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A COMPARISON OF TWO MODELS OF
STIMULUS SET AND RESPONSE SET
IN SELECTIVE ATTENTION

by

James K. Habinek

A Dissertation Submitted to the Faculty of the Graduate School
of Loyola University of Chicago in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

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VITA

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INTRODUCTION

Psychologists are in general agreement that humans are limited in their ability to process all the information that is available to them from the environment at any moment in time (Broadbent, 1958; Egeth, 1967; Kahneman, 1973; Treisman, 1964). As a consequence, some stimuli are ignored or rejected, while others are subjected to a variety of perceptual and cognitive analyses. The concept of selective attention has been developed to describe the ability of humans to select some information for analysis and reject other information. The questions of whether this active involvement is possible, and if so, the means by which it may be accomplished have stimulated a considerable amount of research using a wide variety of experimental paradigms.

Studies of selective attention have frequently employed some type of partial report paradigm (Egeth, 1967). An observer is presented with an array of stimuli exceeding in number the span of apprehension, and is required to attend to and report on a subset of the stimuli in the array (the relevant items) defined in terms of some selection criterion. Each such experiment may be described as having a vocabulary of allowable responses -- i.e., all members of the class or classes to which the relevant responses belong. The ability to report accurately on the appropriate subset of stimuli is generally taken as evidence for the existence of selective attention, while the inability to do so is regarded as evidence against the existence of selective attention.

Broadbent (1970) has identified two basic methods whereby the relevant and irrelevant stimuli may be differentiated in such a paradigm. On the one hand, the vocabulary of responses may be used to determine selection. This would be the case if irrelevant responses did not belong to the vocabulary of allowable responses. A simple example of such a situation is an experiment employing mixed arrays of letters and digits in which only digits are relevant stimuli. Subjects would never be expected to respond with a letter, since letters, by definition, are not allowable responses. Broadbent has termed selection of this type "response set" to emphasize the fact that selection is based on the meaning that is attached to the stimulus (a response), rather than upon physical differences among stimuli. On the other hand, selection may take place through the operation of what Broadbent calls "stimulus set". With this type of selection, irrelevant items are members of the set of allowable responses, but are differentiated from relevant items by some physical characteristic or feature uncorrelated with the class of allowable responses. An example of selection based on stimulus set is an experiment employing all-letter arrays, but consisting of both red and black letters, from which subjects must select red letters only. The selection criterion in this example is obviously based on a physical difference rather than upon the vocabulary of allowable responses, since both red and black letter names belong to the class of allowable responses.

Broadbent has argued that confusion in the experimental literature concerning evidence for or against the existence of selective attention is due largely to a failure to differentiate between stimulus set and response set conditions. Contradictory findings have been reported in

selective attention studies employing a pre- versus post-instruction paradigm. The method entails comparison of partial report performance when the criterion for selecting relevant items is presented before the stimulus array with performance when the criterion is presented after the array. Pre-instruction superiority suggests a mechanism capable of selectivity in the intake of information. According to Broadbent, researchers such as Lawrence and LaBerge (1956), Lawrence and Coles (1954), and Sperling (1960) failed to find such a superiority because they based selection on response set, while Broadbent (1952), Sperling (1960), and Swets and Sewall (1961) found the expected superiority in studies employing stimulus set. Broadbent contends that stimulus set allows rejection of irrelevant items after only one binary decision, whereas response set involves considerable analysis of irrelevant items prior to their rejection.

KEREN'S MODEL

Keren (1976) has recently taken this classification scheme of Broadbent and attempted to relate it to an attentive process scheme, devised by Neisser (1967) to describe two basic perceptual mechanisms involved in attention. According to Keren's model, preattentive processes -- which Neisser describes as acting rapidly, automatically, and in parallel to segregate objects in the stimulus array into integral units and to extract certain crude features from these units -- act in stimulus set conditions, while the processes of focal attention -- which are slower and operate serially to perform a detailed cognitive analysis of stimulus items -- are required in response set conditions. Different levels of cognitive processing of irrelevant items are implicated in the two selection methods, according to Keren, since with stimulus set conditions, analysis of irrelevant items can cease when preattentive mechanisms have identified the appropriate distinguishing characteristic upon which selection is to be based, whereas with response set conditions, irrelevant items must be fully analyzed by the processes of focal attention to determine whether or not they belong to the vocabulary of allowable responses.

Given these assumptions about the nature of preattentive processes and focal attention, Keren was able to devise experiments aimed at providing evidence to link these perceptual processes with Broadbent's stimulus classification scheme. Broadbent (1970) had demonstrated that pre- and post-stimulus presentation of instructions (selection criteria)

affected stimulus set and response set conditions differently. Basically, giving subjects the selection criterion before exposure to the stimulus array was shown to have a beneficial effect upon performance under stimulus set conditions, but not under response set conditions. Keren interpreted these results as showing that preattentive mechanisms could facilitate performance in the stimulus set pre-instruction condition by allowing rapid rejection of irrelevant items prior to their analysis by focal attention. For the stimulus set post-instruction condition, however, all items had to be analyzed by focal attention until selection was made possible upon presentation of the post-instruction. For response set conditions, all items must be analyzed thoroughly by focal attention before selection, regardless of the time at which selection instructions are given.

Keren replicated Broadbent's finding, using an improved methodology, and included an additional variation to test his model. He manipulated the spatial grouping of the relevant items in his stimulus arrays, arguing that the preattentive processes (functioning primarily in stimulus set conditions), which can operate in a parallel fashion, should be unaffected by such a manipulation, while the processes of focal attention (functioning in response set conditions), which must analyze items serially, would be facilitated by grouping relevant items together. Results were as predicted: the pre- versus post-instruction difference was significantly greater for the stimulus set condition than for the response set condition, and the spatial arrangement variable was significant for response set only.

Keren's Experiment 2 tested some predictions about the influence of various types of irrelevant (noise) items upon performance in stimulus

set and response set conditions. Subjects detected one target from among eight items in a circular array under pre-instruction conditions. The items in the irrelevant set were either response compatible, response incompatible, or neutral with respect to the target item. It was predicted that type of irrelevant items would not influence reaction time for detection in stimulus set conditions, since the irrelevant items would be incompletely processed. In response set conditions, however, response compatible irrelevant items were predicted to facilitate performance and response incompatible items to disrupt performance, since irrelevant items undergo a detailed analysis under response set. The significant interaction between type of irrelevant items and type of set bore out the predictions.

Keren's third experiment used an incidental learning paradigm and a depth of processing interpretation (Craik & Lockhart, 1972) to show that irrelevant items are probably "encoded" in response set conditions, but not in stimulus set conditions. After 20 selective attention trials similar to those in Experiments 1 and 2, subjects in response set conditions were able to recall significantly more irrelevant items than subjects in stimulus set conditions.

Keren concluded that stimulus set and response set should be regarded as being mediated by two types of underlying mechanisms or processes.

. . . Response set material requires the higher level processing of focal attention; it might be termed a process of cognitive selection. Stimulus set material requires only a rough and general processing, which is performed by preattentive mechanisms. This kind of selection might be labeled sensory perceptual selection. (p. 366.)

He further asserted that the two underlying attentional mechanisms are "to a certain extent" independent.

THE UNDIFFERENTIATED CAPACITY MODEL

Keren's suggested relationship between stimulus set and response set on the one hand, and preattentive processes and focal attention, on the other, provides that point of departure for an investigation of the nature of these hypothetical perceptual processes and their alleged independence. For example, he describes preattentive mechanisms as processing items in parallel and having no capacity limitations (i.e., their operation requires little or no capacity), and focal attention as operating serially and being bound by capacity limitations (i.e., its operation requires considerable capacity). Further, since the two mechanisms are independent, he asserts that the cognitive effort that must be allocated for their operation is probably not interchangeable. Thus, Keren's model is basically a structural model in which different tasks may be distinguished on the basis of the underlying mechanisms responsible for their completion.

An alternative theory of attention, called the undifferentiated capacity hypothesis by Kerr (1973), has been proposed and developed by Moray (1967) and Kahneman (1973). The theory is an energy model of attention in the sense that it suggests that all mental processes require "effort" or "capacity", available from a common, limited pool, the size of which fluctuates with demand and level of arousal. Two or more mental processes or mechanisms may operate simultaneously and without interference provided that their total demand does not exceed the available capacity. Thus, all mental processes are interdependent

because the mechanisms responsible for their completion are basically the same and tap a common pool of processing capacity. Two processes may appear to be independent if the sum of their capacity demands does not exceed that which is momentarily available.

The undifferentiated capacity model of attention might attempt to accommodate Keren's findings by suggesting that a more parsimonious way of describing response set and stimulus set tasks, rather than an appeal to two independent underlying mechanisms with different operating characteristics, would be to say the two stimulus classification schemes define tasks at different points on a continuum of capacity demand. Stimulus set tasks and response set tasks are mediated by mechanisms which tap the same pool of available processing capacity, but stimulus set tasks place only a very small demand on this pool, while response set tasks place a large demand on it. Parallel processing appears possible in stimulus set conditions because the amount of capacity required for the analysis of each item is so small that the total demand of multiple analyses falls short of the available capacity. Response set conditions elicit serial processing because the analysis of each item requires a large portion of the available momentary capacity.

