
| CORRECTION FACTOR | | 294.0000 | | | |

Reaction Time for Auditory Subjects: Memory Set Absent

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU* | 3 | 110934.1875 | 36978.0625 | | |
| SS** | 2 | 3633.5000 | 1816.7500 | 1.3123 | 0.337 |
| SU SS | 6 | 8306.5625 | 1384.4270 | | |
| CORRECTION FACTOR | | 2580768.7500 | | | |

Error Rate for Auditory Subjects: Memory Set Absent

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 13.6667 | 4.5556 | | |
| SS | 2 | 18.6667 | 9.3333 | 4.9412 | 0.054 |
| SU SS | 6 | 11.3333 | 1.8889 | | |
| CORRECTION FACTOR | | 56.3333 | | | |

Reaction Time for Visual Subjects: Memory Set Absent

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 13561.0000 | 4520.3320 | | |
| SS | 2 | 2732.1665 | 1366.0833 | 5.9031 | 0.038 |
| SU SS | 6 | 1388.4976 | 231.4163 | | |
| CORRECTION FACTOR | | 1680008.3333 | | | |

Error Rate for Visual Subjects: Memory Set Absent

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 44.9167 | 14.9722 | | |
| SS | 2 | 106.1667 | 53.0833 | 6.6585 | 0.030 |
| SU SS | 6 | 47.8333 | 7.9722 | | |
| CORRECTION FACTOR | | 290.0833 | | | |

*SU=Subjects
**SS=Set Size(*M*=1 *T*=1, Session 15, Experiment 1 vs. *M*=4 *T*=1, Session 15, Experiment 1 vs. *M*=X *T*=1, Memory Set Absent, Experiment 2)

# APPENDIX C

## SUMMARY ANOVA TABLES FOR EXPERIMENT 3

Reaction Time for Auditory Subjects: Secondary Task Baseline Measures

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU* | 3 | 115204.1875 | 38401.3945 | | |
| SS** | 2 | 5850.5000 | 2925.2500 | 29.1765 | 0.001 |
| SU SS | 6 | 601.5625 | 100.2604 | | |
| CORRECTION FACTOR | | 2170050.7500 | | | |

Error Rate for Auditory Subjects: Secondary Task Baseline Measures

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 47.5833 | 15.8611 | | |
| SS | 2 | 88.6667 | 44.3333 | 1.7655 | 0.249 |
| SU SS | 6 | 150.6665 | 25.1111 | | |
| CORRECTION FACTOR | | 102.0833 | | | |

Reaction Time for Visual Subjects: Secondary Task Baseline Measures

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 22018.2461 | 7339.4141 | | |
| SS | 2 | 2523.5000 | 1261.7500 | 4.9921 | 0.053 |
| SU SS | 6 | 1516.5039 | 252.7506 | | |
| CORRECTION FACTOR | | 1757970.7500 | | | |

Error Rate for Visual Subjects: Secondary Task Baseline Measures

| SOURCE | DF | SUM OF SQAURES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 48.9167 | 16.3055 | | |
| SS | 2 | 32.6667 | 16.3333 | 5.6538 | 0.042 |
| SU SS | 6 | 17.3333 | 2.8889 | | |
| CORRECTION FACTOR | | 184.0833 | | | |

*SU=Subjects
**SS=Set Size(*M*=4 *T*=1 vs. *M*=1 *T*=1 vs. *M*=4 *T*=1)

Reaction Time for Auditory Subjects in the Secondary Auditory Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 1117949.0000 | 372649.6250 | | |
| SS* | 2 | 29333.3750 | 14666.6875 | 9.4679 | 0.014 |
| SU SS | 6 | 9294.6250 | 1549.1040 | | |
| DU** | 3 | 2006982.0000 | 668994.0000 | 13.1730 | 0.002 |
| SU DU | 9 | 457067.0000 | 50785.2188 | | |
| SS DU | 6 | 14082.0000 | 2347.0000 | 1.3256 | 0.296 |
| SU SS DU | 18 | 31869.3750 | 1770.5208 | | |
| CORRECTION FACTOR | | 29030296.6875 | | | |

Error Rate for Auditory Subjects in the Secondary Auditory Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 82.2500 | 27.4167 | | |
| SS | 2 | 53.3750 | 26.6875 | 1.8379 | 0.238 |
| SU SS | 6 | 87.1250 | 14.5208 | | |
| DU | 3 | 150.9167 | 50.3055 | 2.5141 | 0.124 |
| SU DU | 9 | 180.0831 | 20.0092 | | |
| SS DU | 6 | 50.4583 | 8.4097 | 0.9284 | 0.501 |
| SU SS DU | 18 | 163.0416 | 9.0579 | | |
| CORRECTION FACTOR | | 396.7500 | | | |

