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Choice Reaction Time as a Function of Set Size and Signal Frequency

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OF SET SIZE AND SIGNAL FREQUENCY

by

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ABSTRACT

CHOICE REACTION TIME AS A FUNCTION OF SET SIZE AND SIGNAL FREQUENCY

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This research was conducted in two experiments. The first experiment assessed whether set size for the negative and positive sets affected reaction time during a visual scanning task. The effects of signal frequency on these relationships were assessed in the second experiment. It was hypothesized that as set size increased, reaction time would increase. In addition, as signal frequency increased, it was hypothesized that reaction time would decrease. In the first experiment, 12 groups of 10 subjects each were tested varying the number of stimuli for the positive and negative sets. The second experiment tested 18 groups by varying the levels of the positive and negative set size, as well as varying the proportion of the stimuli presented for each group. Reaction time served as the major dependent variable for each group of subjects. The results indicate that the size of the positive set does affect reaction time; however, the size of the negative set does not appear to affect reaction time. As the proportion of the stimuli presented in the positive set increased, reaction time was found to decrease.

ACKNOWLEDGMENTS

Given the time that this research project has taken many insights and thoughts have been gained from recognizing the educational prospect involved in this type of project. My appreciation and gratitude is extended to the committee; Dr. Raymond H. Kirby, Dr. Glynn D. Coates, and Dr. Frederick G. Freeman. In addition, to their time, interest, and insight in this project, I am thankful for their continued support and availability.

I would also like to thank my parents, brothers, sisters, and my friends for their support and confidence in me as I continue to succeed on my chosen path.

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Since the study in 1850 by Helmholtz, reaction time has been established as a robust measure in experimental psychology. An initial surge of research on reaction time was stimulated by Donders (1868). He contributed the subtraction method, which is based on three types of reaction time procedures - a-reaction time, b-reaction time, and c-reaction time. A-reaction time is simple reaction time, where there is one stimulus presented and only one possible response. B-reaction time involves presentation of more than one stimulus with an equal number of response selections, one for each stimulus. This is referred to in the literature as disjunctive or choice reaction time. In c-reaction time, there is presentation of more than one stimulus, however only one stimulus requires a response.

Donders hypothesized that by using the different types of reaction time he could estimate the speed of the internal cognitive processes. The three processes he believed he was measuring were: 1) simple reaction, which is the time to respond to a stimulus; 2) stimulus categorization, which is the time needed to decide which stimulus had been presented; and 3) response selection, which is the time needed to select the correct response key. Indeed, a-reaction is a component of b-reaction, and c-reaction shares two processes of b-reaction. By comparing performance in these various tasks, Donders believed he could obtain estimates of the time needed for two processes, stimulus categorization and response selection. To determine how long it takes to categorize a stimulus, a-reaction time is subtracted from c-reaction time. Similarly, response-selection time can be obtained by subtracting c-reaction time from b-reaction time. Originally, Donder's subtraction method was very popular; however, subsequent criticism has reduced its appeal. Largely, criticism focused on how the stages are different in an a-reaction time task compared to the stages in a b-reaction time task (Kulpe, 1895). Donder's distinction of a-reaction time, b-reaction time, and c-reaction time tasks have, however, found great favor. Ample research has been conducted on a-reaction time and b-reaction time; however, research on c-reaction time is relatively unstudied.

Subsequent investigation of mental processes and review of Donders' subtraction method on reaction time tasks by Sternberg (1969) has led to the current adaptation of information processing theory. Information processing theory concerns the method by which an observer perceives, identifies, and encodes data in memory. Sternberg proposed the additive factor method, where four serial information-processing stages compose his theoretical model of memory scanning analysis. The four stages of the model are stimulus encoding, serial comparison, binary-decision, and response organization. In this method Sternberg, unlike Donders, tested the RT components by "inferring the organization of mental operations from RT data without requiring procedures that add or delete stages" (Sternberg, 1969). This enabled evidence for the existence and characteristics of stages, rather than the measurement of stage duration. Thus, Sternberg believed that the additive method established that processing stages do exist. For different tasks the actual cognitive processing may differ; however, the stages remain similar. Sternberg's task required the subject to memorize numbers in the set to which subjects were to respond. This he called the memory set. Subjects had a choice of two response keys, for either yes or no, "yes" if the stimulus was in the memory set and "no" if it was not in the memory set, or in what was called the negative set.

In Sternberg's paradigm, the serial comparison stage is when the presented stimulus is compared serially with each member of the positive set. The binary-decision stage is based on the outcome of the serial comparison stage and the appropriate response is selected. According to Sternberg, RT to a specific stimulus increases linearly with the size of the memory set, which is due to what Sternberg calls a serial exhaustive search. This indicates that people compare the test digit to all of the items in the positive set before responding. Sternberg's experimentation led to the conclusions that the size of the positive set influenced the serial comparison stage. The binary decision stage is influenced by the response criterion. However, the size of the negative set was found to have no effect on any stage.

Other reaction time studies have shown that discrimination is a more difficult task than is detection. Merkel (1885) found that with several alternative stimuli and multiple response choices, reaction time increased as the number of response alternatives increased. Hick (1952) believed that the information that a subject derives from the stimulus presented is obtained at a constant rate and that it is an automatic process. Therefore, the more information a subject needs to process, the longer the reaction time will be. Thus, Hick's law was formulated, which asserts that CRT is on the average a constant function of the amount of information presented in the stimulus. Hick expressed this linear relationship as:

$$RT = a+b(Ht)$$

where a and b are statistical constants, RT is the reaction time of the subject measured from a CRT task, and Ht is the uncertainty of information in an error-free CRT task and is equal to log2 of the number of alternatives. Hyman's (1953) research varied the stimulus category in three ways - by varying the signal probability, by varying the number of stimulus alternatives, and by varying the probability by sequential dependencies. Hyman's research indicated that RT did increase linearly as the amount of stimulus information increased for all three independent variables; thus, providing independent support for Hick's Law. Hyman defined simple RT as a function of the amount of information, not just the log of the number of alternatives in an error free CRT assignment. All four of his subjects showed about the same relationship between RT and information. In addition, Hyman found that RT was slower when the probability of a signal was low and when the probability of a signal is high, RT was faster; therefore, varying the probability of the signal had a significant effect on RT. Further, this research provides evidence on how the subject derives information from the presented stimulus.

The following research indicates how a subject cognitively processes information in order to select a response after he/she derives the information from the presented stimulus. During CRT studies a subject needs to select his/her response from a group of possible selections. One cognitive theory, concerning pattern recognition, characterizes how a subject discriminates the choice that he/she will make. Evidence has demonstrated that both data driven and conceptually driven processing determines the way in which the actual pattern of the stimulus presented is recognized (Ashcraft, 1989). Data driven processing, also known as bottom-up processing, is "when the mental processing of a stimulus is guided largely or exclusively by the features and elements in the pattern itself" (Ashcraft, 1989). Conceptually driven processing, also known as top-down processing, is when "mental processing is guided and assisted by the knowledge already stored in memory" (Ashcraft, 1989). Therefore, based on pattern recognition theories, a subject would use top-down processing in choice reaction time studies that presented a stimulus already stored in long-term memory and required a response discrimination. Consequently, when a subject needs to choose from multiple responses in a CRT task, cognitive processes are guided by serial processing of knowledge already stored in a subject's memory.