THE EXPERIMENTS

The present study involves a further investigation of the properties of stimulus set and response set in an attempt to lend support to one or the other of the two models described above. In all experiments, stimuli consist of visually presented arrays of items in which half the items are relevant (to be reported) and half are irrelevant (to be ignored). In Experiment 1, a pre- versus post-instruction procedure is used to insure that the response set and stimulus set tasks employed in subsequent experiments fulfill an operational test suggested by both Broadbent (1970) and Keren (1976): namely, pre-instruction performance should be facilitated relative to post-instruction performance for stimulus set, but not response set conditions. Two response set and two stimulus set conditions, which fulfilled this criterion, were selected.

In Experiment 2, a secondary task technique (see Kerr, 1973) is employed to assess the processing demands of each of the tasks chosen in the first experiment. The technique involves performing a short term memory task simultaneously with an attention task. The capacity demands of the attention task are assessed in terms of the deficit in performance on the memory task, relative to when the memory task is performed alone. In addition, array size is manipulated in Experiment 2 to test some predictions of the two models. Keren's model predicts increases in capacity requirements with increases in

array size for response set, but not for stimulus set tasks. The undifferentiated capacity model predicts such increases for all tasks.

In Experiment 3, each possible pairing of the four tasks chosen in Experiment 1 is investigated using a compound task procedure. With this method, relevant items in each stimulus array are defined in terms of either one of two selection criteria. Thus, in a given experimental condition, (1) selection of some relevant items in a single stimulus array may be based on stimulus set and selection of others on response set; (2) selection of some relevant items may be based on one type of stimulus set and selection of others on another type of stimulus set; and (3) selection of some relevant items may be based on one type of response set and selection of others on another type of response set. Interest in Experiment 3 lies in the difficulty produced by attempting to select two types of items in an array in comparison to when selection is for only one type of item. The two models of stimulus set and response set make testable predictions about the outcome of Experiment 3.

Three predictions may be derived from Keren's mode. First, simultaneously performed response set and stimulus set tasks should not interfere with one another, since they are mediated by two independent mechanisms. Second, two simultaneously performed stimulus set tasks should not interfere with one another, since the mechanism mediating their performance makes minimal capacity demands and can operate on items in parallel. Third, two simultaneously performed response set tasks should interfere with one another, since the mechanism mediating their performance must operate on items serially and requires considerable capacity. Predictions of the undifferentiated capacity model are less specific. Basically, degree of interference is predicted to be

directly related to the total amount of capacity demanded by the two tasks. Any two tasks will interfere with one another if their total demand on capacity is great and exceeds the capacity that is available. By the same reasoning, two tasks will not interfere with one another if their total demand is small and does not exceed the available capacity. Thus, the undifferentiated capacity model makes the general prediction that the results of Experiment 3 will reflect the capacity demands of the four tasks as measured in Experiment 2, and will not depend specifically on the type of set required by the tasks involved in each condition.

EXPERIMENT 1

Stimulus set and response set conditions may be defined in terms of task and type of stimulus materials. To reiterate, stimulus set is produced when relevant and irrelevant items can be differentiated from one another solely on the basis of simple physical differences. Both correct (relevant items) and incorrect (irrelevant items) responses belong to the class of allowable responses, so the two sets of stimulus items must be distinguished by some feature unrelated to response class. For example, stimulus arrays may consist entirely of letters of the alphabet, with relevant and irrelevant items being differentiated on the basis of orientation. Relevant items might be defined as those presented in a normal orientation, and irrelevant items as those rotated clockwise 90° . In this example response to both relevant and irrelevant items belong to the class "letters of the alphabet." Orientation, which distinguishes relevant from irrelevant items, is unrelated to the class of allowable responses, but serves as the basis of selection.

Response set, on the other hand, is produced when relevant and irrelevant items may be distinguished on the basis of membership in the class of allowable responses. If stimulus arrays consist of a mixture of letters and digits, for example, then a "number" response is clearly incorrect when the relevant items are defined as those belonging to the class "letters of the alphabet." The supposition is made that no single physical feature differentiates reliably the relevant and

irrelevant items, although it is recognized that it would be impossible to specify two classes of responses in which no stimulus differences existed between relevant and irrelevant items (Garner, 1976).

A simple prediction can be made about the relative effectiveness of stimulus set and response set when selective attention is studied by employing a pre-instruction versus post-instruction technique. In such a paradigm, an array of relevant and irrelevant items is either immediately preceded by or immediately followed by an instruction concerning which items to report. Superior performance when the instruction is presented before the array is widely accepted as evidence for selective attention in the intake of information. Equivalent performance in both the pre- and post-instruction conditions is regarded as evidence against selectivity in information intake. Both Broadbent (1970) and Keren (1976) predict that stimulus set will produce greater superiority in the pre-instruction condition than will response set. The advantage of stimulus set in pre-instruction conditions arises from the ease with which irrelevant items may be rejected from further analysis. In stimulus set, a single binary decision about the physical dimension which distinguishes relevant from irrelevant items will determine whether an item should be retained or rejected. In response set, a more detailed analysis of an item -- certainly more than one stimulus dimension -- must be conducted before a decision can be reached about that item's relevance. Therefore, the pre-instruction condition will produce relatively little advantage when response set is employed.

Broadbent (1970) argues that controversy in the research literature concerning the ability of human observers to selectively attend to some

portions of a stimulus array while ignoring others can be dispelled if one takes into account whether stimulus set or response set is used. Failure to find a pre-instruction advantage has been associated with the use of response set in studies by Lawrence and LaBerge (1956), Lawrence and Coles (1954), Sperling (1960), and Treisman (1964), whereas the occurrence of a pre-instruction advantage appears to be dependent upon the use of stimulus set in studies by Broadbent (1952), Cherry (1953), Cherry and Taylor (1954), Sperling (1960), Swets and Sewall (1961), and Von Wright (1968, 1970).

In Experiments 2 and 3, various predictions about stimulus set and response set tasks are tested through the use of secondary tasks and compound tasks. Two examples of each task type are required for these experiments. Therefore, in Experiment 1 two nominal stimulus set tasks and two nominal response set tasks are studied in a pre-instruction versus post-instruction paradigm to assure that they fulfill the prediction described above. Specifically, it is predicted that an analysis of variance of the results will yield a significant interaction between task type (stimulus set versus response set) and time of instruction (pre- versus post-). The pre-instruction advantage of the stimulus set tasks should be significantly greater than the pre-instruction advantage of the response set tasks. The two stimulus set tasks consist of differentiating between small and large items in all-letter arrays, and between bright and dim items in all-letter arrays. The two response set tasks consist of differentiating between odd and even digits in all-number arrays, and between vowels and consonants in all-letter arrays.

METHOD

Subjects

Eight Loyola University undergraduates, participating in the experiment to fulfill a course requirement, served as subjects.

Apparatus

Stimuli were presented on a VR-14 cathode ray tube display screen under the control of a DEC PDP 8/e computer. The display surface of the CRT was coated with an ultra-short-persistence phosphor (P24), having a decay time of a few microseconds. The software employed permitted presentation of alphanumeric characters at any location on the display surface for any length of time. Characters were formed by intensifying the appropriate points in a five by seven matrix of points. The CRT was located in a dimly illuminated room adjacent to the room housing the computer. Experimenter and subject communicated with one another by means of an Archer Intercom System (Model no. 43-221). A chinrest was used to minimize head movements and to insure that all subjects sat at a distance of 60 cm from the display screen surface.

Stimuli

For all conditions of Experiment 1, a stimulus character was presented in each of eight equally spaced locations of a circular array,

3° of visual angle in diameter. Four locations contained relevant (to-be-reported) items and four locations contained irrelevant (to-be-ignored) items. The location of irrelevant and relevant items was random with the restriction that no array contain more than two adjacent relevant items.

Four basic types of stimulus arrays were constructed, corresponding to the four different tasks investigated in Experiment 1. For the first stimulus set task (S1), arrays consisted of four large and four small uppercase letters. Large letters subtended $.3^{\circ}$ of visual angle, and small letters $.2^{\circ}$ in height and width. All letters were presented at a luminance of 1.35 mL (as measured by an Ilford (SEI) photometer), on the dark background of the screen. The letters C, J, P, and X were chosen for stimulus characters on the basis of their minimal visual interconfusability (Mayzner, 1972). Selection of letters from this set for appearance in each location of each array was random. For the second stimulus set task (S2), arrays consisted of four bright and four dim letters. Bright letters were presented at a luminance of 1.35 mL and dim letters at 0.28 mL. All letters subtended $.3^{\circ}$ of visual angle. Differences in luminance in this condition and in subsequent experiments were achieved by manipulating the rate at which characters were refreshed on the CRT. Bright characters were plotted three times as frequently as dim characters. Again, the letters C, J, P, and X were used, and selection of letters to fill the eight locations in each array was random. For the first response set task (R1), single digit numbers (2-9) were used as stimulus items. Four digits in each array were even (2, 4, 6, or 8), and four were odd (3, 5, 7, or 9). All numbers subtended $.3^{\circ}$ and were presented at a luminance of 1.35 mL.