Reaction Time for Auditory Subjects in the Primary Visual Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 236619.5000 | 78873.1250 | | |
| SS | 2 | 27785.0391 | 13892.5195 | 3.8271 | 0.085 |
| SU SS | 6 | 21780.0859 | 3630.0142 | | |
| DU | 3 | 7857.1641 | 2619.0547 | 1.4144 | 0.301 |
| SU DU | 9 | 16665.2734 | 1851.6970 | | |
| SS DU | 6 | 3664.4609 | 610.7434 | 0.5347 | 0.776 |
| SU SS DU | 18 | 20561.0781 | 1142.2820 | | |
| CORRECTION FACTOR | | 14511201.3333 | | | |

*SS=Set Size($\underline{M}$=4 $\underline{T}$=1 vs. $\underline{M}$=1 $\underline{T}$=1 vs. $\underline{M}$=1 $\underline{T}$=4)
**DU=Single vs. Dual Task manipulations(Single Task vs. Load Level 11 in the Other Task vs. Load Level 14 in the Other Task vs. Load Level 41 in the Other Task)

Error Rate for Auditory Subjects in the Primary Visual Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 133.7292 | 44.5764 | | |
| SS | 2 | 7.5417 | 3.7708 | 0.9065 | 0.545 |
| SU SS | 6 | 24.9583 | 4.1597 | | |
| DU | 3 | 3.0625 | 1.0208 | 0.3338 | 0.803 |
| SU DU | 9 | 27.5208 | 3.0579 | | |
| SS DU | 6 | 26.6250 | 4.4375 | 0.8726 | 0.535 |
| SU SS DU | 18 | 91.5415 | 5.0856 | | |
| CORRECTION FACTOR | | 266.0208 | | | |

Reaction Time for Visual Subjects in the Secondary Visual Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 1569264.0000 | 523088.0000 | | |
| SS | 2 | 10440.0391 | 5220.0195 | 1.5695 | 0.283 |
| SU SS | 6 | 19955.9609 | 3325.9934 | | |
| DU | 3 | 2239145.0000 | 746381.6250 | 11.8811 | 0.002 |
| SU DU | 9 | 565388.0000 | 62820.8867 | | |
| SS DU | 6 | 29012.0000 | 4835.3320 | 1.6784 | 0.133 |
| SU SS DU | 18 | 51858.0000 | 2881.0000 | | |
| CORRECTION FACTOR | | 26508755.0208 | | | |

Error Rate for Visual Subjects in the Secondary Visual Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 156.5625 | 52.1875 | | |
| SS | 2 | 4.8750 | 2.4375 | 0.2000 | 0.824 |
| SU SS | 6 | 73.1250 | 12.1875 | | |
| DU | 3 | 18.5625 | 6.1875 | 0.6085 | 0.629 |
| SU DU | 9 | 91.5208 | 10.1690 | | |
| SS DU | 6 | 64.6250 | 10.7708 | 1.5382 | 0.222 |
| SU SS DU | 18 | 126.0415 | 7.0023 | | |
| CORRECTION FACTOR | | 841.6875 | | | |

Reaction Time for Visual Subjects in the Primary Auditory Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 917798.4375 | 305932.8125 | | |
| SS | 2 | 123189.8750 | 61594.9375 | 2.0494 | 0.209 |
| SU SS | 6 | 180331.6875 | 30055.2813 | | |
| DU | 3 | 180798.4375 | 60266.1445 | 3.2480 | 0.074 |
| SU DU | 9 | 166994.1250 | 18554.9023 | | |
| SS DU | 6 | 30943.1875 | 5157.1953 | 1.2087 | 0.346 |
| SU SS DU | 18 | 76800.2500 | 4266.6797 | | |
| CORRECTION FACTOR | | 16964652.0000 | | | |

Error Rate for Visual Subjects in the Primary Auditory Task: Dual Memory Search

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 1762.4165 | 587.4722 | | |
| SS | 2 | 511.1665 | 255.5833 | 1.8694 | 0.234 |
| SU SS | 6 | 820.3335 | 136.7222 | | |
| DU | 3 | 99.4167 | 33.1389 | 0.7698 | 0.541 |
| SU DU | 9 | 387.4165 | 43.0463 | | |
| SS DU | 6 | 89.3333 | 14.9722 | 0.7142 | 0.644 |
| SU SS DU | 18 | 377.3333 | 20.9630 | | |
| CORRECTION FACTOR | | 1704.0833 | | | |

# APPENDIX D

## DUAL TASK EXPERIMENT: PARTIAL OVERLAP OF TRIALS

## PARTIAL OVERLAP OF DUAL TASK TRIALS

The effects of automatic responding processes for one task on the encoding of stimuli associated with another unpracticed task were investigated. These effects were examined by presenting the memory period for visual trials during the test period for auditory trials for subjects previously trained in auditory target responding. Thus, visual stimuli were encoded while subjects automatically responded to auditory targets. It was predicted that automatic auditory target responding requires increasing amounts of central resources as task load increments. This hypothesis would be confirmed if increases in test set size in the auditory task produced corresponding deficits in performance in the visual task. These deficits should be greater during encoding of four items than a single item.

