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INTERSECTION DECISIONS AND REACTION TIME

BY

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B.A. June 1990, Earlham College

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ABSTRACT

Reaction time (RT) as a dependent variable can be used to assess human performance and identify variables influencing performance. Donders (reprinted in English as Donders, 1969) defined three types of reaction time (RT). Simple RT is defined as RT in a situation involving one stimulus and one response. The selective reaction time (SRT) is defined by a situation involving two or more stimuli with only one possible response. Choice reaction time (CRT) is defined by a situation with more than one stimulus category and an equal number of possible responses.

The Hick-Hyman law defines CRT as a logarithmic function of stimulus information. The Hick-Hyman law was founded on searches using union decisions. A union decision requires that a decision be based on an 'or' rule. An intersection decision requires that a decision be based on an 'and' rule. The relationship between intersection decision making and RT is examined in the present research. A specific question this research attempted to answer is whether a linear/logarithmic relationship, similar to Hick's law, exists between RT and the number of elements that are found in conjunction.

Subjects consisted of 96 undergraduate students, 48 males and 48 females. A six factor mixed model design was employed to compare the RT for males and females measured in the intersection and union decision conditions. Four levels

of difficulty, varying the number of positive set items, were used. Reaction time, the dependent variable, was measured a total of 480 times for each subject. The design uses 10 blocks of 48 trials, two display set sizes (6 or 8) and two decision types (positive or negative) as within-subject variables.

There were two main conditions. In the Union Decision condition subjects were required to decide whether <u>any</u> member of the positive set was represented in the display set. In the Intersection Decision condition subjects were required to decide whether <u>all</u> of the members of the positive set were contained in the display set. The response set for all conditions contained two possibilities: 1) a positive response, or, 2) a negative response.

The stimuli were presented on a 12 inch monochrome monitor driven by an IBM compatible computer. The display sets were presented at the center of the screen in a single row with no spaces separating the characters. As a memory aid, the positive set appeared at the bottom of the screen. Each subject responded to 480 display sets which were randomly generated for each trial from the set of 26 characters (A to Z). The positive set, consisting of 2, 3, 4 or 6 characters appeared at the bottom of the screen on the far left in a single row with spaces separating each character. RT in milliseconds was measured for each trial and recorded by the computer.

The RT data were analyzed with a 4 x 2 x 2 x 2 x 2 x 10 (Positive Set Size [2,3,4 or 6] x Type of Decision [Union or Intersection] x Type of Trial [Positive or Negative] x Gender x Display Set Size [6 or 8] x Block). Five main effects and 16 interaction effects reached statistical significance at the $p < .05$ level. The results are discussed in terms of the roles the independent variables played in determining and predicting human information-processing performance. The degree to which the RT data agree with the Hick-Hyman and Sternberg models of human information-processing is also examined.

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INTRODUCTION

Reaction time as a dependent variable can be used to assess human performance and identify variables influencing performance. Reaction time (RT), simply defined, is the interval between the onset of a stimulus and the beginning of an overt response. Donders (1969) proposed an early theoretical model of (RT) and defined three types. Simple RT is defined as RT in a situation involving one stimulus and one response. The selective reaction time (SRT) is defined by a situation involving stimuli with only one possible response. Choice reaction time (CRT) is defined by a situation with more than one stimulus category and an equal number of possible responses.

According to Donders' (1969) RT model, CRT is composed of three discrete and sequential temporal events: (a) simple reaction time, (b) time required for stimulus categorization, and (c) time required for response selection. Simple RT or the (a) event is assumed by this model to be a constant for all three types of RT. The model specifies that the SRT requires the stimulus categorization stage but not the response selection stage since only one response is possible. The distinct and non-overlapping nature of the components in Donders' model and the constancy of the simple RT component allowed Donders' to estimate the amount of time needed for response selection by subtracting SRT from CRT. Using the additive logic of Donders' RT model, simple RT situations would require the shortest amount of time and CRT situations would require the longest amount of time which is, of course, compatible with actual data.

RT and Practice Effects: Reaction time has been used as a measure of the level of learning where RT decreases as a function of the learning process. Mowbray and Rhoades (1959) examined the effects of practice in a CRT situation. Subjects engaged in key-pressing in response to lights. Mowbray and Rhoades (1959) observed practice effects through 45,000 trials for both two and four-choice conditions. The largest drop did, however, occur early in the practice sessions. Seibel (1962) found that RT continued to reduce in a three-choice task even after 20,000 trials. Newell and Rosenbloom (1981) conducted a study examining the effects of practice on CRT in a situation where subjects responded to any of 10 lights by pressing a corresponding set of 10 keys. Results showed that the log RT decreased linearly with the log number of practice sessions. The results of these studies support the contention RT decreases as a function of practice (i.e. learning).