For the second response set task (R2), arrays were composed of four consonants and four vowels. The letters C, J, P, and X were used as consonants, and A, E, I, and O as vowels. All letters subtended $.3^\circ$ and were presented at a luminance of 1.38 mL. For both response set tasks, selection of appropriate characters for each location in each array was random.

Stimulus arrays in all conditions were preceded and followed by indicators on each trial. The indicator consisted of a single character presented at a location on the display screen equivalent to the center of the circular stimulus array. Indicators served as both a fixation point and as a cue informing the subject which items to report. All indicators subtended $.25^\circ$ of visual angle and were presented at a luminance of 1.35 mL. In task S1, the letter S indicated that the four small letters should be reported on that trial, while the letter L indicated that the four large letters should be reported. Similarly, in task S2 a B called for report of bright items and a D report of dim items; in task R1 an O called for report of odd items and an E report of even items; and in task R2 a V called for report of vowels and a C for report of consonants.

Within each condition, a report indicator appeared either before or after each trial (pre-instruction versus post-instruction conditions). When the report indicator followed the array, a dummy indicator was used before the array to warn the subject that a trial had begun and to serve as a fixation guide. Dummy indicators consisted of a five by seven matrix of intensified points. When the report indicator preceded the stimulus array, an additional indicator consisting of either the digit 0 or 1 was used after the array. This post-array indicator

instructed the subject to place his or her answers in one of two columns on the answer sheet. The rationale for this additional column indicator in the pre-instruction condition was to insure that the duration of the retention period between offset of the stimulus array and written report of the relevant items was equivalent in both the pre-instruction and post-instruction conditions. The following sequence of events took place on each trial: a 1000 msec presentation of either a report indicator or a dummy indicator, a 250 msec interstimulus interval (ISI), a 60 msec presentation of the stimulus array, a 250 ISI, and a 1000 msec presentation of either a report indicator or a column indicator. Inter-trial intervals were determined by subjects and averaged approximately five to ten seconds. Indicator and array durations, and ISIs were determined on the basis of pilot data which indicated that such values would elicit performance that was typically well above chance and well below perfect performance.

For each of the four experimental tasks, a total of 96 arrays was constructed. Forty-eight arrays were used in the pre-instruction condition, and 48 in the post-instruction condition. Since each task type contained two criteria by which relevant items could be selected (e.g., in S1, small or large items), a random half of the arrays in each condition required report by one criterion, and the other half report by the other criterion.

Procedure

There were eight conditions in Experiment 1 created by factorially combining each task type with pre- and post-stimulus display of

instructions. Subjects attended two experimental sessions, approximately 60 min in duration, and participated in two conditions per session. Order of tasks was counterbalanced across subjects, with the added restriction that both sessions included one stimulus set and one response set task. Within the 96 trials devoted to each task, order of pre- and post-instruction trials was randomized. A different random order was used for each subject. Prior to performing the experimental trials in each task, subjects were given 12 practice trials identical in nature to the experimental trials of that task. Subjects were required to guess if they were uncertain of the appropriate response; four answers were thus obtained per trial from each subject.

RESULTS

The main results of Experiment 1 are presented in Table 1. Mean percent correct responses are given for each task in both the pre-instruction and post-instruction conditions. A four-way analysis of variance of the data of Experiment 1, considering type of set (stimulus set or response set), task nested within set type (S1, S2, R1, or R2), temporal position of instruction (pre- or post-), and response criterion nested within set and task type (small, large, bright, dim, odd, even, vowel, or consonant), as factors, yielded significant main effects of instruction, $F(1,7) = 158.34$, $p < .001$; task, $F(2,14) = 4.48$, $p < .05$; and criterion, $F(4,28) = 8.50$, $p < .001$; and a significant interaction of set with instruction, $F(1,7) = 49.04$, $p < .001$. Further comparisons of each stimulus set task with each response set task indicated that the pre-instruction advantages found in both stimulus set tasks were clearly superior to those found in both response set tasks. A significant task by instruction interaction in the expected direction was found for the comparison of S1 with R1, $F(1,7) = 40.10$, $p < .001$; for the comparison of S1 with R2, $F(1,7) = 21.25$, $p < .005$; for the comparison of S2 with R1, $F(1,7) = 35.92$, $p < .001$; and for the comparison of S2 with R2, $F(1,7) = 40.82$, $p < .001$. Performance in all conditions was significantly better than chance.

Table 1

MEAN PERCENT CORRECT PERFORMANCE SUMMED ACROSS SUBJECTS
FOR EACH CONDITION OF EXPERIMENT 1

Instruction	Stimulus Set		Response Set	
	Small/Large	Bright/Dim	Odd/Even	Vowel/Consonant
Pre-				
\bar{X}	72.66	77.34	69.86	70.51
SD	3.91	4.61	5.69	5.19
Post-				
\bar{X}	62.43	66.02	66.08	69.08
SD	4.75	5.49	5.28	6.52

DISCUSSION

The primary purpose of Experiment 1 was to insure that the tasks chosen for further study were representative of two stimulus set conditions and two response set conditions. By definition, selecting items from an array on the basis of size or brightness involves stimulus set, and selection by membership in the categories odd and even, or vowel and consonant involves response set. Experiment 1 was designed to test the prediction suggested by Broadbent (1970) and Keren (1976), that a greater advantage would occur in pre-instruction trials when a task involved stimulus set than when it involved response set. Analysis of the results showed that the four tasks chosen fulfilled this prediction. Significant interactions between task type and temporal position of instructions found in comparisons of each stimulus set task with each response set task demonstrated a clear pre-instruction advantage for the stimulus set tasks. Predictions about the perceptual and cognitive mechanisms mediating processing in stimulus set tasks and response set tasks were tested in Experiments 2 and 3 using the four tasks tested in Experiment 1.

EXPERIMENT 2

According to the undifferentiated capacity model of attention, different mental tasks impose different demands upon the hypothesized pool of capacity available for the performance of such tasks. It seems reasonable to propose that one difference between tasks involving stimulus set and those involving response set is the amount of capacity each type of task requires. Stimulus set tasks could be characterized as making small demands on available capacity, and response set tasks as making large demands. On the other hand, capacity demand may be unrelated to type of set. For the present interpretation of the undifferentiated capacity model, differences in required capacity are assumed to be the only differences in the performance of various types of tasks. Experiment 2 has been designed to provide a relative measure of the amount of capacity required by the four tasks selected in the previous experiment.

In Experiment 2, a secondary task technique is used to assess the capacity demands of the attention tasks. Kerr (1973), in an extensive review of research involving an attempt to measure processing demands of various mental operations, describes the secondary task technique as being appropriate for this purpose. Basically, the technique requires subjects to perform to the best of their ability on a primary task, while at the same time performing a secondary task. Performance deficits on the secondary task are assumed to reflect the demands of the primary

task. If performance of the secondary task under these conditions is worse than performance in a secondary task alone control condition, and if performance on the primary task remains equivalent to performance in a primary task alone control condition, then the primary task may be said to require attention, and the decrement in performance on the secondary task may be taken as a measure of the capacity demands of the primary task. The technique has been used extensively to study the capacity demands of a wide variety of mental operations including visual detection and discrimination (Logan, 1978; Shulman & Greenberg, 1971; Shulman, Greenberg, & Martin, 1971), auditory detection and discrimination (Aldridge, 1978; Briggs, Peters, & Fisher, 1972; Lindsay & Norman, 1969; Reitman, 1971, 1974; Shiffrin, 1973), short term memory (Johnston, Greenberg, Fisher, & Martin, 1970), and mental transformations (Kahneman, 1970; Kahneman, Beatty, & Pollack, 1967; Posner & Rossman, 1965).

Perhaps the most critical requirement of the technique is that the secondary task demands considerable capacity. This requirement is necessary to insure that when the primary and secondary tasks are performed simultaneously, their total demand will exceed the available capacity and yield some measurable deficit in secondary task performance. Many studies have demonstrated that short term retention requires considerable attentional capacity (Brown, 1958; Crowder, 1967; Peterson & Peterson, 1959; Posner & Rossman, 1965), and is therefore a suitable secondary task. Posner and Rossman (1965) have shown that retention, used as a secondary task, varies systematically with the difficulty of the primary task, rather than acting in an all-or-none fashion. In Experiment 2, the retention and recall of six visually presented geometric

shapes was used as the secondary task, since such a task is known to require considerable capacity and can be expected to sensitively reflect differences in the difficulty of various primary tasks. Retention of geometric shapes, rather than the more traditional retention of digits, letters, or trigrams, was used to minimize specific confusions between the secondary task items and the various primary task items.

Capacity demands were measured by requiring performance on the attention tasks during the retention interval of the memory task. Attention tasks were similar to those used in the pre-instruction conditions of Experiment 1. In addition to the combined task conditions, a primary task alone control condition was employed to insure that performance on the primary task did not suffer when it was performed in conjunction with the secondary task. A secondary task alone control condition was also employed to determine the extent to which secondary task performance suffered in the combined task conditions.