The two dominant approaches to research with reaction time use Sternberg memory search tasks and CRT tasks. Substantial research has been conducted using the Sternberg memory search task. Variations of the number of letters and/or numbers presented to subjects in the positive and negative sets are numerous. Lively & Stanford (1972) performed an experiment where: 1) the size of the positive and negative sets were varied and 2) the response sets were varied by using consonants or digits. The experimenters were looking at how the conceptual relationship between the presented stimulus in the positive set and varying the conceptual category of the response set would effect RT. If the positive set had consonants then a subject was given a response set of digits in one condition and a response set of consonants in another condition. Subjects gave a verbal response of yes or no after the stimulus was presented to state whether or not the stimulus that was presented was in the positive set or not. Results showed that the effect of the size of the positive set was significant. The data from the positive set size and the category of the negative set produced significant results. Thus, when the category for the positive set was consonants and the category for the negative set was digits RT was faster than when the category for the negative set was consonants. Thus, the less alike the stimuli are the faster the RT. This conforms with research on conceptually driven processing since the patterns of the categories for this experiment (digits and consonants) were already stored in long-term memory and required a response discrimination. The investigators suggested that detection of a stimulus using different patterns demonstrates that people make faster decisions when they need only respond "yes" or "no" to the stimulus. Therefore, a subject in a CRT task where there are several alternative responses to choose from will have a longer RT to the presented stimulus when compared to a subject that needs to respond with only a "yes" or "no" response. Thus, in CRT tasks where subjects are required to make multiple response decisions, RT is expected to increase as the number of responses increase.

In memory scanning tasks the response requirement normally involves a two-key response set utilizing one key for "yes" if the presented stimulus is in the positive set, or another key for "no" if the stimulus is in the negative set. In a one-key response set a subject responds by pressing the designated key if the presented stimulus is in the positive set, if the presented stimulus is in the negative set no response is made. The one-key task is like Donder's c-reaction time. Investigators such as Kristofferson (1975) have studied the effect of a memory scanning task comparing the set size and response requirement. Results indicated a significant positive set-size effect for both a one and two-response condition. However, this positive set-size effect was significantly greater for the two-response condition than for the one-response condition. It was concluded that response requirement does have a significant effect on the set-size effect.

Other investigators have studied what the effects of the negative set size are on reaction time. Haygood & Johnson (1983) conducted two studies where they presented both the negative and positive set for the subject to memorize and varied the number of stimuli in each group. In addition, they wanted to de-emphasize the connotations attributed to "positive" and "negative"; therefore, they presented the set with "your memory set is" and "the other digits are". Subjects had the choice of two response keys, either yes or no, for positive and negative sets, respectively. Results indicated that when the negative set-size is equal to or more than the positive set-size, the negative set-size has no effect on RT for memory search tasks. However, when the negative set size is smaller than the positive set, subjects have faster RT when information concerning the negative set is available. Thus, RT can be influenced by the negative set if information about that set is available and it is a smaller set size.

Memory search tasks and choice reaction time tasks are similar in many ways. In a study conducted by Ogden & Alluisi (1980) effects of these two types of tasks were compared in the same study. They compared numeral-verbal (verbal naming) and numeral-motor (responding to the presented stimulus with a keypress) S-R groupings in CRT and memory search tasks using differing levels of alternative stimuli. S-R compatibility was found to produce a significant difference between performance on the verbal and motor-CRT tasks. In addition, fewer errors were found and a decrease in RT fluctuations occurred in the verbal-CRT task. For the motor-memory task RT increased proportionally with size of the positive memory set. The results of the verbal-memory task showed that RT was not affected by the size of the negative set that was stored in memory. The authors believed that this indicates that people are more familiar with responding to "yes" or "no" decisions, rather than making a choice decision.

In a recent CRT study by Keiser & Kirby (1990), a task was administered to subjects that combined b and c-reaction time procedures, where the numbers of stimuli in the positive and negative sets were varied. The task differed from Sternberg's memory search studies in two ways. Subjects were not asked to memorize the positive set, the positive set was listed at the bottom of the computer screen throughout the entire trial. Secondly, subjects were required to give more than a "yes" or "no" response. For example, they had the same number of response keys as the number of stimuli in the positive set. Results indicated that there was a significant increase in CRT for the positive set size. Results of the negative set size, although nonsignificant, indicated a possible small effect. Therefore, follow-up research that addresses the issue of increasing the negative set size along with varying the proportion of the stimuli presented in the positive set may determine whether the negative set has an effect on RT. The possible effect of negative set size was addressed in the current study. Also addressed was whether, by increasing the number of stimuli in the positive set, a significant effect could be produced in RT for different negative set sizes.

The proportion or probability of the signal is another important variable for study in CRT tasks, since most research conducted has an equal probable signal of 50% for each presented stimulus. The initial research reported herein assisted in planning a second experiment involving the proportion of positive and negative set trials. In order to understand how subjects are affected by changes in signal probability literature on signal detection theory is presented. Studies on signal detection theory provide information about how a subject reacts to different proportions of stimulus presentation, and how the subject's criterion affects the subject's response. This theory emphasizes the relationship between two kinds of response outcomes, a hit or a false alarm, rather than the relationship between stimulus and response. It recognizes that the subject is not a passive receiver of information, but rather, is engaged in a decision making process. One bias that occurs in signal detection situations is when a subject can anticipate making a response and has only one possible response, the subject's RT may be faster due to anticipation or expectancy effects. However, if the subject has to chose among multiple responses, a decision is necessary before the subject can press the correct key. Thus, when the signal probability is varied in CRT tasks, the response criterion is affected by either increasing or decreasing the number of times the subject expects to respond to the presented stimulus. This general theory of response criterion can explain the effect that varying the signal probability has on CRT and a subject's decision-making process.

Along with varying the absolute number of stimuli in the negative and positive sets, researchers have varied the proportion at which each of these types of stimuli are presented as well. Most studies, however, do present the stimuli in equal proportions. Hyman (1953) and Miller & Pachella (1973) found that by changing the probability of the presented stimulus in a CRT task RT was increased or decreased. When the information presented was at a low probability, RT increased, and when the information presented was at a higher probability, RT decreased. In a memory scanning task where the memory set size ranged from one to five and the signal probability was varied, it was found that by increasing the signal probability of the stimulus, a significant decrease in RT occurred for both the positive and negative memory set sizes from two through five items (Theios & Smith, 1972; Theios, Smith, Haviland, Traupmann, & Moy, 1973).

Other researchers have found conflicting results when looking at unequal signal frequencies in CRT tasks. Bertelson & Barzeele (1965) found that RT decreased as signal probability increased. However, four experiments by De Jong & Sanders (1986) found no effect on RT when signal probability is varied with set size.

The present studies examined the effects of both positive and negative set size, and the signal probability of the positive stimuli by administering a task that combines b and c-reaction time procedures. Two experiments were administered. In Experiment 1, it was expected that reaction time would increase with increasing numbers of positive and negative stimuli. Further, in Experiment 2, the variable of signal probability was addressed, and it was expected that as the proportion of the positive signals increased, CRT would decrease significantly.

Experiment 1

Method

Subjects

One hundred and twenty female undergraduate students, between 18 and 30 years of age, participated in this study. The subjects were students who received extra credit for an undergraduate psychology course for their participation. A sign up sheet on a psychology experiment bulletin board assisted in the recruitment of subjects.

Design

A 3 (positive set size) x 4 (negative set size) factorial between-subjcts design was employed. The three levels in the positive set were the number of alternative stimuli presented for each condition, either two, four, or eight alternative stimuli. The four levels in the negative set were the number of alternative stimuli presented on trials requiring no response - either 0, 4, 8, or 16 alternative stimuli. The dependent variable was reaction time for each trial.

Materials and Apparatus

The study used an IBM clone personal computer and a Zenith monochrome monitor with a 16.5 cm by 50 cm screen. A PC/PCXT compatible keyboard was used. The computer hardware was situated in a 1.82 m x 3.66 m room. A computer program was designed to display a square in the middle of the computer screen, where letters were presented one at a time, with 5 sec intervals between trials. Each session lasted approximately 10 min. A warning signal sounded one sec before the stimulus appeared on the screen. The positive set of letters for the condition that was presented was listed at the bottom of the screen throughout the entire trial. Subjects were to respond to the stimuli in the positive set only.

Procedure

Subjects were randomly assigned to one of the 12 conditions before arriving for individual testing. Upon arrival the subject was briefed and an informed consent form was signed. The subject then was read standard instructions (Appendix A), after which she could ask any questions regarding the instructions. The subject's responses were made by striking the corresponding key on the keyboard for the letter presented on the screen. Refer to Table 1 for a list of the letters that were presented in each positive set.