Although it has been shown that RT decreases as a function of practice, research has shown that error rates remain fairly constant. Subjects, in a study by Howell and Kreidler (1963) performed a CRT task for 20 trials. Although response speeds increased significantly throughout the 20 trial session, there was no significant trend in improvement of response accuracy. Bailey and Koch (1976) monitored the performance of newly trained clerks over a four week period and compared their performance with the performance of experienced clerks. The authors of the field study found that the amount of time the new clerks spent each customer decreased significantly over the four week period. After the first week, the new clerks reached an error rate equal to that of the experienced clerks and this rate did not change for the remainder of the study. Experience continues to affect RT while the proportion of errors, once a basic skill is developed, remains about the same.

RT and Age: Age has been shown to have an effect on the human information processing system and RT. Wickens, Braune, and Stokes (1987) tested 60 subjects ranging in age from 20 to 65. Subjects performed a series of tasks designed to evaluate the speed of information processing in relation to age. Subjects performed a tracking task while concurrently engaging in a version of the Sternberg memory search task. RT results showed a monotonic decrease in information processing speed (an increase in RT) as a function of age. At the other end of the life spectrum, Fairweather and Hutt (1978), interested in the rate of information processing in children, had six boys and six girls engage in a choice RT task. Results indicated that RT decreased with age. A gender difference was found but the authors attributed this to the differential rates of cerebral maturation between males and females. Other research supports the findings which suggest that a positive correlation exists between age and RT (Rabbitt & Maylor, 1991; Reynolds, 1991).

RT and Intelligence: Research investigating the relationship between RT and intelligence has revealed a positive relationship between the speed of information processing and intelligence. Neubauer (1990) used 60 subjects in his study of the relationship between RT in the Hick paradigm and intelligence. Results showed that intelligence was negatively correlated with mean RT scores. Small, Raney and Knapp (1987) also compared the relationship between RT and intelligence using a simple RT task and the Wechsler Adult Intelligence Scales as a measure of intelligence. The research found a significant negative correlation between RT and intelligence ($r = -.31$). Other research efforts have arrived at similar conclusions regarding the inverse relationship between RT and intelligence (Neubauer, 1991; Smith & Stanley, 1983; Widaman & Carlson, 1989).

RT and Stimulus Discriminability: Reaction time can be used to assess the degree of stimulus discriminability. Research has demonstrated that CRT increases as the similarity between stimuli choices increases (Schwartz, Pomerantz, & Egeth, 1973; Sanders, 1970). Duncan and

Humphreys (1989) systematically varied the similarity between non-targets in a visual search task. Subjects indicated, after being exposed to a 180-ms display of 2, 4 or 6 letters, whether a specified target letter was present in the display set. Stimulus similarity was varied by altering the size and orientation of the stimuli. The results indicated that visual search difficulty, as reflected by RT, increased with increased similarity of targets to non-targets and decreased similarity between non-targets. Farmer and Taylor (1980) used a similar experimental procedure and varied the similarity between targets and non-targets through color. Results showed that RT increased as the color of the targets approached those of the non-targets. Farmer and Taylor's data also revealed a decrease in RT when non-targets approached redundancy sharing similar colors. Eriksen and Eriksen (1974) identified another variable affecting stimulus discriminability and RT. Their RT data revealed a negative relationship between inter-stimulus spacing and RT. Eriksen and Eriksen (1974) concluded that a positive relationship exists between inter-stimulus spacing and stimulus discriminability.

<u>RT and Stimulus-Response Compatibility</u>: RT can also be used to assess the degree of stimulus-response (S-R) compatibility. Deininger and Fitts (1955) defined S-R compatibility to be maximal when elements in the stimulus

set possessed a direct physical correlation with elements in the response set.

One significant variable in the S-R relationship is the spatial orientation between each stimulus and response. For example, if two stimuli (lights configured on a horizontal plane) are associated with two response keys also configured horizontally such that the left light is associated with the left key and the right light is associated with the right key the S-R relationship is assumed to be compatible. If, however the S-R relationship were to be reversed so that the left light is associated with the right key, the S-R compatibility advantage would be lost and CRT would consequently be greater.

Another S-R compatibility issue involves the nature or type of the stimulus and response. Brainard, Irby, Fitts and Alluisi (1962) explored all possible combinations of stimuli (lights or digits) and responses (key pressing or voice). Their results indicated that the fastest CRT and the highest rate of information transmission was obtained with the digit-voice condition and the slowest CRT occurred with the light-voice condition. Welford (1960) suggests that results such as these are indicative of a temporal information processing stage between the stimulus categorization stage and the response selection stage in CRT situations. An inverse relationship exists between the degree of S-R compatibility and both the length of Welford's proposed translation stage and RT. The inverse relationship between S-R compatibility and CRT has been repeatedly tested and verified (Fitts, 1964; Fitts and Posner, 1967; Welford, 1968)