A choice between the undifferentiated capacity model and Keren's model cannot be made on the basis of their predictions about the capacity demands of the four attention tasks investigated. By asserting that the preattentive processes have no capacity limit, but that focal attention does, Keren's model predicts that response set will require more attentional capacity than will stimulus set. The undifferentiated capacity model simply asserts that the more difficult the task, the greater its capacity demands will be. Thus, only the finding that stimulus set tasks require more capacity than response set tasks would appear to contradict Keren's model. A more rigorous test of these models can be made, however, by varying the size of the stimulus array

in the attention tasks. According to Keren's model, response set tasks, mediated by the serially operating, capacity-limited mechanism of focal attention, can be expected to require more capacity as array size is increased. Stimulus set tasks, mediated by the preattentive mechanisms which operate in parallel and have no capacity limits, should show no increase in capacity requirements as array size is increased. The undifferentiated capacity model predicts increases in capacity demands with increases in array size for all tasks, although the rate of increase should be affected by the difficulty of the tasks. By manipulating array size in Experiment 2, an initial test of the two models was conducted. Furthermore, a relative measure of the capacity demands of each of the four attention tasks was obtained. This information was of importance in generating predictions for the outcome of Experiment 3 in which compound attention tasks were introduced.

METHOD

Subjects

Ten Loyola University undergraduates, participating in the experiment to fulfill a course requirement, served as subjects. None of the ten had served in Experiment 1.

Apparatus

The apparatus employed was identical to that described in Experiment 1.

Stimuli

Three geometric shapes were selected for use as secondary task items: a character consisting of two short, vertical parallel lines; a character consisting of two, short, horizontal parallel lines; and a character consisting of a four by six matrix of points. All three subtended approximately $.2^{\circ}$ of visual angle in height and width. The memory items were presented in two rows of three items with a space of approximately $.2^{\circ}$ between rows and between items in each row. One memory item was randomly selected to fill each location in the array. Thirty-two such arrays were constructed for use in Experiment 2.

Two basic types of attention task arrays were constructed. For the eight-item arrays, four relevant and four irrelevant items were

randomly placed in a circular array identical to the type employed in Experiment 1. For the two-item arrays, one relevant and one irrelevant item were placed at random in two diametrically opposite locations of an otherwise empty eight-location array. Forty-eight arrays of each type were constructed for use in Experiment 2.

As in Experiment 1, one stimulus set condition required selection on the basis of stimulus size (S1), and the other on the basis of stimulus brightness (S2). One response set condition required distinguishing between odd and even digits (R1), and the other required distinguishing between vowels and consonants (R2). In the two stimulus set conditions, the uppercase letters C, J, P, and X were used as both relevant and irrelevant items. In the first response set condition, the digits 2, 4, 6, and 8, and 3, 5, 7, and 9 were used as relevant and irrelevant items and vice versa. In the second response set condition, the letters C, J, P, and X, and A, E, I, and O were used as relevant and irrelevant items and vice versa. Small items in condition S1 subtended $.2^{\circ}$ of visual angle, and large items $.3^{\circ}$. Items in all other conditions subtended $.3^{\circ}$. Bright items in condition S2 were presented at a luminance of 1.35 mL, and dim items at 0.28 mL. Items in all other conditions and in the secondary task arrays were presented at 1.35 mL.

Procedure

Nine basic conditions were investigated in Experiment 2. Subjects performed the memory task alone in one condition, an attention task alone in four conditions, and the memory task plus an attention task in

four other conditions. Trials were divided into five large blocks, and blocks were counterbalanced across subjects.

In one block of trials, subjects performed the memory task alone. Each trial began with a 6 sec presentation of a six-item memory array. Array offset was followed by a 1500 msec retention interval--approximately equal to the time required to present and report upon an attention array in the combined task conditions--and a 1000 msec presentation of a report indicator. The report indicator was either a letter Y or a letter N. On trials in which the Y appeared, subjects were required to report upon the memory items. On trials in which an N appeared, subjects were instructed to report nothing and to proceed to the next trial. Twenty trials were presented in the memory task alone control condition: sixteen randomly selected trials required report, and four randomly selected trials required no report. Use of a report indicator insured that subjects did not respond prior to the end of the retention interval. Subjects reported by placing a simple line drawing of the appropriate character in each of six spaces per trial provided on an answer sheet. Subjects were instructed to guess if they were uncertain, so six responses were always obtained on each trial.

In each of the four other blocks of trials, subjects performed a specific attention task, both by itself and with the memory task. These blocks were further divided into four smaller trial blocks (two selection criteria by two array sizes). Order of presentation of these smaller blocks was randomized across subjects. Within each of the smaller blocks, 10 trials of the attention task alone and 10 trials of the combined attention task plus memory task were presented in a random

fashion. Subjects were informed of the array size and the criterion by which relevant items were to be selected prior to the start of each block of trials. They were instructed to perform as accurately as possible on both of the tasks, when required, but to devote their maximum effort toward performance of the attention task if it became impossible to do both at once. The attention task alone and the combined attention task plus memory task conditions were combined within a single block of trials to increase the likelihood that the subjects would perform equivalently on the attention task in both conditions.

Attention task alone trials began with a 1000 msec presentation of a fixation point located in a position on the display screen equivalent to the midpoint of the eight-item attention array. Attention arrays were presented for 60 msec following a 250 msec ISI. Combined attention task plus memory task trials began with a 6 sec presentation of the memory array. Offset of the memory array was followed by a 1000 msec presentation of a fixation point, a 250 msec ISI, and a 60 msec presentation of the attention array. Responses were written by the subjects on an answer sheet. A space for the attention task items and six spaces for the memory task items were available for each trial. Subjects were instructed to always report the attention task items first on each combined task trial. Order in which attention task items were reported on each trial was deemed unimportant when trials were scored for accuracy. When eight-item attention arrays were presented, subjects were required to report four relevant items, guessing when necessary. When two-item arrays were presented, subjects were required to write the single relevant item four times before reporting the memory task items, guessing

when necessary. The first four trials of each block were considered to be practice or warm-up trials, and were not included in the data analyses.

Subjects participated in two experimental sessions, each approximately 60 min in duration. At the start of the first session, each subject performed eight practice trials of the memory task alone condition. During the experimental trials, subjects initiated trials at their own pace, and generally took a total of 10 to 15 sec per trial.

RESULTS

Mean performance across subjects on the attention tasks in both the attention task alone and the combined attention task plus memory task conditions is presented in Table 2. Inspection reveals that the means in each pair of conditions (attention task alone versus attention task plus memory task) are essentially equivalent. For no condition is performance on the attention task plus memory task markedly worse than performance on the attention task alone control. Data on the memory tasks are presented in Table 3, which provides mean number of memory items recalled per trial in the eight experimental conditions and in the memory task alone control condition.

A one-way analysis of variance for the data in Table 3 indicated a significant effect of conditions, $F(8,72) = 10.43$, $p < .001$. Calculation of Dunnett's t -statistic revealed that performance on the memory task when combined with an experimental task was significantly worse than performance on the memory task alone control, only when eight-item attention arrays were used, and only in conditions S1, R1, and R2. The value of t for conditions S1 ($t = -5.11$), R1 ($t = -8.99$), and R2 ($t = -4.93$) exceeded the critical value of t for a one-tail test at $p < .01$. In addition, planned comparisons among the four means in the eight-item array conditions revealed the following significant differences: conditions S1 and S2, $F(1,72) = 7.98$, $p < .01$; conditions S1 and R1, $F(1,72) = 9.37$, $p < .005$; conditions S2 and R1, $F(1,72) = 34.65$, $p < .001$; condi-

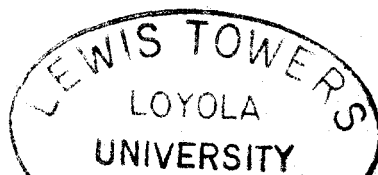


Table 2

MEAN PERCENT CORRECT ATTENTION TASK ITEMS FOR ATTENTION TASK ALONE
AND COMBINED ATTENTION TASK PLUS MEMORY TASK CONDITIONS
SUMMED ACROSS SUBJECTS IN EXPERIMENT 2

Condition	Stimulus Set		Response Set	
	Small/Large	Bright/Dim	Odd/Even	Vowel/Consonant
Two Item Arrays				
Attention Tasks				
Alone				
\bar{X}	99.38	98.13	98.13	99.38
SD	1.98	3.02	5.93	1.98
Combined Tasks				
\bar{X}	99.38	99.38	95.00	96.88
SD	1.98	1.98	4.93	3.29
Eight Item Arrays				
Attention Tasks				
Alone				
\bar{X}	74.53	69.22	67.81	76.88
SD	7.26	3.13	4.73	7.99
Combined Tasks				
\bar{X}	72.50	74.38	71.09	78.28
SD	5.62	3.55	2.88	5.92