### Method

The same subjects, apparatus, stimuli, design and procedure used in Experiment 1 were utilized in this experiment, except as noted. Limitations in instrumentation made it infeasible to present the memory period for auditory trials during the test period for visual trials. Consequently, subjects who developed visual target detection in Experiment 1 were not tested. The trial format consisted of 1) the auditory memory period for 250 ms 2) an auditory mask for 750 ms 3) simultaneous presentation of the auditory test period and visual memory period for 250 ms 4) an auditory mask and a visual mask for 750 ms 5) an auditory mask and the visual test period for 250 ms 6) an auditory mask and a visual mask for 750 ms and 7) a visual mask for 1 s.

The trial sequence is illustrated in Figure 1. The ITI was 1 s. This duration was sufficient for subjects to respond.

Six blocks of 64 trials were given. For three of these blocks, memory set size equalled 1 and test set size varied at 1, 2 or 4 in the auditory task while memory and test set size were held constant at M=1 T=1 in the visual task. For the other three blocks M=1 and T=1, 2 or 4 in the auditory task while M=4 and T=1 in the visual task. Thus, load varied systematically during the test period of the automated auditory task (constituting automatic auditory search) and at the lowest and highest load levels during the memory period of the visual task (constituting visual memory search). Subjects were instructed to perform each task with speed and accuracy. All blocks were given in one session.

## Results and Discussion

Mean RT and error rate were calculated for each subject for each condition. Data for positive and negative trials were combined. The results are presented in Figure 5. The left panel displays performance in the automated auditory task across test set size at load levels 11 and 41 in the visual task. Error rates for load levels 11 and 41 in the visual task are represented on the left and right of each test set size mark, respectively. Responses in the visual task as a function of memory set size and load level in the auditory task appear in the right panel. Error rates for auditory test set sizes 1, 2 and 4 are indicated by the open and shaded bars to the left and open bar to the right of each memory set size mark, respectively.

Responses in the Automated Auditory Task

RT data were analyzed using a 3(auditory test set size) X 2(visual memory set size) repeated measures ANOVA. No significant difference was found for the main effect of auditory test set size, $F\ (2, 6)=.43$, $p>.05$, $MSe=644$, and visual memory set size, $F\ (1, 3)=.15$, $p>.05$, $MSe=1460$. Their interaction was significant, $F\ (2, 6)=5.49$, $p<.05$, $MSe=156$.

The same analysis was performed on the error rate data. No significant difference in error rate was obtained across test set size, $F\ (2, 6)=.31$, $p>.05$, $MSe=1.61$, memory set size, $F\ (1, 3)=.00$, $p>.05$, $MSe=1.44$, and for the interaction term, $F\ (2, 6)=.57$, $p>.05$, $MSe=2.61$.

The results were as expected. Responding in the auditory task was automatic. No changes over test set size in the auditory task were observed. Also, changes in memory set size in the visual task did not affect performance in the auditory task.

Responses in the Visual Task

A 2(visual memory set size) X 3(auditory test set size) repeated measures ANOVA was applied to the RT scores. RT varied significantly across memory set size levels, $F(1, 3)=67.49$, $p<.005$, $MSe=40.15$. Load manipulations in the auditory task caused a significant change in RT, $F\ (2, 6)=6.01$, $p<.05$, $MSe=272$. The interaction term was not significant, $F\ (2, 6)=.33$, $p>.05$, $MSe=289$.

The same analysis performed on error rate data revealed no significant main effects of memory set size, $F\ (1, 3)=.93$, $p>.05$, $MSe=1.61$, and test set size, $F\ (2, 6)=1.09$, $p>.05$, $MSe=5.5$, or their interaction, $F\ (2, 6) =1.93$, $p>.05$, $MSe=.78$.

Responses in the visual task were consistently slower at memory set size 4. The unusual finding was that response latency decreased as a function of increases in auditory test set size. This results does not support the prediction that increases in test set size in the automated auditory task would cause RT to increase in the visual task.

Conclusions

The results showed that performance in an automated task had relatively no deleterious effects on encoding processes associated with another task. However, the possibility of time-sharing between tasks cannot be confidently ruled out because of a possible methodological weakness. It was anticipated that simultaneous presentation of the auditory test period and visual memory period for 250 ms would be sufficiently brief to make it difficult for subjects to switch attention between tasks. It is argued, however, that a much shorter time interval is required to eliminate to possibility of attention-switching. It is estimated that the duration should be approximately 100-150 ms.