Each condition contained 80 trials. The entire set was divided into five blocks, thus there were 16 trials per block, eight of which subjects responded to and eight that they did not respond to. The number of letters in the negative set was either 0, 4, 8, or 16 and the letters were randomly assigned for each trial from the remaining list of letters not listed in the positive set.

Table 1

The List of Letters Presented in the Positive Set

Condition	Letters
2	S, L
4	S, F, J, L
8	S, D, F, G, H, J, K, L

Code numbers for each subject were used in order to ensure confidentiality of the data. After typing the subject's code number and the condition number, the trial began. Each subject was asked to place her fingers on a piece of tape that was located in front of the keyboard so that she began from the same location each time she responded. The experimenter asked the subject if she was ready to begin the trial, and the experimenter began the trial by pressing the return key.

Each subject was run individually on a set of 80 trials, which took approximately 10 minutes. When the set was complete the subject was asked two questions regarding whether the subject was familiar with the keyboard and whether the subject memorized or scanned the information to which responses were made (See Appendix B for actual questions). Subjects were then debriefed, and any questions the subject had were answered. Last, each subject was given a credit slip for extra credit in her psychology class and thanked again for her participation in the study.

Results and Discussion

The mean RT for each subject was computed for each block of 16 trials, resulting in five mean RT's per subject. Mean RT's were analyzed across subjects in a 3x4x5 (positive set size x negative set size x trial blocks) analysis of variance with repeated measures for trial blocks (See Table 2). A significant main effect for the positive set $F(2,108) = 69.08$, $p<.0001$ was indicated. There was no significant effect for the negative set $F(3,108) = 0.14$ $p>.10$. Similarly, no significant effect was found for the interaction between positive and negative set size, $F(6,108) = 1.60$, $p>.10$. Figure 1 shows the mean RT as a function of the number of positive and the negative stimuli.

As expected RT significantly increased with the number of stimuli in the positive set. A significant difference was found between each level of the positive set (2,4,8) according to the Student-Newman-Keuls test. Figure 2 shows mean CRT as a function of the positive set size. This finding does support prior studies (Keiser & Kirby, 1990; Kristofferson, 1975; Lively & Sanford, 1972; Merkel, 1885; Ogden & Alluisi, 1980; Sternberg, 1969), which indicate that reaction time linearly increases with the size of the positive set as well as showing an increase in RT as the number of response choices are increased. This result is also consistent with Hick's law.

Table 2

Summary Table for 3x4 Analysis of Variance

Source	SS	df	MS	F
Test of Hypotheses using Block*S(Pos*Neg) as an Error Term				
Block	1.282	4	0.321	27.00*
Block*Pos	0.168	8	0.021	1.77
Block*Neg	0.069	12	0.006	0.48
Block*Pos*Neg	0.173	24	0.007	0.61
Test of Hypotheses using S(Pos*Neg) as an Error Term				
Pos	7.527	2	3.764	69.08 *
Neg	0.022	3	0.007	0.14
Pos*Neg	0.524	6	0.087	1.60