Table 3

MEAN NUMBER OF MEMORY ITEMS RECALLED PER TRIAL
SUMMED ACROSS SUBJECTS IN EXPERIMENT 2

	Combined Attention Task Plus Memory Task				Memory Task Alone Control
	Stimulus Set		Response Set		
Array Size	Small/ Large	Bright/ Dim	Odd/ Even	Vowel Consonant	
Two Items					
\bar{X}	5.275	5.244	5.125	5.025	5.400
SD	0.620	0.678	0.764	0.763	0.554
Eight Items					
\bar{X}	4.481	5.144	3.894	4.575	
SD	1.006	0.603	0.893	0.778	

tions S2 and R2, $F(1,72) = 7.17$, $p < .01$; and conditions R1 and R2, $F(1,72) = 10.29$, $p < .005$. Clearly all of the conditions using eight-item arrays differed from one another except for conditions S1 and R2. A four-way analysis of variance of the data from the experimental conditions (i. e., attention task plus memory task) of Experiment 3, treating array size (two or eight items), set (stimulus or response set), task nested within set (S1, S2, R1, or R2), and selection criterion nested within set and task (small, large, bright, dim, odd, even, vowel, or consonant) as factors, revealed significant main effects of array size, $F(1,9) = 32.48$, $p < .001$; and set, $F(1,9) = 15.15$, $p < .005$. A significant interaction between array size and task was also found, $F(2,18) = 10.52$, $p < .001$. A closer analysis of this interaction showed that performance on the memory tasks in conjunction with eight-item attention arrays was significantly worse than performance on the memory task in conjunction with two-item attention arrays for conditions S1, $F(1,9) = 20.96$, $p < .005$; R1, $F(1,9) = 59.41$, $p < .001$; and R2, $F(1,9) = 7.96$, $p < .05$.

DISCUSSION

Results for both attention tasks and memory tasks suggest that the secondary task technique was successfully applied in Experiment 2. The data of Table 2 show that the subjects were able to perform the attention task as well in the combined conditions as they did in the attention task alone conditions. Memory task performance, on the other hand, was significantly worse in some experimental conditions than in the memory task alone control condition. We may conclude that the tasks in these conditions require a significant amount of attentional capacity.

When two-item arrays were employed, none of the four attention tasks produced a significant decrement in memory task performance, although in all cases the difference was in the expected direction. An initial conclusion might be that performance of these tasks requires no capacity. It is more likely, however, that these tasks do require capacity, but that the particular secondary task used was not sensitive enough to measure these demands. Despite the fact that performance in the secondary task alone control condition was less than perfect, we cannot make the assumption that the memory task consumed all the available capacity. Kahneman (1973) cites evidence to support the argument that the standard amount of capacity allocated to a task is usually somewhat less than that required for perfect performance. Thus, in combined conditions, the capacity not allocated to the secondary task (the memory task) may be sufficient to allow performance of the primary

task (the attention task), without interfering with the normal performance of the secondary task. If this is the case, measurement of small capacity demands would always be somewhat inaccurate.

The change in demand for each task with increases in array size is of primary interest, however, since the two models make different prediction about the nature of this change. The stronger prediction was derived from Keren's model. According to this model, capacity demands would be expected to increase with increases in array size for response set tasks, but not for stimulus set tasks. The analysis revealed that for condition S2, selecting on the basis of stimulus brightness, the capacity demand did not increase, whereas for the other three conditions it did. Thus, one stimulus set task produced performance as predicted, while the other did not. Capacity-unlimited, parallel processing does not appear feasible when selection must be based on size differences, as in condition S1.

The undifferentiated capacity model also seems to have fallen short in its predictions, although perhaps not so seriously as the alternative model. The strongest evidence supporting Keren's model--that selecting on the basis of stimulus brightness from an eight-item array requires no more capacity than does selecting from a two-item array--is also the strongest evidence against the undifferentiated capacity model, since the latter model predicted increases in demand for all tasks. Perhaps the most straightforward apology for the failure of the model's prediction would again be an appeal to the argument that the method is insensitive to small capacity demands. It would seem that further research

could resolve the issue in one of two ways: either the sensitivity of the secondary task could be increased, perhaps by using a different task or by increasing the memory load in the current task, or the size of the attention array could be increased still further in order to magnify any changes in capacity demands with increases in array size. If capacity demands of the task in condition S2 are very small, then either of these two manipulations might be capable of revealing them.

In summary, the results of Experiment 2 are somewhat unsatisfactory in terms of helping to reach a decision concerning the two models. Both models find some support in the data, but both also fall short in their predictions. Experiment 3 was designed to yield further evidence in support of one or the other of the two models.

EXPERIMENT 3

In Experiments 1 and 2, four tasks were analyzed to determine their compliance with predictions about the degree of pre-instruction facilitation in a pre- versus post-instruction paradigm, and to measure their demands for capacity in a secondary task paradigm. The results of these experiments failed to lend unequivocal support to either of the two models of the processes underlying the performance of stimulus set and response set tasks. Experiment 3 was designed to test further predictions of the models, generated in part on the basis of information obtained in these previous experiments. In Experiment 3, subjects were required to perform compound tasks in a pre-instruction condition. Compound tasks were tasks in which two criteria were used to select relevant items on each trial. In essence, subjects were required to perform two of the four tasks used in the previous experiments for a single array of attention items. Different predictions about how performance on the compound tasks would compare to performance on single criterion tasks can be formulated on the basis of whether the two criteria in the compound task reflect the use of the same type of set or two different types of set (Keren's model), or on the basis of the combined capacity demands of the two tasks as revealed in Experiment 2 (the undifferentiated capacity model).

Three predictions about the outcome of the third experiment may be deduced from Keren's model. First, subjects should be able to perform

each task within the compound task as well as they perform those tasks individually if the two tasks both require stimulus set. The mechanism mediating performance of stimulus set tasks is hypothesized to make minimal capacity demands and to be capable of analyzing multiple inputs in parallel. Thus, there should be no difficulty in performing either stimulus set task while simultaneously performing the other. Second, subjects should be able to perform each task within the compound task as well as they perform those tasks individually if one of the tasks requires stimulus set and the other requires response set. The two mechanisms mediating performance of response set and stimulus set tasks are presumed by Keren to be independent, and the capacity required for the performance of one type of task is hypothesized not to be interchangeable with the capacity required for performance of the other type of task. Therefore, the two should not interfere with one another while operating simultaneously.

The third prediction depends upon a particular interpretation of an aspect of the model which is not clearly specified by Keren. He argues that the processes of focal attention, which predominate in response set tasks, operate serially to perform an analysis of one item at a time, but he does not elaborate on the exact nature of the processing that occurs for each item. Neisser (1967) suggests that the processing of a single item by focal attention involves a hierarchy of increasingly more sophisticated decisions regarding that item, perhaps beginning with identification and ending with a thorough analysis of the semantic content of that item. In single task conditions involving response set, since all the items in the array belong to a single broad

category such as letters or digits, a single binary decision following extraction of semantic content would be sufficient to classify an item as a member or non-member of the specific category to which the relevant items belong. When two response set tasks are performed simultaneously in a compound task however, two sequential binary decisions will be required, the first to determine the general category to which an item belongs (e. g., letter or digit), and the second to determine the specific category (e. g., odd or even, or vowel or consonant) to which the item belongs. If we assume that this additional step requires a significant amount of time to perform, and that it is not automatically performed in single conditions as well, then we may conclude that the processing of each item in the array for compound task conditions involving two response set tasks will be slower than the processing of items in single task conditions, resulting in a decrement in performance on such a compound task relative to single task performance.

The level of detail of Keren's model is insufficient to warrant such a conclusion with absolute certainty, however. It might be argued that such additional decisions impose negligible additional time and capacity requirements relative to the entire analytic process, or that the decisions about general category membership and specific category membership are performed simultaneously, or that the hierarchy of analytic steps is so rigid and automatic that an unnecessary test of general category membership is conducted in the single task conditions. In these latter instances, compound task performance would be no worse than single task performance. A conservative third prediction from Keren's model, therefore, would be that if a decrement in compound task

performance relative to single task performance does occur in Experiment 3, it can only occur in the condition involving two response set tasks. The outcome of that particular may in fact help to illuminate the nature of the processes involved in focal attention under Keren' model.

Predictions of the undifferentiated capacity model are formulated on the basis of the capacity demands of the tasks. Since all processing operations are interdependent, according to the model, compound task performance should reflect the sum of the capacity demands of the two tasks being performed. If this total demand is small, performance of neither task should suffer relative to performance of each task individually. If total demand is large, one or both of the tasks may be expected to suffer. In Experiment 2, it was determined that, for eight-item arrays, the four tasks could be classified into different levels of difficulty in terms of capacity demand. Separating bright from dim items appeared to require very little capacity. Separating odd from even items, on the other hand, appeared to require a great deal of capacity. The capacity needed to differentiate between small and large items or between vowels and consonants was approximately equivalent and fell somewhere between these two extremes in capacity demand.