SUMMARY ANOVA TABLES FOR THE PARTIAL OVERLAP EXPERIMENT

Reaction Time in the Auditory Task

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU* | 3 | 321151.4375 | 107050.4375 | | |
| SS** | 2 | 549.0000 | 274.5000 | 0.4264 | 0.674 |
| SU SS | 6 | 3862.6875 | 643.7813 | | |
| PO*** | 1 | 222.0417 | 222.0417 | 0.1521 | 0.719 |
| SU PO | 3 | 4380.0820 | 1460.0273 | | |
| SS PO | 2 | 1714.3333 | 857.1665 | 5.4944 | 0.044 |
| SU SS PO | 6 | 936.0417 | 156.0070 | | |
| CORRECTION FACTOR | | 4739259.3750 | | | |

Error Rate in the Auditory Task

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 12.8333 | 4.2778 | | |
| SS | 2 | 1.0000 | 0.5000 | 0.3103 | 0.747 |
| SU SS | 6 | 9.6667 | 1.6111 | | |
| PO | 1 | 0.0000 | 0.0000 | 0.0000 | ***** |
| SU PO | 3 | 4.3333 | 1.4444 | | |
| SS PO | 2 | 3.0000 | 1.5000 | 0.5745 | 0.594 |
| SU SS PO | 6 | 15.6667 | 2.6111 | | |
| CORRECTION FACTOR | | 13.5000 | | | |

Reaction Time in the Visual Task

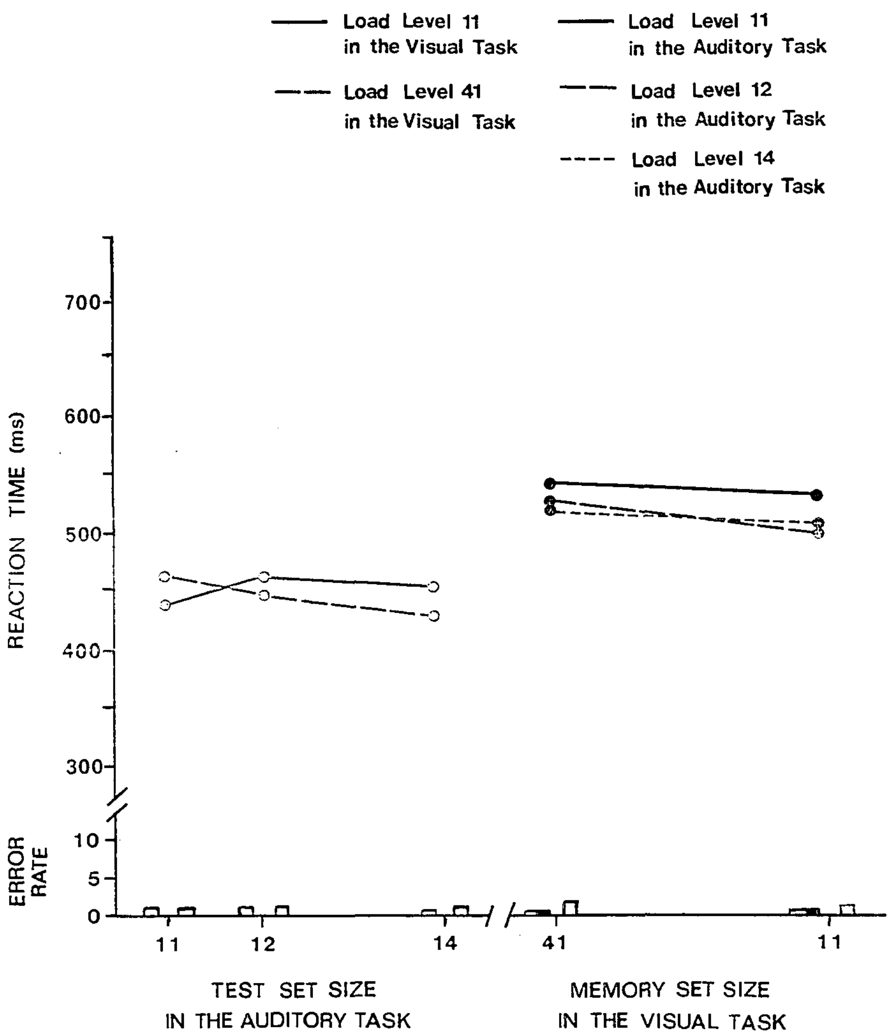
| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 108650.4375 | 36216.8125 | | |
| SS**** | 1 | 2709.3750 | 2709.3750 | 67.4883 | 0.003 |
| SU SS | 3 | 120.4375 | 40.1458 | | |
| PO***** | 2 | 3263.2500 | 1631.6250 | 6.0081 | 0.037 |
| SU PO | 6 | 1629.4375 | 271.5728 | | |
| SS PO | 2 | 187.7500 | 93.8750 | 0.3250 | 0.737 |
| SU SS PO | 6 | 1732.9375 | 288.8228 | | |
| CORRECTION FACTOR | | 6424245.3750 | | | |

*SU=Subjects
**SS=Set Size(_M_=1 _T_=1 vs. _M_=1 _T_=2 vs. _M_=1 _T_=4)
***PO=_M_=1 _T_=1 in the Visual Task vs. _M_=4 _T_=1 in the Visual Task
****SS=Set Size (_M_=4 _T_=1 vs. _M_=1 _T_=1)
*****PO=_M_=1 _T_=1 in the Auditory Task vs. _M_=1 _T_=2 in the Auditory Task vs. _M_=1 _T_=4 in the Auditory Task