*p<.01

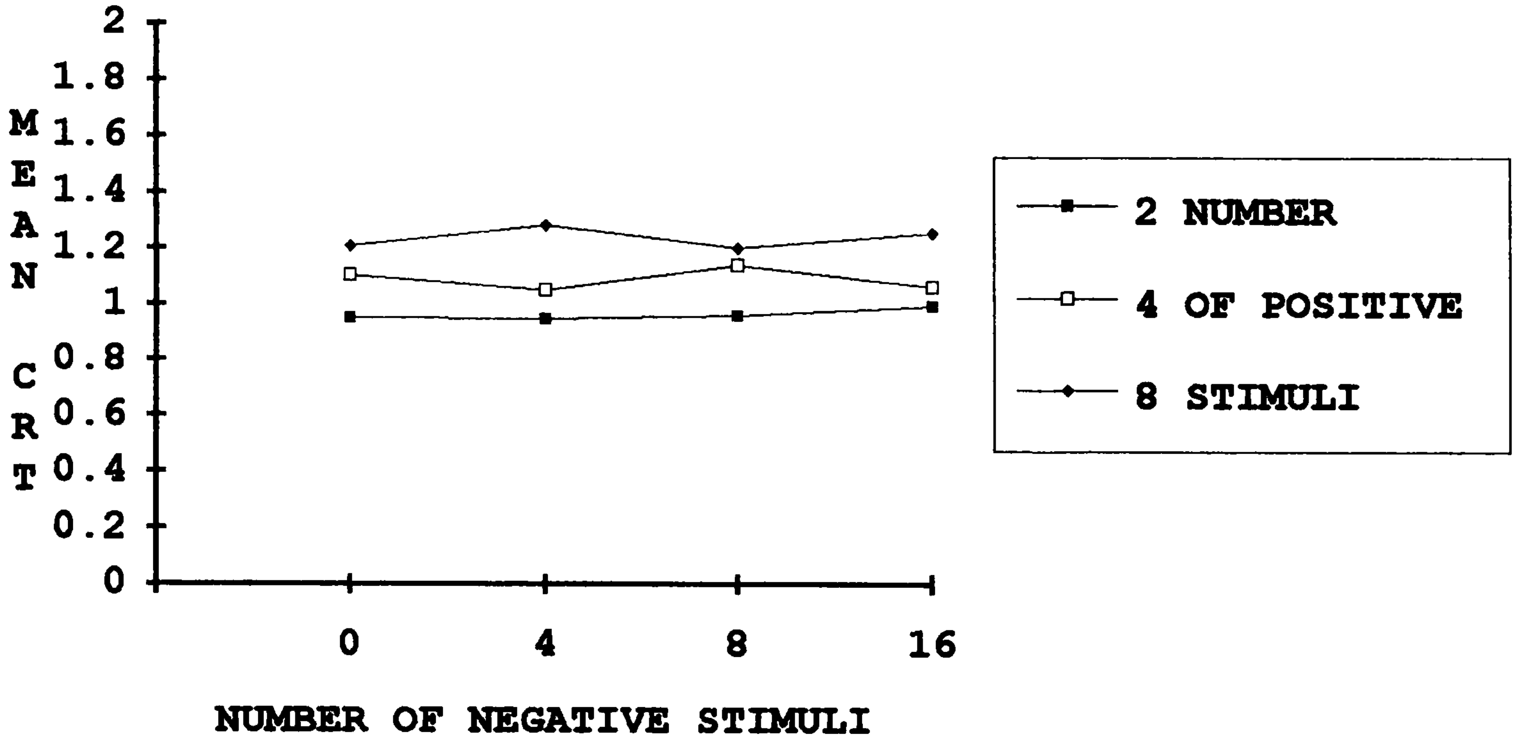

Figure 1. CRT as a Function of the Number of Positive and Negative Stimuli

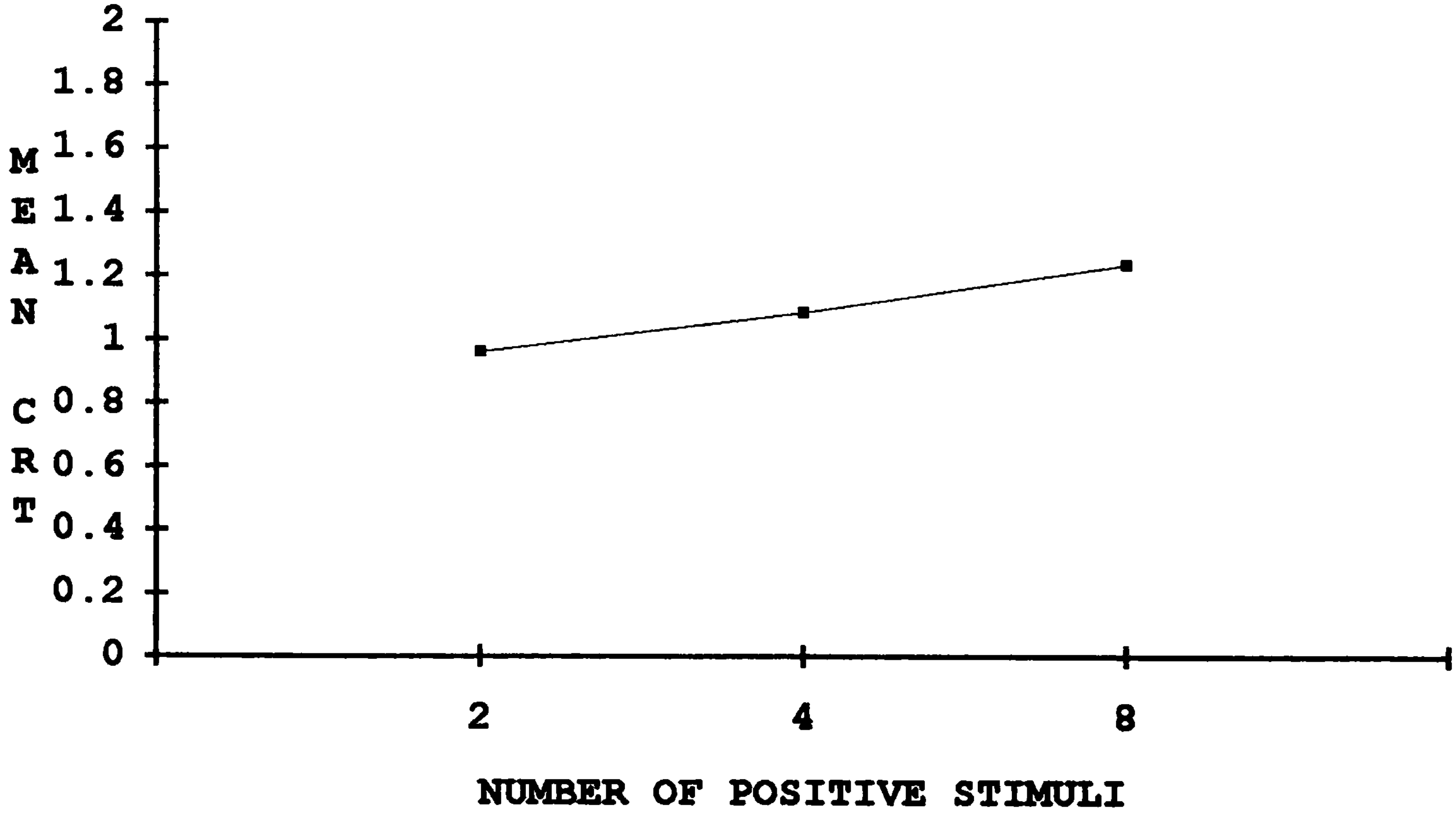

Figure 2. CRT as a Function of the Positive Set Size

The size of the negative set was not found to have a significant effect on RT, thus supporting the findings by Sternberg, (1969) and Haygood & Johnson (1983). Figure 3 depicts CRT as a function of the negative set, which is not only non-significant, but the results prove the null hypothesis. The small insignificant effect found by Keiser & Kirby (1990) for the negative set size was again not found to be significant in this study. The size of the negative set does not appear to affect RT even when a wider range of numbers of stimuli are presented in the negative set. Results indicate that subjects are able to detect the difference between the positive and the negative set at the same rate, so as not to affect RT significantly; however, response discrimination appears to increase reaction time significantly, which supports prior studies (Lively & Stanford, 1972; Merkel, 1885).

No significant interaction between the negative and the positive set was found, which supports prior studies (Keiser & Kirby, 1990; Sternberg, 1969). According to Sternberg (1969) when variables affect the information processing stages similarly, there will be an interaction between the positive and negative set; however, when the stages are affected differently by the variables presented, there will be additive effects on RT. Therefore, these results indicate that the factors presented in this study affected

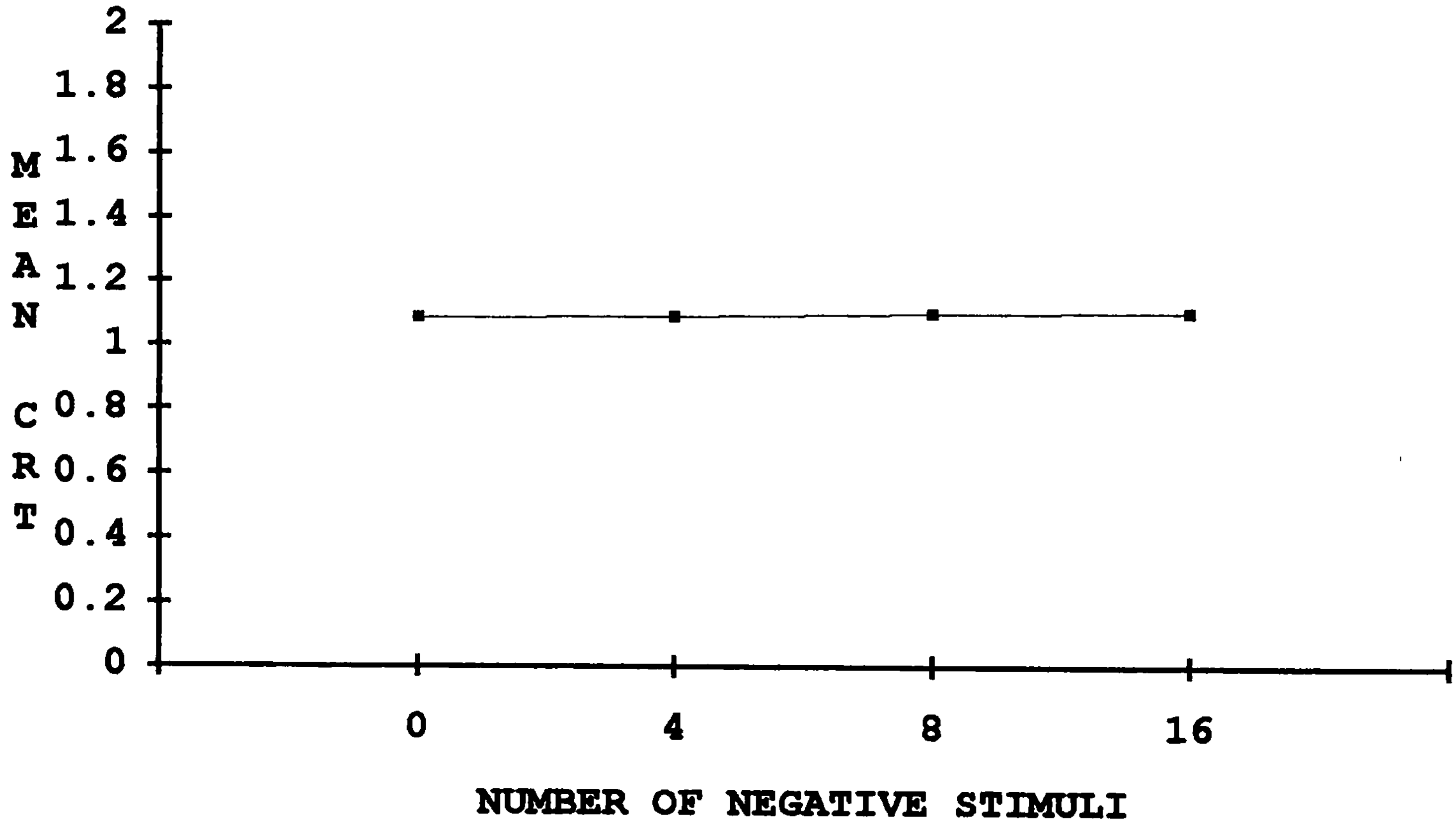

Figure 3. CRT as a Function of the Negative Set Size

the stages differently, thus supporting the Sternbergs information processing theory.