The undifferentiated capacity model makes broad predictions about the pattern of results in Experiment 3. The first such prediction is that performance on compound tasks should in all cases be equivalent to or worse than performance on the tasks performed individually. The second prediction is that performance on a compound task should be related to the demands for capacity made by the two tasks within the pair. For example, based on the results of Experiment 2, the undifferentiated

capacity model predicts that performance on the compound task involving selection on the basis of membership in the class odd or even and on the basis of size will be the worst, since the two tasks involved require the most capacity. By the same reasoning, performance would be expected to be best on the compound task involving selection on the basis of brightness and on the basis of membership in the class vowel or consonant since these tasks were found to require the least capacity. Furthermore, the prediction may be made that the likelihood that compound task performance will be worse than performance of the tasks individually will be directly related to total capacity demand. Thus, unlike Keren's model which predicts a decrement in compound task performance only for the condition involving two response set tasks, the undifferentiated capacity model predicts that a decrement is probable in any condition, but is most likely for the condition involving selection on the basis of size and membership in the class odd or even.

In summary, in Experiment 3, the degree to which compound task performance is affected adversely relative to single task performance should depend either on the type of set of the two tasks (Keren's model), or on the combined capacity demands of the two tasks (the undifferentiated capacity model).

METHOD

Subjects

Six Loyola University undergraduates, participating in the experiment to fulfill a course requirement, served as subjects. None of the six had served in Experiment 1 or 2.

Apparatus

The apparatus employed was identical to that described in Experiment 1.

Stimuli

For all conditions of Experiment 3, a stimulus character was presented in each of eight equally spaced locations of a circular array, 3° of visual angle in diameter. All stimulus characters subtended $.3^\circ$ of visual angle except for those designated as small characters, which subtended $.2^\circ$ of visual angle. All characters were presented at a luminance of 1.35 mL, except for those designated as dim characters, which were presented at a luminance of 0.28 mL. A small fixation dot, presented at a location on the display screen equivalent to the midpoint of the circular array, preceded the stimulus array on each trial. The fixation dot was presented for 1000 msec and was separated from a 60 msec

presentation of the stimulus array by a 250 msec ISI.

Trials were run in blocks of 16, and subjects were always told at the start of each block what criterion or criteria should be used to select relevant items. There were always four relevant items and four irrelevant items in each stimulus array. On single task trials, the four relevant items satisfied a single selection criterion. On combined task trials, two relevant items satisfied one selection criterion and two another. No items satisfied both criteria. Irrelevant items satisfied neither criterion. Location of the relevant items in each array was random with the additional restriction that no array contained more than two adjacent relevant items.

Ninety-six different stimulus arrays were prepared for each of six experimental conditions. The six conditions were formed by combining each possible pair of tasks investigated in the two previous experiments. Task S1 involved selecting relevant items on the basis of size; task S2 involved selecting on the basis of stimulus brightness; task R1 involved selecting on the basis of membership in the class odd or even; and task R2 involved selecting in the basis of membership in the class vowel or consonant. Each experimental condition of Experiment 3 involved four blocks of trials in which a single task was performed (control condition), and four blocks in which a compound task was performed. Since each pair of tasks involved four possible selection criteria, a block of trials in each condition was devoted to the use of each of these criteria. In four other blocks within each condition, each possible pair of selection criteria (one from each task) was used in a compound task. The basic conditions of Experiment 3 are presented in Table 4.

Table 4

CONDITIONS STUDIED IN EXPERIMENT 3
AND TYPES OF TRIAL BLOCKS

Condition	Number and Type of Relevant Items Per Array							
	Single Task Trials				Compound Task Trials			
S1S2	4 Sml	4 Lrg	4 Brt	4 Dim	2 Sml 2 Dim	2 Sml 2 Brt	2 Lrg 2 Dim	2 Lrg 2 Brt
S1R1	4 Sml	4 Lrg	4 Odd	4 Evn	2 Sml 2 Odd	2 Sml 2 Evn	2 Lrg 2 Odd	2 Lrg 2 Evn
S1R2	4 Sml	4 Lrg	4 Vow	4 Con	2 Sml 2 Vow	2 Sml 2 Con	2 Lrg 2 Vow	2 Lrg 2 Con
S2R1	4 Brt	4 Dim	4 Odd	4 Evn	2 Brt 2 Odd	2 Brt 2 Evn	2 Dim 2 Odd	2 Dim 2 Evn
S2R2	4 Brt	4 Dim	4 Vow	4 Con	2 Brt 2 Vow	2 Brt 2 Con	2 Dim 2 Vow	2 Dim 2 Con
R1R2	4 Odd	4 Evn	4 Vow	4 Con	2 Odd 2 Vow	2 Odd 2 Con	2 Evn 2 Vow	2 Evn 2 Con

Sml = Small, Lrg = Large, Brt = Bright, Dim = Dim, Odd = Odd, Evn = Even, Vow = Vowel,
Con = Consonant

On single task trials, items in the array were held constant with respect to the selection criterion from the task not being performed in that block of trials. For example, in condition S1S2, in which selection was sometimes based on size, sometimes on brightness, and sometimes on both, for those single task trials during which selection was to be based on size, all the stimulus items in the array were the same brightness. A different set of 16 stimulus arrays was constructed for each of the 24 combined task conditions investigated in Experiment 3. A different set of 16 stimulus arrays was constructed for each pair of single task conditions. Since all items in arrays constructed for single task conditions satisfied one of two selection criteria, these arrays could be used twice--once with selection by each criterion. For example, in condition S1S2 the set of arrays used in the condition in which selection was for small items was also used in the condition in which selection was for large items.

In condition S1S2, the letters C, J, P, and X were used as stimulus items in all conditions. In condition S1R1, the digits 2, 4, 6, and 8 were used as stimulus items when selection was based on size, and the digits 2, 4, 6, and 8, and 3, 5, 7, and 9 were used when selection was based on membership in the class odd or even. In condition S1R2, the letters C, J, P, and X were used as stimulus items when selection was based on size, and the letters C, J, P, and X, and A, E, I, and O were used when selection was based on membership in the class vowel or consonant. In condition S2R1, the digits 2, 4, 6, and 8 were used when selection was based on brightness, and the digits 2, 4, 6, and 8, and 3, 5, 7, and 9 were used when selection was based on membership in the

class odd or even. In condition S2R2, the letters C, J, P, and X were used when selection was based on brightness, and the letters C, J, P, and X, and A, E, I, and O were used when selection was based on membership in the class vowel or consonant. In condition R1R2, the digits 2, 4, 6, and 8, and 3, 5, 7, and 9 were used when selection was based on membership in the class odd or even, and the letters C, J, P, and X, and A, E, I, and O were used when selection was based on membership in the class vowel or consonant.

Procedure

Each subject participated in six experimental sessions, lasting approximately 30 min apiece and distributed at irregular intervals over a two to three week period. Subjects performed two conditions per session. Order of conditions was counterbalanced across subjects. Order of the eight blocks of trials within each condition was randomized for each subject. Prior to performing on the experimental trials of each condition, subjects performed 12 practice trials -- six of a randomly selected compound task from that condition, and six of a randomly selected single task from that condition. In addition, the first trial of each block of trials in each condition was considered to be a practice or warm-up trial, and was not included in the data analyses. On each trial, subjects wrote four responses in the appropriate spaces on an answer sheet provided by the experimenter. For the compound tasks, the two answers for each selection criterion were placed in different columns. The column (right or left) to which answers for particular tasks within the compound tasks were

assigned were counterbalanced across subjects. Subjects were instructed to devote equal effort to the performance of both tasks in compound task conditions. Subjects were also instructed to guess when uncertain of an answer, so four responses were always given on each trial.

RESULTS

Results for Experiment 3 were corrected for guessing according to the formula:

$$CPC = \frac{UPC - PCG}{1 - PCG}$$

where CPC = percent correct, corrected for guessing; UPC = uncorrected percent correct; and PCG = expected percent correct by guessing. For each of the single task trials, subjects were required to give four responses, selected from a set of four possible responses (e.g., if the four allowable responses were C, J, P, and X, subjects may have responded C, C, C, and C, or P, P, P, and J, or X, X, C, and P, or C, J, P, and X, and so on). Since no attempt was made to require subjects to identify a particular location in the array with a particular response, the four responses per trial were scored together rather than independently. The expected percent correct per trial by guessing alone in these single task trials was 42%. In the compound task trials, the two sets of two responses for each trial were scored independently. In these conditions, subjects gave two responses selected from a set of four possible responses for each of the selection criteria employed in a condition. The expected percent correct per trial by guessing alone in the compound task trials was 34%. The single task data and the compound task data were made directly comparable with one another by means of the correction formula cited above. Table 5 depicts the results of Experiment 3 for each of the twelve conditions. Percentages in Table 5 are corrected for guessing.