Error Rate in the Visual Task

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F-RATIO | PROB |
|---|---|---|---|---|---|
| SU | 3 | 29.5000 | 9.8333 | | |
| SS | 1 | 1.5000 | 1.5000 | 0.9310 | 0.592 |
| SU SS | 3 | 4.8333 | 1.6111 | | |
| PO | 2 | 12.0000 | 6.0000 | 1.0909 | 0.396 |
| SU PO | 6 | 33.0000 | 5.5000 | | |
| SS PO | 2 | 3.0000 | 1.5000 | 1.9286 | 0.225 |
| SU SS PO | 6 | 4.6667 | 0.7778 | | |
| CORRECTION FACTOR | | 13.5000 | | | |

*Figure 5*. Performance curves for the partial overlap of dual task trials are shown. Reaction time and error rate are plotted against test set size in the auditory task and memory set size in the visual task. Error rates in the auditory task at load levels 11 and 41 in the visual task are given to the left and right of each test set size mark, respectively. Error rates in the visual task at auditory test set sizes 1, 2 and 4 are represented by the open and shaded bars to the right and open bar to the left of each memory set size mark, respectively. Data are collapsed across positive and negative trials.


Load Level 11
in the Visual Task
Load Level 41
in the Visual Task
Load Level 11
in the Auditory Task
Load Level 12
in the Auditory Task
Load Level 14
in the Auditory Task
REACTION TIME (ms)
700
600
500
400
300
ERROR RATE
10
5
0
11
12
14
41
11
TEST SET SIZE
IN THE AUDITORY TASK
MEMORY SET SIZE
IN THE VISUAL TASK

TABLES

TABLE 1

Percent Errors for Experiment 1

Auditory Subjects

| | | Memory/Test Set Size | | | | |
|---|---|---|---|---|---|---|
| | | 41 | 21 | 11 | 12 | 14 |
| Session 1: | positive trials | 6 | 6 | 2 | 2 | 1 |
| | negative trials | 6 | 2 | 2 | 3 | 1 |
| Session 15: | positive trials | 2 | 3 | 0 | 0 | 0 |
| | negative trials | 4 | 2 | 0 | 1 | 1 |

Visual Subjects

| | | Memory/Test Set Size | | | | |
|---|---|---|---|---|---|---|
| | | 41 | 21 | 11 | 12 | 14 |
| Session 1: | positive trials | 6 | 5 | 6 | 6 | 7 |
| | negative trials | 5 | 2 | 1 | 2 | 6 |
| Session 15: | positive trials | 4 | 4 | 2 | 4 | 7 |
| | negative trials | 6 | 3 | 1 | 4 | 2 |

TABLE 2

Percent Errors for Target Cueing, Experiment 2

Auditory Subjects

| | Test Set Size 11 | 12 | 14 |
|---|---|---|---|
| No Target Cue Condition | 0.75 | 2.00 | 0.50 |
| Target Cue Condition | 0.75 | 0.75 | 2.50 |

Visual Subjects

| | Test Set Size 11 | 12 | 14 |
|---|---|---|---|
| No Target Cue Condition | 1.25 | 2.75 | 3.75 |
| Target Cue Condition | 3.75 | 3.50 | 6.00 |

TABLE 3

Reaction Time and Error Rate for the Memory Set Absent Phase of Experiment 2

Auditory Subjects

| | Memory Set Size | | | | | |
|---|---|---|---|---|---|---|
| | Reaction Time | | | Percent Errors | | |
| | 41 | 11 | X1* | 41 | 11 | X1 |
| Positive Trials | 479 | 439 | 472 | 2 | 0 | 1 |
| Negative Trials | 488 | 443 | 462 | 4 | 0 | 7 |

Visual Subjects

| | Memory Set Size | | | | | |
|---|---|---|---|---|---|---|
| | Reaction Time | | | Percent Errors | | |
| | 41 | 11 | X1 | 41 | 11 | X1 |
| Positive Trials | 386 | 347 | 360 | 4 | 2 | 6 |
| Negative Trials | 403 | 371 | 377 | 6 | 1 | 12 |

*Absence of the Memory Set

TABLE 4

Percent Errors for Experiment 3

Auditory Subjects

| | Memory/Test Set Size 41 | 11 | 14 |
|---|---|---|---|
| Secondary Auditory Task: | | | |
| single task baseline measures | 7 | 1 | 1 |
| load level 11 in the visual task | 6 | 6 | 5 |
| load level 14 in the visual task | 2 | 1 | 1 |
| load level 41 in the visual task | 3 | 1 | 1 |
| Primary Visual Task: | | | |
| single task baseline measures | 1 | 4 | 2 |
| load level 11 in the auditory task | 3 | 2 | 2 |
| load level 14 in the auditory task | 4 | 2 | 2 |
| load level 41 in the auditory task | 3 | 2 | 0 |