As expected a significant effect was indicated for reaction time across the trials, $F(4,108) = 27.00$, $p<.0001$. Figure 4 shows the mean reaction time as a function of blocks of five trials. The first three trial blocks are significantly different from each other for reaction time according to the Student-Newman-Keuls post hoc tests. There was a significant decrease in RT across Blocks 1, 2, and 3; however there were no significant differences found among Blocks 3, 4, and 5. Thus, a practice effect is indicated by the significant decrease in reaction time noted across trials, which is consistent with the findings by Keiser & Kirby (1990) and Lively (1972).

To establish how each subject cognitively stored the data presented, each subject was asked after completion of her set of trials whether she memorized, scanned, or used both methods to determine her response. Although, each subject had the positive stimulus set before them at the bottom of the computer monitor throughout the trials, 59% of the subjects reported that they memorized that set. Thirty-three percent reported that they used both methods, while 7% stated that they continued to scan, comparing the presented stimuli with the listed positive set. A 3x3 Chi Square analysis across the positive set size was significant, 3x3 $X^2 = 17.605$, $p<.01$ (See Table 3). As expected, these

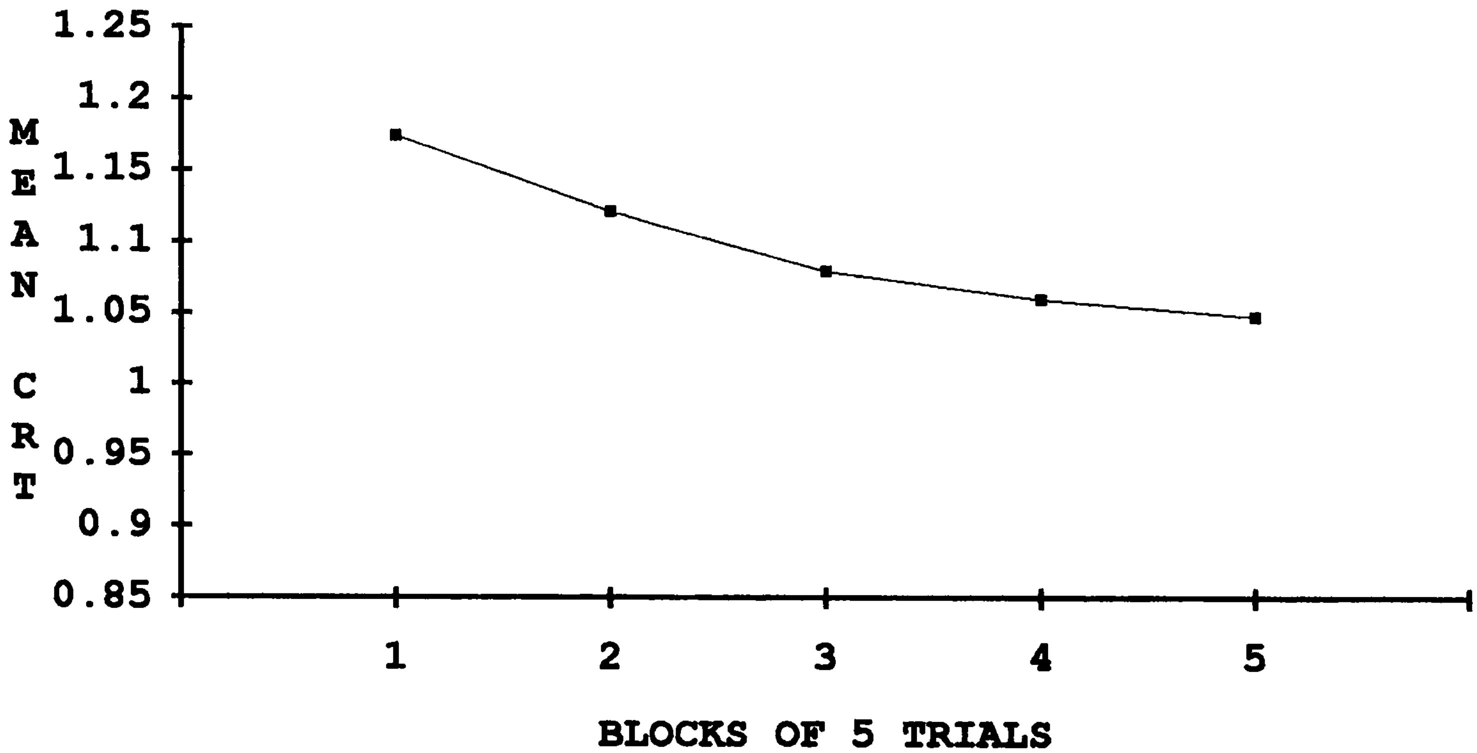

Figure 4. CRT as a Function of Blocks of Trials

results indicate that many subjects used some top-down processing to assist them in their response discrimination. In addition, the results indicate that the positive set size and the method used (memorization, scanning, or both) were not independent. Thus, a subject's method of search during the serial comparison stage is dependent on the number of stimuli in the positive set.

Table 3

Summary Table for 3x3 Chi Square Analysis

Number of Positive Stimuli	Memorized	Scanned	Both
2	29	2	9
4	29	3	8
8	13	6	21

Error rates were nearly 0%; therefore, further analysis was not performed on this measure.

Experiment 2

In order to test the effect of the positive signal frequency on CRT, a second study was conducted incorporating variation of the proportion of trials on which positive stimuli were presented. The task was a visual scanning task similar to that used in the first study except in this study the proportion of trials with positive versus negative stimuli was also varied.

Method

Subjects

One hundred eighty female undergraduate students from Old Dominion University participated in this study. As in the first study, subjects received extra credit for a course for their participation. Subjects were between 18 and 30 years of age. Subjects were recruited by posting requirements of the study on a psychology experiment bulletin board.

Design

A 2(positive set) x 3(negative set) x 3(signal frequency) factorial between-subject design was employed. The two levels of the positive set were either four or eight alternative stimuli. The three levels in the negative set were either 4, 8, or 16 alternative stimuli. The proportion trials on which positive set stimuli were presented was varied across three levels, either 20%, 50%, and 80%. Thus, when the proportion of presented stimuli for the positive set was 20%, the proportion of the stimuli presented in the negative set was 80%. When the proportion presented was 80% for the positive set, the negative set was presented 20% of the time. The two sets were presented equally in the 50% condition. As in Experiment 1, the dependent variable was CRT on the positive trials.

Materials and Apparatus

The materials and apparatus were the same as for Experiment 1.

Procedure

Subjects were randomly assigned to one of the 18 treatment conditions. Refer to Table 1 for the list of letters presented in the positive set. Each condition contained 80 trials. The entire set was divided into five blocks, thus there were 16 trials per block. All other procedures were the same as in Experiment 1.

Results and Discussion

As in the first experiment, the mean RT for each subject was computed for each block of sixteen trials, resulting in five mean RT's per subject. Mean RT's were analyzed across subjects in a 2x3x3x5 (positve set size x negative set size x positive set proportion x trial blocks) analysis of variance with repeated measures for trial blocks (See Table 4). A significant main effect was found for the proportion of trials in which a positive stimulus was presented $F(2,162) = 25.37$, $p<.0001$. In addition, there was a significant main effect for the size of positive set $F(1,162) = 74.24$, $p<.0001$. No significant effect was found for the size of negative set $F(2,162) = 0.57$, $p>.1$.

As expected RT decreased significantly as the proportion of the stimuli presented from the positive set increased, which supports prior research (Bertelson & Barzeele, 1965; Miller & Pachella, 1973; Theios & Smith, 1972; Theios, etal., 1973). According to the Student-Newman Keuls tests that were calculated for RT as a function of the signal frequency, significant differences were found between each signal frequency presented (80%,50%,20%). Figure 5 depicts reaction time as a function of the signal frequency.