Table 5

MEAN PERFORMANCE, SUMMED ACROSS SUBJECTS,
ON BOTH TASKS TREATED TOGETHER
IN ALL CONDITIONS OF EXPERIMENT 3
(PERCENT CORRECT CORRECTED FOR GUESSING)

Task Type	S1S2	S1R1	S1R2	S2R1	S2R2	R1R2
Single						
\bar{X}	41.03	50.20	40.68	49.53	44.82	39.55
SD	2.67	6.71	3.60	10.73	5.44	4.87
Compound						
\bar{X}	40.98	37.22	47.20	46.77	50.43	39.82
SD	12.76	11.72	12.56	13.18	14.60	10.32

A two-way analysis of variance with repeated measures on both factors was used for an initial analysis of the results. Condition (S1S2, S1R1, S1R2, S2R1, S2R2, and R1R2) and task type (single tasks or compound tasks) were treated as factors. Performance on both tasks combined within a condition was treated as the dependent measure. The analysis indicated a significant main effect of condition, $F(5, 25) = 4.04$, $p < .01$, and a significant interaction of condition with task type, $F(5, 25) = 5.89$, $p < .005$. Tests for simple effects revealed significant differences among conditions for single tasks, $F(5, 25) = 3.70$, $p < .05$, as well as for compound tasks, $F(5, 25) = 4.71$, $p < .01$. A Newman-Keuls test was conducted with the data from the six compound task conditions to determine differences among mean performances in those conditions. The results indicated that performance in condition S2R2 was significantly superior to that in conditions S1R1, R1R2, and S1S2; performance in condition S1R2 was significantly superior to that in condition S1R1; and performance in condition S2R1 was significantly superior to that in condition S1R1. Planned comparisons between single task performance and compound task performance for each condition revealed a significant difference only for condition S1R1, $F(1, 5) = 12.83$, $p < .05$. Compound task performance was poorer than single task performance in this condition.

Results from Experiment 3 were further broken down by task within each condition (see Table 6), and a $2 \times 6 \times 2$ analysis of variance with repeated measures on all factors was performed on these data, treating task type (single or compound), condition (S1S2, S1R1, S1R2, S2R1, S2R2, and R1R2), and task within condition (S1, S2, R1, or R2) as factors. Significant main effects of condition, $F(5, 25) = 4.00$,

Table 6

MEAN PERFORMANCE ON INDIVIDUAL TASKS IN ALL CONDITIONS OF EXPERIMENT 3
SUMMED ACROSS SUBJECTS (PERCENT CORRECT CORRECTED FOR GUESSING)

Task Type	Condition						
	S1S2		S1R1		S1R2		
	S1	S2	S1	R1	S1	R2	
Single							
\bar{X}	39.92	42.24	59.05	41.32	38.25	42.95	
SD	5.15	5.88	8.70	7.91	2.40	5.76	
Compound							
\bar{X}	38.33	43.58	43.18	31.18	55.17	39.38	
SD	8.88	18.75	14.79	12.41	14.58	12.25	
Task Type	Condition						
	S2R1		S2R2		R1R2		
	S2	R1	S2	R2	R1	R2	
Single							
\bar{X}	58.43	40.58	44.18	45.38	36.28	42.75	
SD	15.44	7.64	7.89	5.76	4.90	5.49	
Compound							
\bar{X}	52.82	40.67	57.03	43.58	33.28	46.33	
SD	19.23	13.49	17.88	13.59	12.47	14.93	

$p < .01$, and task within condition, $F(6, 30) = 6.48$, $p < .001$, were obtained, as was a significant interaction between task type (single or compound) and condition, $F(5, 25) = 5.89$, $p < .005$. Planned comparisons between performance on the two tasks within each compound task condition were carried out. Significant differences between the two tasks were found in five conditions: for condition S1R1, $F(1, 30) = 4.84$, $p < .05$; for condition S1R2, $F(1, 30) = 7.95$, $p < .01$; for condition S2R1, $F(1, 30) = 4.60$, $p < .05$; for condition S2R2, $F(1, 30) = 5.47$, $p < .05$; and for condition R1R2, $F(1, 30) = 5.30$, $p < .05$.

In Table 7, the six experimental conditions of Experiment 3 are rank ordered in terms of combined performance on the two compound tasks within each condition (percent correct, corrected for guessing) as found in Experiment 3, and also in terms of the assumed combined capacity demands of the two tasks within each compound task condition as measured in Experiment 2. Ranks for assumed capacity demand were determined by treating the difference between mean memory task performance in the memory task alone control condition and mean memory task performance in the experimental conditions of Experiment 2 as a measure of the capacity required by each of the four basic tasks (see Table 3). Demands of the two tasks in each compound task condition of Experiment 3 were summed and these sums ranked. A Spearman rank order correlation coefficient for the data in Table 7 was calculated and found to be significant, $r_s = .829$, $p < .05$.

Table 7

ACTUAL RANK PERFORMANCE IN CONDITIONS OF EXPERIMENT 3
AND PREDICTED RANK BASED ON CAPACITY DEMANDS

Condition	Actual Rank	Predicted Rank
S1S2	4	2
S1R1	6	6
S1R2	2	3
S2R1	3	4
S2R2	1	1
R1R2	5	5

DISCUSSION

The results of Experiment 3 pose severe interpretational problems for Keren's model of selective attention. The primary prediction of the model was that interference in the performance of compound tasks would depend solely on the set required by the tasks within the compound tasks. Specifically, it was predicted that interference (defined here as a decrement in performance on the compound tasks relative to performance of the two tasks individually) would arise only in the compound task condition involving two response set tasks, RLR2, if at all. Not only did this predicted interference fail to materialize, but more importantly, a difference between compound task and single task performance was found in a condition in which, according to the model, it should not have been. In condition SLR1, in which a task involving stimulus set and a task involving response set were combined, performance on the compound task was significantly worse than performance on the single tasks. Since the hypothetical mechanisms mediating response set tasks and stimulus set tasks are allegedly independent, no such interference was expected.

Much of the results of the third experiment lend support to the undifferentiated capacity model, on the other hand. Of primary importance is that fact that compound task performance and single task control performance differed significantly only in condition SLR1. The two tasks in this condition were found to be the two tasks requiring the most capacity in Experiment 2. Their combined performance is

predicted by the capacity model to be most likely to show interference in Experiment 3. Clearly, the strongest evidence contradicting Keren's model is also the strongest evidence in support of the undifferentiated capacity model.

Further evidence for the model can be found in the results of Experiment 3. Perhaps the strongest is the high rank order correlation between actual performance and performance predicted on the basis of capacity demands. It seems apparent that capacity demands, as measured by the secondary task technique, are closely related to performance on compound tasks. These results suggest that capacity demand of the tasks involved is a superior predictor of compound task performance than is the set required by the tasks involved.

Some additional suggestive evidence in support of the undifferentiated capacity model is found in the comparison of performance on each of the two tasks in each compound task condition. With the exception of condition SLR2, performance is always better on the task in the pair requiring less capacity. In four of the six conditions, the differences were found to be significant in the appropriate direction.

If we assume that the total available processing capacity was divided equally between the two tasks in a compound task condition, then we would expect performance on the task requiring less capacity to be better in each case, since more could be accomplished with an equal share of the capacity. In general, this was found to be true.

CONCLUSION

Keren's Model

The present set of studies attempted to compare two models of the processes underlying performance of stimulus set and response set tasks. One of the models, Keren's, might be regarded as a structural model since it makes a distinction between two perceptual mechanisms thought to mediate stimulus set task and response set task performance. The model's predictions about the outcome of the present experiments were derived from the operating characteristics ascribed to these two mechanisms. On the one hand, preattentive mechanisms or structures are hypothesized to process inputs in parallel and to be unhindered by capacity limitations. These mechanisms are described by Keren as performing the analysis of stimulus set material. On the other hand, the mechanisms of focal attention, which operate on inputs serially and are subject to capacity limitations, are viewed as being responsible for the performance of response set tasks. An important additional assumption made by the model is that these two mechanisms are independent.

Since, according to Keren's model, tasks requiring different types of set activate different underlying perceptual mechanisms, various manipulations of stimulus set and response set tasks should confirm the existence of the hypothesized mechanisms and their characteristics. Three experiments were designed for this purpose.

The first experiment was conducted primarily to confirm that the two examples of stimulus set tasks and two examples of response set tasks chosen for use in the experiments fulfilled an initial prediction suggested by Keren (1976) and Broadbent (1970). It was shown that when selection instructions are given before the array, stimulus set tasks show a larger advantage relative to when selection instructions are presented after the array than do response set tasks. Keren's model suggests that this result is due to the rapidity with which irrelevant items may be rejected by the preattentive mechanisms in the pre-instruction condition of stimulus set tasks.

Experiment 2, designed primarily to produce a measure of the capacity demands of the four tasks studied, also involved an initial test of Keren's model. The size (number of items) of the attention array was varied in the experiment. Since the preattentive processes are described as operating in parallel and having no capacity limitations (i.e., requiring minimal capacity), Keren's model predicted no increase in capacity requirements with increases in array size for those tasks involving stimulus set. The prediction was shown to have failed for one of the stimulus set tasks, selecting items on the basis of size. Further, it was argued that the probable reason that a similar increase in demand was not found in the other stimulus set task was that the procedure for evaluating capacity demands was insensitive to small demands.