Visual Subjects

| | Memory/Test Set Size 41 | 11 | 14 |
|---|---|---|---|
| Secondary Visual Task: | | | |
| single task baseline measures | 5 | 2 | 4 |
| load level 11 in the auditory task | 3 | 5 | 4 |
| load level 14 in the auditory task | 3 | 5 | 2 |
| load level 41 in the auditory task | 5 | 6 | 5 |
| Primary Auditory Task: | | | |
| single task baseline measures | 6 | 2 | 6 |
| load level 11 in the visual task | 15 | 3 | 7 |
| load level 14 in the visual task | 8 | 1 | 6 |
| load level 41 in the visual task | 8 | 1 | 7 |

FIGURES

Figure 1. The auditory memory search trial sequence is illustrated in a. In this example, M=2 T=1 and the trial is negative. Sections within horizontal lines depict different tracks on ¼" magnetic recording tape. The trial format for visual memory search is presented in b. A positive trial is shown at M=1 T=2.

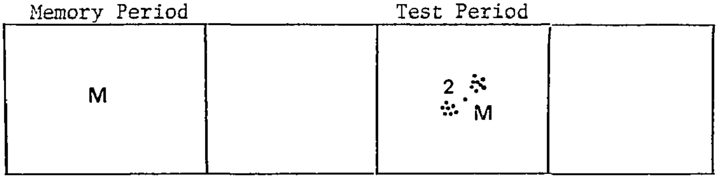
Auditory Trial Format

| Memory Period | | Test Period | |
|---|---|---|---|
| | white noise | | white noise |
| 210 Hz | white noise | | white noise |
| | white noise | 590 Hz | white noise |
| 360 Hz | white noise | | white noise |
| -----250 ms----- | ----750 ms--- | ----250 ms--- | ----1.75 s--- |

a

Visual Trial Format

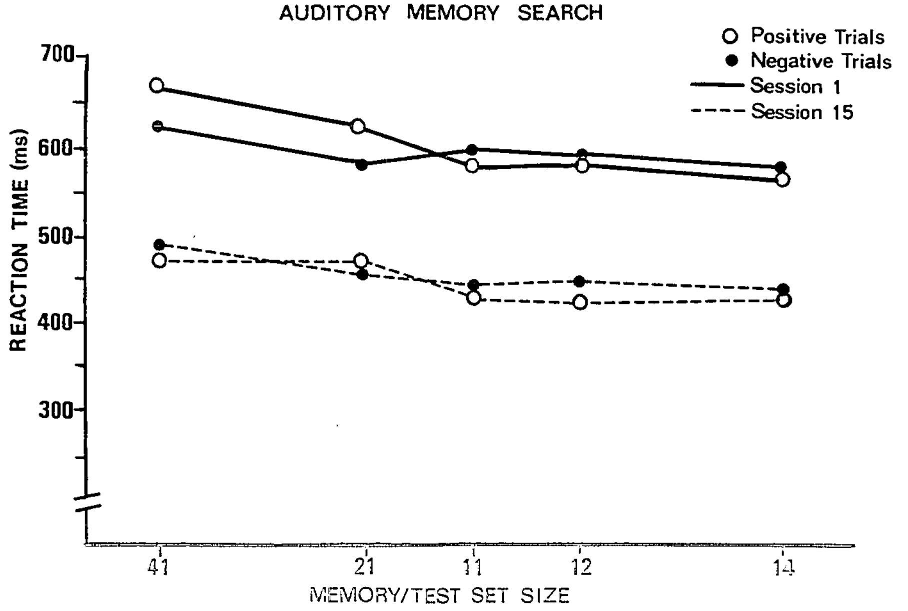
Memory Period                Test Period




-----250 ms----- ----750 ms--- ----250 ms--- ----1.75 s---

b

*Figure 2*. Reaction time is plotted as a function of memory/test set size, trial type and Sessions 1 and 15 for the auditory and visual memory search tasks of Experiment 1. (Error rates appear in Table 1.)


AUDITORY MEMORY SEARCH
Positive Trials
Negative Trials
Session 1
Session 15
700
600
500
400
300
REACTION TIME (ms)
41
21
11
12
14
MEMORY/TEST SET SIZE