Table 4

Summary Table for 2x3x3x5 Analysis of Variance

Source	SS	df	MS	F
Test of Hypotheses using Block*S(Pos*Neg*PS) as Error Term				
Block	2.690	4	0.672	37.05*
Block*Pos	0.017	4	0.004	0.23
Block*Neg	0.154	8	0.019	1.06
Block*PS	0.233	8	0.029	1.60
Block*Pos*PS	0.193	8	0.024	1.33
Block*Neg*PS	0.320	16	0.020	1.10
Block*Pos*Neg*PS	0.346	16	0.022	1.19
Block*Pos*Neg	0.139	8	0.017	0.96
Test of Hypotheses using S(Pos*Neg*PS) as Error Term				
Pos	4.688	1	4.688	74.24*
Neg	0.072	2	0.036	0.57
PS	3.204	2	1.602	25.37*
Pos*Neg	0.199	2	0.099	1.57
Pos*PS	0.085	2	0.043	0.68
Neg*PS	0.168	4	0.042	0.67
Pos*Neg*PS	0.401	4	0.100	1.59

* $p<.01$

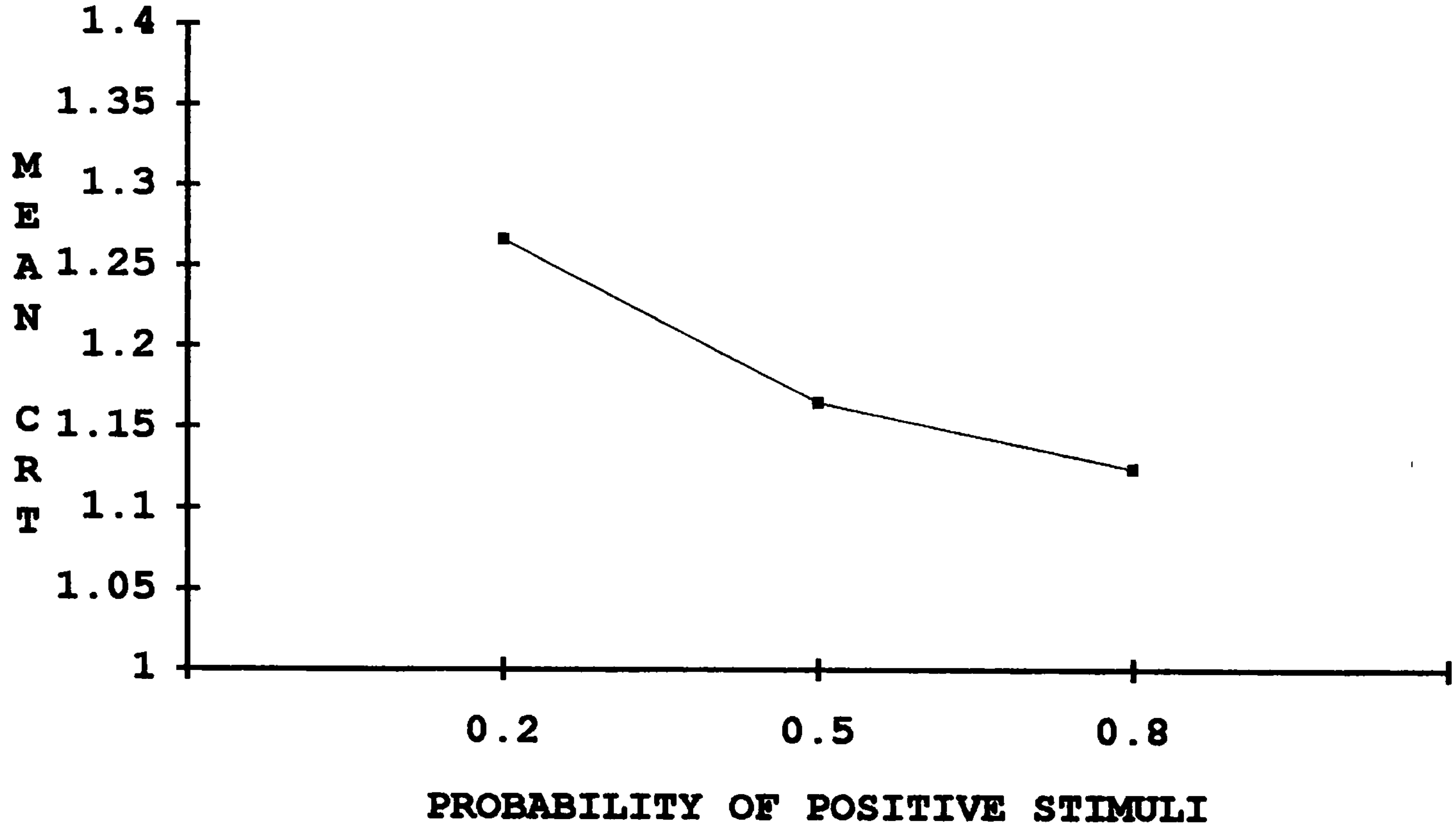

Figure 5. CRT as a Function of the Signal Frequency

Significant effects for the positive set size support prior studies; see Figure 6. The results support signal detection theory for discrimination. When there are multiple responses to choose from, the decision making process cannot be anticipated; thus, RT was longer when there were more choices, showing an increase in the amount of time to choose the correct response.

The negative set size was not found to have a significant effect on RT, even when signal frequency was varied and when a wide range of number of letters was presented in the negative set. Therefore, results indicate that subjects were able to detect the difference between the two sets at the same rate, regardless of negative set size. Since response discrimination was not required for the negative set, RT did not vary significantly. Figure 7 presents the RT for positive stimuli as a function of the negative set size. Again, this figure depicts the null hypothesis.

No significant interaction was found between the negative and positive set sizes, thus providing support for the Information Processing Theory, since the factors presented in this study indicated that the stages were affected differently. In addition, no interactions were found with proportion of stimuli from the positive set nor blocks of five trials.