Perhaps the greatest failure of this structural model occurred in Experiment 3. In this experiment subjects performed compound tasks requiring selection on the basis of two criteria simultaneously. Keren's model predicts that interference will occur on a compound task only

when both of the individual tasks involve response set. Since the preattentive processes, which mediate performance of stimulus set tasks, can process many items at once without approaching some limit on capacity, two tasks involving stimulus set should not interfere with one another when performed simultaneously. Since the mechanisms of focal attention, which mediate performance of response set tasks, are presumed to be independent of the preattentive processes, a task involving stimulus set and a task involving response set should not interfere with one another when performed simultaneously. Two response set tasks performed simultaneously may be expected to interfere with one another, however, since both of them will require the use of a structure which can only perform an analysis of one item at a time. In Experiment 3, contrary to these predictions, no interference was evident in a condition involving the simultaneous performance of two response set tasks (condition R1R2), but interference was found in a condition involving the simultaneous performance of a stimulus set task and a response set task (condition S1R1). The model in its present state cannot accommodate these findings. It must either be abandoned or revised considerably, particularly regarding the claim of independence of the two perceptual structures.

In all fairness to Keren's position, it must be pointed out that he repeatedly emphasizes that rarely does an experimental task involve only stimulus set or only response set; rather, most tasks involve elements of both (Keren, 1976). Thus, typically the preattentive processes and the mechanisms of focal attention are both elicited by a given task, and tasks differ primarily in the saliency of these two structures. While the distinction between stimulus

and response set, on the one hand, and the corresponding one between preattentive processes and focal attention, on the other, have been treated as being all-or-none in the present report, it is probably more correct to view these distinctions as existing on a continuum. Certainly in the experiments involved here, the requirement that items be analyzed sufficiently to allow written report can be regarded as involving the mechanisms of focal attention, regardless of the task type. Therefore, the stimulus set tasks employed in these experiments could be viewed as involving elements of response set, lessening the intended distinction between sets of tasks. The tests imposed upon the model and the conclusions drawn in this report, however, are legitimate to the extent that one or the other type of set was clearly more salient in each task. Keren's own tasks were quite similar.

The admission by Keren that the distinction between stimulus set and response set is ordinarily not clearcut leads one to question the utility of such a distinction. If all tasks will elicit the activation of the same basic perceptual structures -- although to various degrees -- then the intended, meaningful distinction between task types becomes blurred. If tasks must be viewed as existing on a continuum, then a model that allows for the accurate placement of tasks on a meaningful continuum is preferable. This lack of precision on the part of Keren's model is perhaps sufficient in itself to motivate a search for an alternative model to distinguish among tasks, but considered in conjunction with the failed predictions of the model in Experiments 2 and 3, it provides a compelling case for abandoning the model as it stands.

The Undifferentiated Capacity Model

The other model under consideration in the current set of studies -- the undifferentiated capacity model -- may be regarded as an energy model, as opposed to a structural model, since mental operations are viewed as requiring different amounts of processing capacity available from a common source. For this approach, tasks are viewed as being distinguishable on the basis of how much capacity they require rather than on the identity of the structures that they activate. In his initial exposition of what is perhaps the most thoroughly developed energy model of attention, Kahneman (1973) refers to this common capacity required by tasks as "effort", and suggests that selective attention consists of the selective allocation of effort to some mental activities in preference to others. The amount of capacity or effort that is momentarily available is presumed to be limited and to depend on the level of arousal of the organism -- the higher the level of arousal, the more capacity available. The amount of effort required by a particular task may be measured by some behavioral analysis, such as the secondary task technique (Kerr, 1973), and also, to some extent, by physiological measures of arousal (Kahneman & Beatty, 1966; Kahneman, Beatty, & Pollack, 1967; Kahneman, Tursky, Shapiro, & Crider, 1969). Beatty and Wagoner (1978), for example, have recently shown that pupil diameter increases systematically with the performance of tasks presumed to require increasingly more complex cognitive decisions and analyses, namely letter matching by physical identity, by name, or by category. The model has the advantage of requiring very few assumptions and of generating relatively easily tested predictions. Furthermore, tasks

may be ranked on a continuum, according to the model, in terms of the demands they make on the common pool of available capacity.

In the present series of studies, the model faired rather well in its predictions. In Experiment 2, the model predicted increases in capacity demand with increases in array size for all tasks, regardless of the set they involved. Three of the four tasks met this prediction, and the argument was advanced that the failure of the fourth task to show signs of increased demand with increases in array size probably reflected the insensitivity of the technique used to small demands.

In Experiment 3, interference in the performance of two tasks in a compound task was shown to depend on the total demand placed on capacity by those two tasks, rather than on the set involved in the tasks. The only compound task to differ significantly from single task control performance was one involving selection on the basis of membership in the category odd or even and selection on the basis of stimulus size, the tasks found in Experiment 2 to require the greatest and the second greatest amounts of capacity, respectively. Further, the large rank order correlation between actual performance on the compound tasks of Experiment 3 and the predicted performance on the basis of capacity demands lends further credence to a capacity model interpretation of the tasks studied. Clearly, for the four tasks investigated, such an interpretation is preferable to one in terms of Keren's structural model.

Future Research

Much additional research is suggested by the current experiments. It would be useful to be able to dichotomize attention tasks, so perhaps it is premature to dispose of Keren's model completely. There are many other tasks that fulfill the requirements of involving primarily stimulus set or primarily response set. The possibility exists that some or all of the tasks chosen here to represent the two types of set are in some way atypical. Similar tests to those conducted here, with different sets of tasks, could help to generalize or limit the current interpretation.

Perhaps the distinction between the preattentive processes and the mechanisms of focal attention is a legitimate one, but the properties of each are not yet fully understood. There are several approaches that might be taken to attempt to illuminate the possible differences. The secondary task technique is a very powerful technique for the analysis of primary task characteristics, and should be used more extensively to investigate the mechanisms thought to underlie the performance of stimulus and response set tasks. One might use the secondary task technique, for example, and vary systematically the nature of the secondary task. In the current studies, a memory task was found to yield orderly measures of capacity demand, but not to differentiate clearly between tasks presumably requiring focal attention and those requiring preattentive processes, on the basis of capacity demands. For example, selecting on the basis of stimulus size and on the basis of membership in the class vowel or consonant -- two tasks engaging the operations of different perceptual mechanisms, supposedly

-- were found to require an approximately equivalent amount of capacity. A wide variety of other tasks that might have been used as the secondary task may have provided a distinction between the two mechanisms in terms of their requirements for capacity. The possibility should be explored. Secondary tasks may require some continuous activity, such as rehearsal or tracking, or a discrete performance, such as in a signal detection task. Perhaps a systematic variation of the secondary task with respect to this dimension would provide information about the relationship of stimulus set and response set to perceptual mechanisms involved in selective attention.

The use of a different dependent measure in studies employing a secondary task technique might also be enlightening. Reaction time to a secondary task, rather than accuracy on the task, has been used in a number of studies (Kerr, 1973; Posner & Klein, 1973; Proctor & Fisicaro, 1977). Results from such studies reveal that some tasks or some components of tasks have different effects upon reaction time and accuracy in the secondary task. It would appear that some components of tasks require time to be performed (as revealed by an increase in reaction time to the secondary task relative to control performance), but not capacity. Perhaps a clue to differences between stimulus set and response set tasks, and the mechanisms hypothesized for their performance, lies in a distinction between their requirements for time and their demands for capacity.

Another potentially useful approach might be the analysis of tasks into component parts. In the present experiment, stimulus set tasks and response set tasks were treated as wholistic units of acti-

vity, but in theory these tasks could be broken down into many component stages, such as encoding, retention, transformation, comparison, decision, and response selection stages (Johnston, et al., 1970; Kerr, 1973; Logan, 1978). Techniques available for differentiating among stages and assessing the attentional involvement of the various stages (e. g., Sternberg, 1969) might reveal differences between these two types of tasks at some processing stage, that would be useful in understanding the mechanisms responsible for their performance. Physiological measures of arousal, such as pupil dilation, which may reflect momentary changes in capacity demand across processing stages, might be particularly enlightening when considered in conjunction with some behavioral measures. Pupil dilation has already been shown to vary systematically with changes in the difficulty of various mental tasks (Beatty & Wagoner, 1978).

Finally, Keren (1973) has suggested that another possible distinction between the preattentive processes and the mechanisms of focal attention is that the former are quite possibly innate while the latter are probably learned. One would predict that the relationship of these mechanisms to stimulus set and response set tasks could be tested by requiring very extended practice on the two types of tasks. Stimulus set tasks would be expected to show less of an improvement with practice than would response set tasks, since the latter rely on learned processes according to Keren. Some suggestive evidence that improvement in response set tasks can be substantial with extended experience -- in fact almost automatic -- can be found in studies using visual search tasks to demonstrate the categorization effect -- the

finding that items may be correctly categorized or classified prior to being identified (Brand, 1971; Gleitman & Jonides, 1976; Ingling, 1972; Jonides & Gleitman, 1976).

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

The dissertation is therefore accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Date

April 22, 1978

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