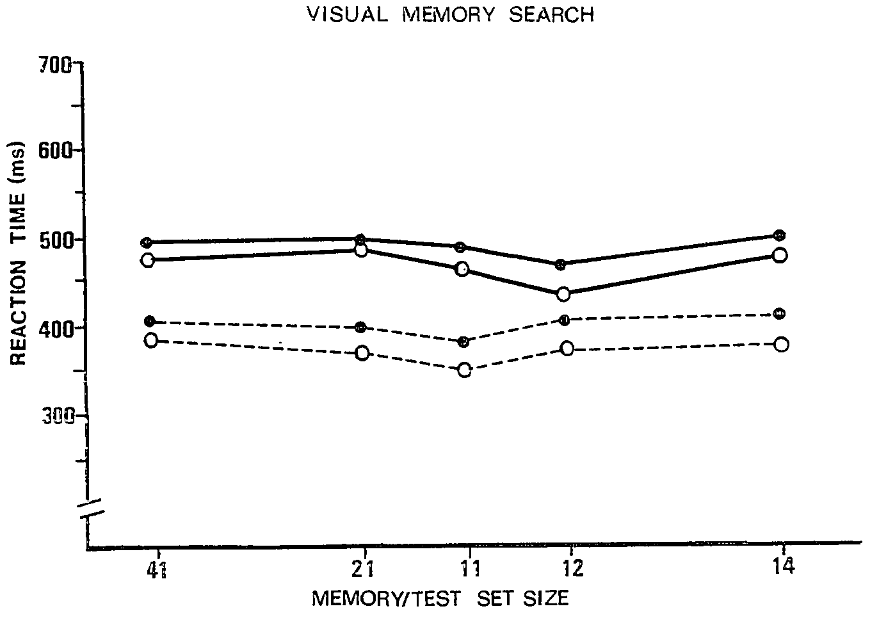
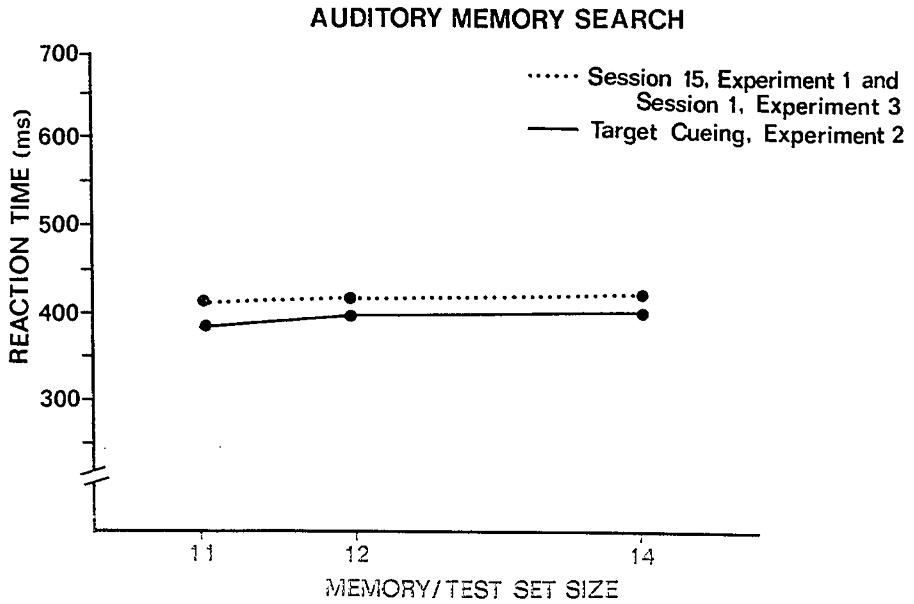

VISUAL MEMORY SEARCH
700
600
500
400
300
REACTION TIME (ms)
41
21
11
12
14
MEMORY/TEST SET SIZE

*Figure 3*. Data for the target cueing phase of Experiment 2 are presented. Reaction time for auditory and visual search are graphed against set size and target cueing vs. non-cueing conditions. The trial type factor is collapsed.


AUDITORY MEMORY SEARCH
Session 15, Experiment 1 and Session 1, Experiment 3
Target Cueing, Experiment 2
REACTION TIME (ms)
700
600
500
400
300
11
12
14
MEMORY/TEST SET SIZE