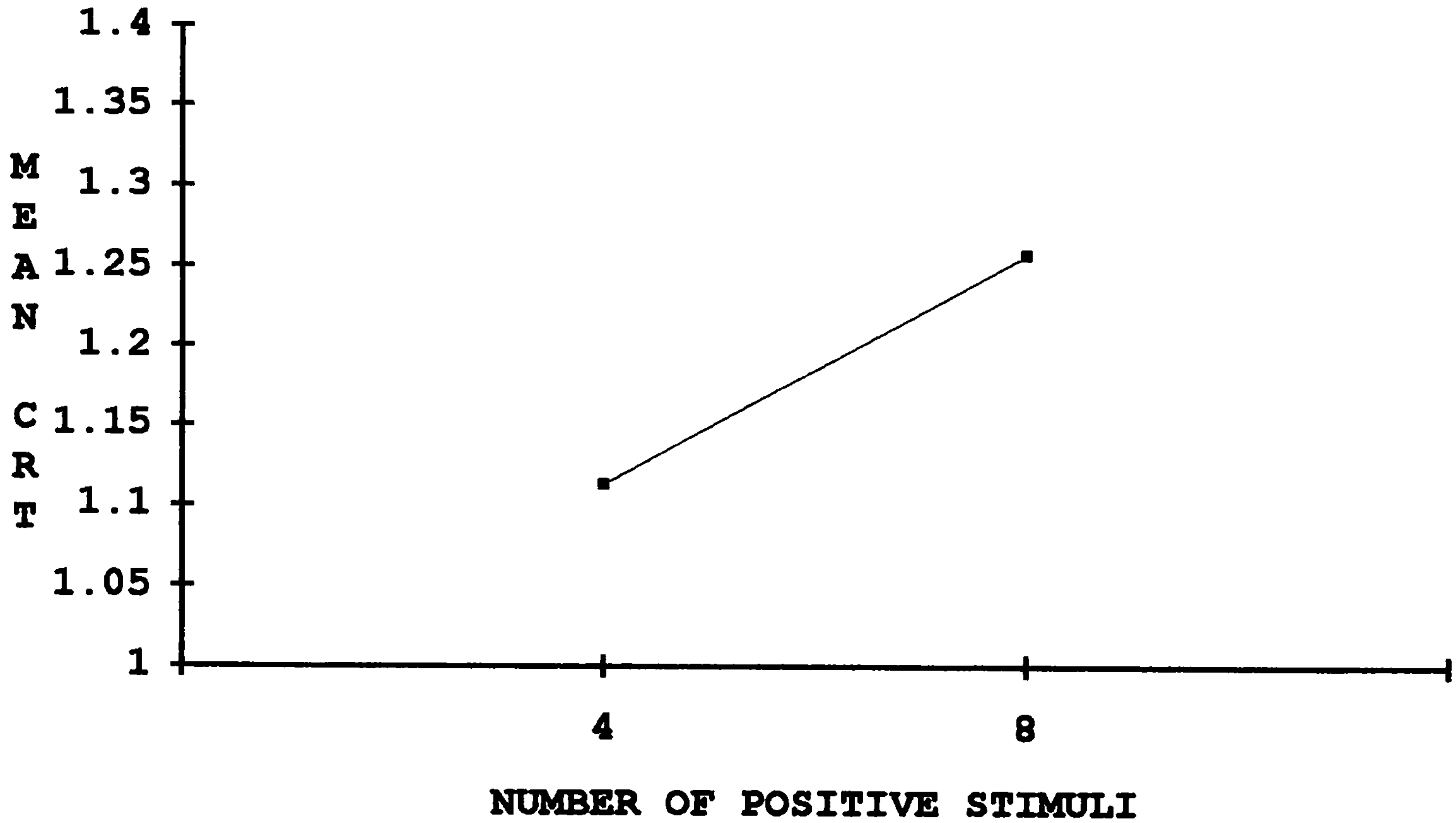

Figure 6. CRT as a Function of the Positive Set Size

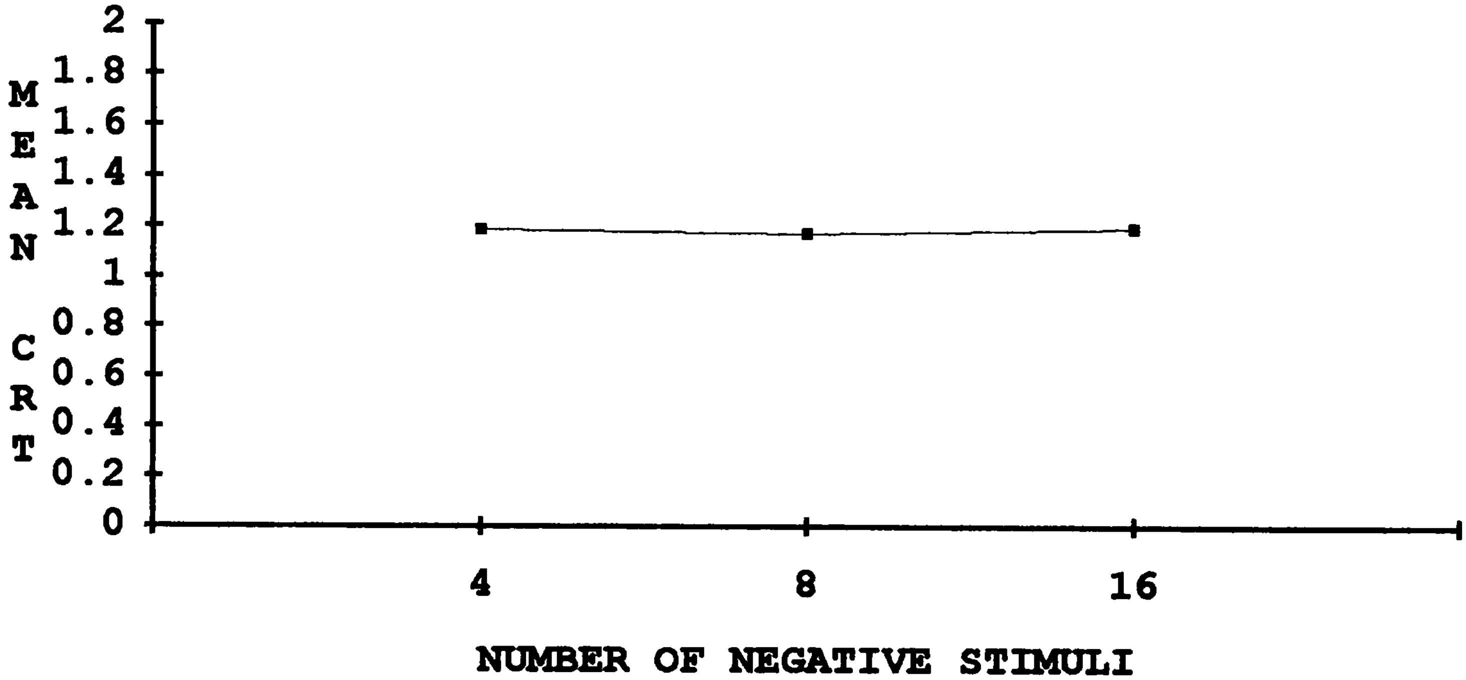

Figure 7. CRT as a Function of the Negative Set Size

A significant decrease in reaction time was found across trials, $F(4,648) = 37.05$, $p<.001$. Figure 8 shows the mean reaction time as a function of each block of five trials. All five trial blocks were found to be significantly different according to the SNK test. According to the data in the first experiment it appears that it took subjects in this study longer to adjust to the differences in the signal frequency. Thus, a longer practice effect is indicated by this result.

As in Experiment 1, error rates were nearly 0%; therefore, an analysis was not performed for this measure. However, this does indicate that the RT's recorded were measuring the amount of time it took subjects to choose a correct response.

After completing the task each subject was asked whether she memorized, scanned, or used both methods to determine her response. Fifty-four percent of the subjects self reported that they used both methods to store the presented data cognitively, while 34% stated that they memorized their response set. Twelve percent recounted that they continued to scan back and forth through the entire trial. A 3x3 Chi Square test found a significant difference across the proportion of positive stimuli, 3x3 $X^2 = 14.679$, $p<.01$ (See Table 5). The results indicate that the proportion of the positive set and the method used (memorization, scanning, or both) were not independent.

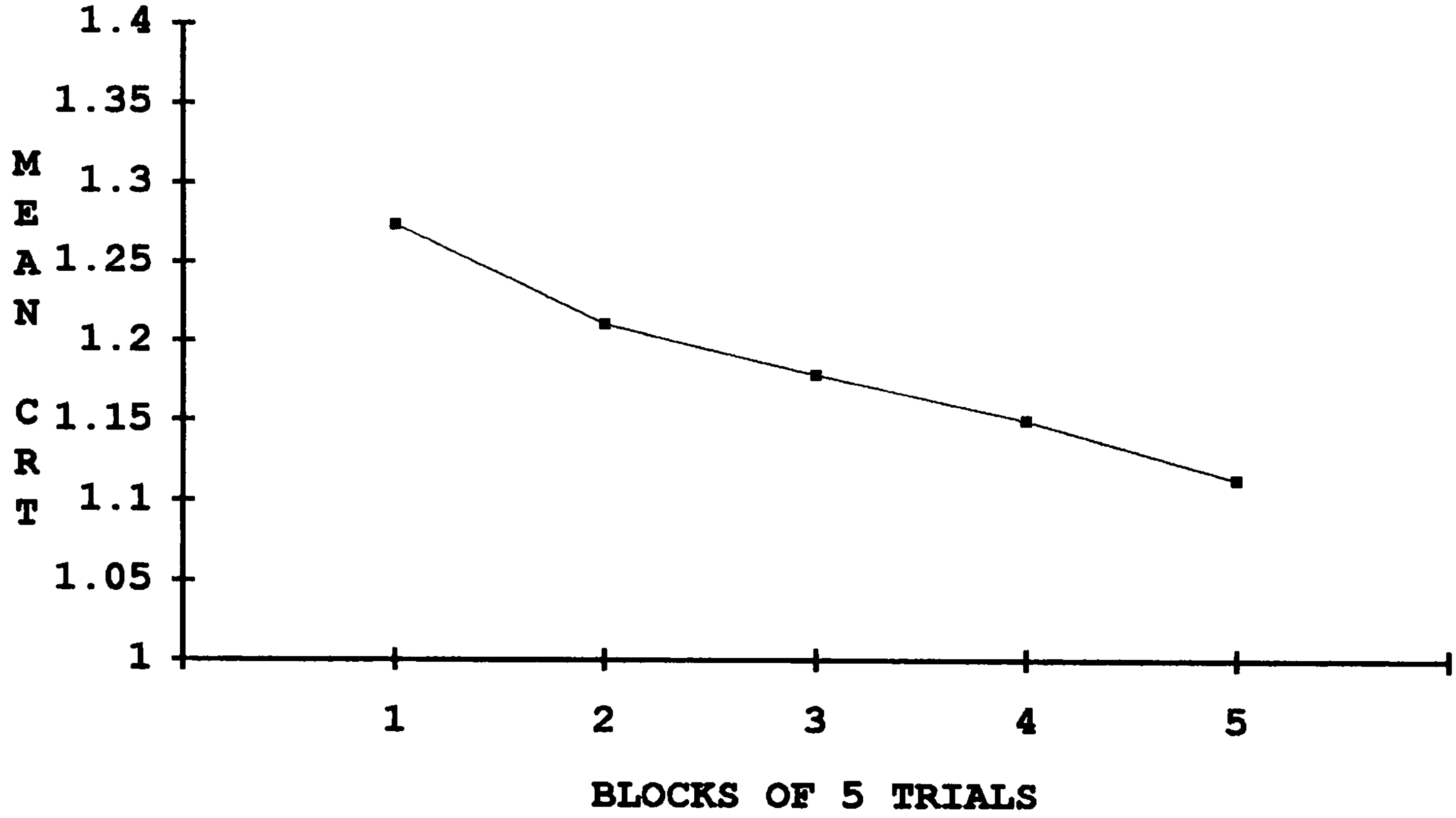

Figure 8. CRT as a Function of Blocks of Trials

significant difference was found between the two experiments, 2x3 $X^2 = 11.397$, $p<.01$ (See Table 6). It appears that subjects did more scanning, along with memorizing, their response set in this study. The results indicate that the experiment and the method used (memorization, scanning, or both) were not independent. Thus, a subject's method of search was dependent on which experimental condition she was assigned to.

Table 5

Summary Table for 3x3 Chi Square Analysis

Proportion of the Positive Set	Memorized	Scanned	Both
0.80	19	8	33
0.50	31	6	23
0.20	12	7	41

Table 6

Summary Table for 2x3 Chi Square Analysis

Experiment	Memorized	Scanned	Both
1	71	11	38
2	62	21	97

General Discussion

At this point, it is clear that reaction time increases as the number of alternatives in the response set are increased. In addition, it is clear that the number of items presented in the negative set does not affect reaction time when subjects are responding to the positive set. The probability of the positive signal does affect a subject's performance by increasing RT on a low probability task, while decreasing RT on high probability tasks. RT did decrease across the trials depicting a clear practice effect. No interactions were found between the positive and negative set size nor with the proportion of stimuli from the positive set.

As expected RT significantly increased with the number of stimuli in the positive set, which supports prior studies (Keiser & Kirby, 1990; Kristofferson, 1975; Lively & Sanford, 1972; Merkel, 1885; Ogden & Alluisi, 1980; Sternberg, 1969). Additionally, support for Hick's Law is provided in that RT linearly increases with the size of the positive set as well as showing an increase in RT as the number of response choices are increased. Results for the negative set size indicate acceptance of the null hypothesis, because negative set size effects were nonexistent. The size of the negative set does not appear to affect RT even when a greater number of stimuli are presented in the negative set. Results indicate that subjects are able to detect the difference between the positive and the negative set at the same rate, so as not to affect RT significantly.

As expected RT decreased significantly as the proportion of the stimuli presented from the positive set increased, which supports prior research (Bertelson & Barzeele, 1965; Hyman, 1953; Miller & Pachella, 1973; Theios & Smith, 1972; Theios, etal., 1973). This result is consistent with Signal Detection Theory. A subject's decision-making process was consistently lengthened during response discrimination; however, varying the response criterion with low or high intervals between responses affected RT significantly differently. Thus, quicker reaction times for subjects in the 80% positive set - 20% negative set were recorded, while slower reaction times were recorded for subjects in the 20% positive set - 80% negative set. Practice effects occurred in both experiments. As subjects became adapted to the task, RT decreased across trials, which supports prior research (Keiser & Kirby, 1990; Lively, 1972).

In addition, no interactions were found between the positive and the negative set sizes. According to Sternberg (1969) when variables affect the information processing stages similarly, there will be an interaction; however, when the stages are affected differently by the variables presented, there will be additive effects on RT. Since negative set size effects were nonexistent stages were only affected in the positive set. Thus, it can be concluded that the CRT in both studies appears to affect the processing stages in the positive set. The Sternberg stages that appear to be affected are the serial comparison and response organization stages. As the number of letters in the positive set increased, the number of letters that the presented stimuli had to be compared to increased. Similarly, the more response keys that subjects had to choose from, the longer the reaction time. Therefore, response discrimination appears to increase reaction time. This appears to support the additivity of processes within information processing theory for the positive set size.

Subjects cognitively stored the data presented by memorizing, scanning - back and forth, or using both methods. Subjects in the first study where the signal probability was equal, reported using memorization most often, using both methods next most often, and using the scanning method the least. These results show that the cognitive methods used were not independent from the size of the positive set. Since, the serial comparison stage involves encoding the stimulus cognitively in a CRT task the number of stimuli in the positive set affected the method in which a subject chose to store the data. Subjects from the second study, where the signal probability was unequal, showed more disruption in short-term memorization. As reported by the subjects, they used both methods most often, memorization next most, and they used scanning the least. This was true except in the equal proportion trial. Subjects seemed to have a more difficult time with their attention wandering; therefore, they needed to return to scanning to reinforce what they had memorized in short-term memory. One reason could be that subjects were less confident using memorization alone, due to the unequal signal probability. In this study the results indicate that the cognitive methods used were not independent from the probability of the stimulus in the positive set. Therefore, it appears that the independent variables of positive set size and signal probability affected the serial comparison stage. It would be interesting in the future to focus more on the cognitive processes that are occurring while subjects are performing a task. One way this could be done is by changing the response set half way through the trial to see if subjects really memorized the set or if they were continually scanning unconsciously.

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Appendix A

Standard Instructions

I would like to thank you for participating in this study on reaction time. I am studying the amount of time it takes for females to react to certain stimuli.

The computer that you see in front of you is programmed to show twelve (eighteen) different levels of conditions of stimuli. Each level is different and the stimuli you will be asked to respond to is varied. The condition that you will be working with has either two, four, or eight (four or eight) letters in the response set and either zero, four, eight, or sixteen (four, eight, or sixteen) letters in the non-response set. When we begin the program, a box will appear in the center of the screen. Letters will appear one at a time in the box and I only want you to respond to the letters that are listed in your response set. I want you to respond to the stimulus by pressing the corresponding key on the keyboard to the letter that appears in the box. For example, if S and L are listed in your response set and a S appears in the box, press the key for S on the keyboard. A warning signal will sound one second before the stimulus appears in the box. If at any time you forget the letters in your response set they will be listed at the bottom of the screen throughout the entire trial.

Any questions so far?

Please place the fingers of both hands in from of the keyboard where the piece of tape is located and only press the corresponding key when a stimulus in your response set is presented. After making a response return your hand to the starting position, so that it takes the same amount of time each time to get to the keys. Do not press any of the keys when a stimulus appears in the non-response set.

Appendix B

Questionnaire

1. Are you familiar with the location of the letters on the keyboard?

2. Can you tell me if you memorized, scanned - back and forth, or used both memorizing and scanning to decide if the letter presented was in your response set?