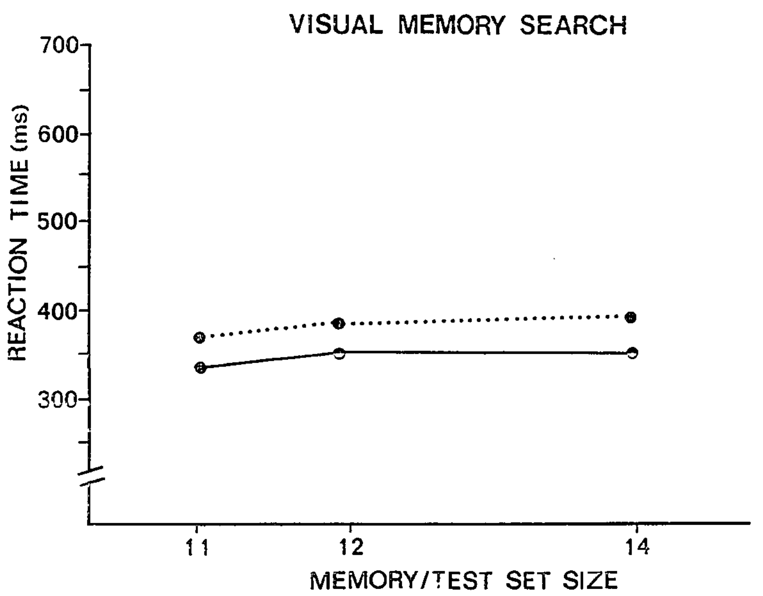
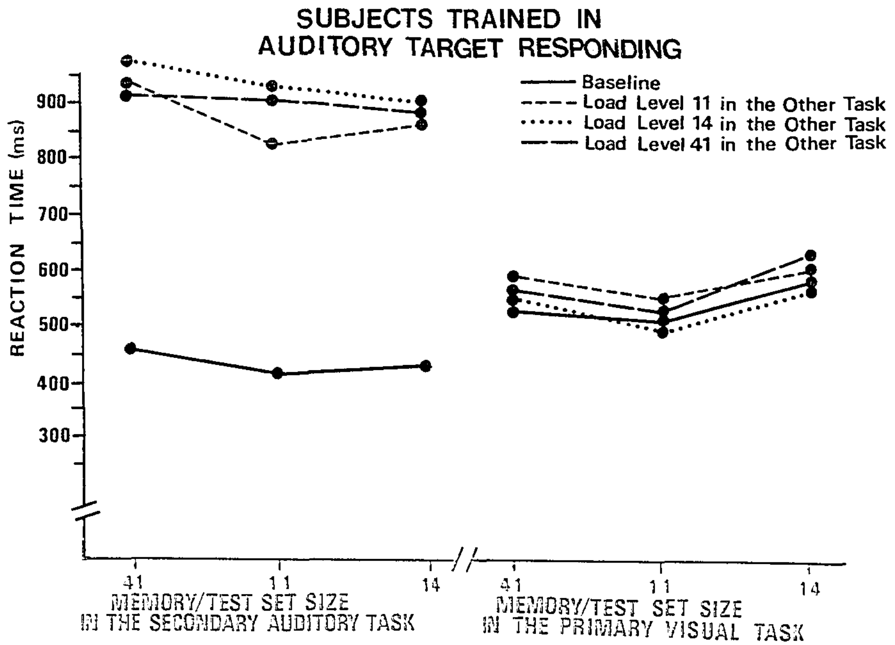
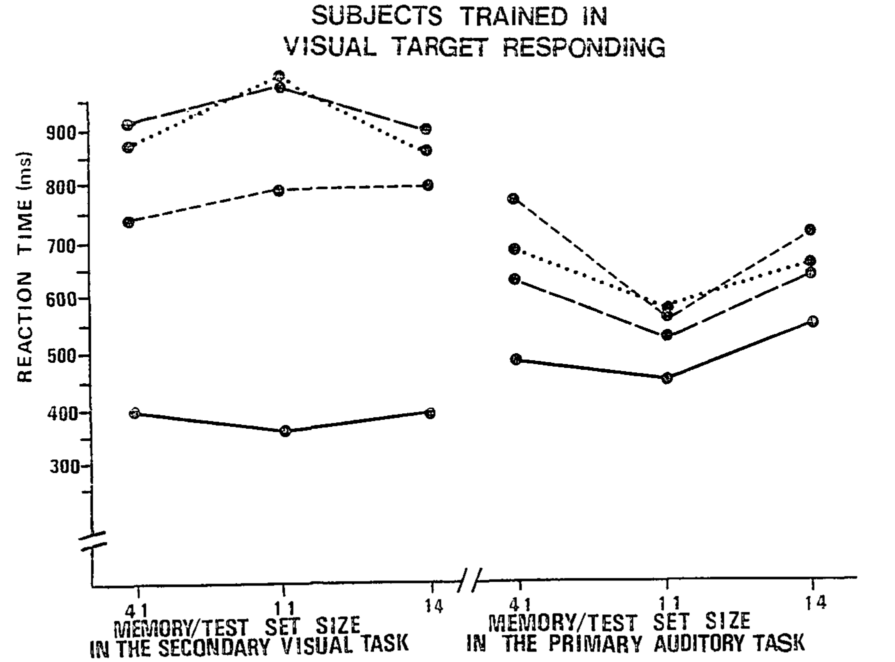

VISUAL MEMORY SEARCH
REACTION TIME (ms)
700
600
500
400
300
11
12
14
MEMORY/TEST SET SIZE

Figure 4. Reaction time for single/dual task conditions in Experiment 3 are plotted as a function of memory/test set size and load level in the other task for both the primary and visual tasks. Data are combined over positive and negative trials. Performance curves for subjects trained in auditory target responding appear in the upper panel and responses for subjects trained in visual target responding are given in the lower panel. Only the extreme load levels were tested.


SUBJECTS TRAINED IN
AUDITORY TARGET RESPONDING
Baseline
Load Level 11 in the Other Task
Load Level 14 in the Other Task
Load Level 41 in the Other Task
REACTION TIME (ms)
900
800
700
600
500
400
300
41
11
14
MEMORY/TEST SET SIZE
IN THE SECONDARY AUDITORY TASK
41
11
14
MEMORY/TEST SET SIZE
IN THE PRIMARY VISUAL TASK


SUBJECTS TRAINED IN
VISUAL TARGET RESPONDING
REACTION TIME (ms)
900
800
700
600
500
400
300
41
11
14
MEMORY/TEST SET SIZE
IN THE SECONDARY VISUAL TASK
41
11
14
MEMORY/TEST SET SIZE
IN THE PRIMARY AUDITORY TASK