A relationship exists between the degree of complexity of a S-R ensemble and RT. Donders (Donders, 1969) in the 1860's proposed an early theoretical model of RT and determined that a positive correlation exists between RT and the number of stimulus alternatives and corresponding responses that can occur in a CRT situation. Merkel, in 1885, conducted some of the early research examining the effects of the number of alternatives on CRT (cited in Woodworth, 1938). His research, extending the findings of Donders showed that CRT increased by a constant amount of approximately 135 msec every time the number of alternatives was doubled. Sixty-seven years later, Hick (1952) reexamined Merkel's data and created one of the earliest quantitative models of CRT. He defines RT as a logarithmic function of the number of alternative stimuli and responses using the following formula:

$$CRT = a \log_2(N+1)$$

where "a" represents simple RT and "N" equals the number of equiprobable alternatives in an error free CRT situation. The "+1" in Hick's equation accounts for the uncertainty about the time of occurrence of the signal (it represents the possibility of no signal). It is interesting to note that when N = 1, then, CRT = a = simple RT.

Shortly thereafter, Hyman (1953) independently arrived at the same conclusion as Hick regarding the logarithmic relationship between RT and the number of alternative stimuli. Hyman, using an information theory approach to the topic, conducted a study testing Hick's formula by varying (a) stimulus probability, (b) sequential dependencies, and (c) the number of alternatives. The results of his study supported Hick's formula revealing the linear correlations of .991, .982, .980, .979 between stimulus information and CRT for each of the four subjects involved in the study. Changes in CRT that occurred in tandem with manipulations of the three independent variables led Hyman to conclude that the best predictor of CRT is not the number of alternative stimuli but the amount of information transmitted ($\log_2 N$ when there were no errors). This provided an independent verification of Hick's Law. Hyman offered an alternative equation to predict CRT:

$$CRT = a + b\ H_t$$

or, in the case of error free performance,

$$CRT = a + b\ \log_2 N$$

where "a" again represents simple RT, "b" represents the time required for stimulus identification and response selection and "N" equals the number of equiprobable alternatives in a CRT situation. Hick's Law has been repeatedly tested and verified (Hyman, 1953; Brainard, Irby, Fitts, and Alluisi, 1962; Welford, 1968).

Reaction time may be used to assess the type of processing (serial or parallel) being employed in one type of CRT situation and to help determine in a serial processing situation whether the search is self-terminating or exhaustive (Sternberg, 1969a). Serial processing involves the consecutive comparison of each element in a stimulus set with each element in a memory or positive set. It has been argued that in a parallel processing search, CRT is shorter than in a serial processing search because the parallel search is relatively independent of the number of items held in memory or displayed visually in the positive set. When an exhaustive search is employed in a serial processing situation, the target stimulus is compared with every item in the memory or positive set before a decision is made as to whether the target stimulus is a member of that set. Since every target stimulus is considered, it is argued that CRT in an exhaustive search situation should be relatively independent of the location of the target item in the memory set. The terminating model contends that the search terminates once a match between the stimulus and a member of the positive set is made. Sternberg (1963) advocates a serial comparison model that employs an exhaustive search process.

Sternberg developed a research paradigm called memory scanning which involved a subject's memorization of a small "positive set" of characters. The subject is then exposed to a "probe" stimulus after which he/she reacts with a "positive" response if the probe was a member of the positive set or a negative "response" if it was not a member. Based on his research conducted with this paradigm, Sternberg developed a model of memory scanning consisting of four consecutive and non-interacting stages: 1) stimulus encoding, 2) serial comparison, 3) binary decision, 4) response translation (Sternberg, 1969a). From this memory scan research Sternberg concluded that RT was a linear function of the memory-set size and RT increased approximately 40 msec for every character added to the positive set. This function is represented by the following formula:

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

where "M" equals the number of items in the positive or memorized list and "a" and "b" are derived empirically. Sternberg concluded that the cognitive search process is serial <u>as well as exhaustive</u> in nature, meaning the positive set items are compared with every item in the display set regardless of whether the probe was matched before reaching the last item in the scan process.

Some research findings challenge Sternberg's conclusions about the exhaustive nature of the memory scanning process. Shaw (1977) required subjects to search for a critical letter embedded in a row of background distractor items. RT data revealed a significant position effect of the positive item in the display set consisting of 10 characters. RT increased as the position of the critical letter deviated from the left-most position in the display set. These data suggests that the subjects adopted a serial-self-terminating search strategy. Shaw also varied the memory set size (2,3,4, or 5) and found that this variable also has additive effects on subjects' RT. These results verify other research suggesting a reading position effect of the probe stimulus on RT (Shaw, 1969; Shaw & LaBerge, 1971).

Research by Neisser (1963) also challenges some of Sternberg's conclusions about nature of the memory scanning process. Neisser (1963) found that subjects were able to search for two letters as rapidly as one; and up to four just as rapidly with practice.

These findings are supported by Neisser, Novick, and Lazar (1963) who found that after 13 days of practice subjects were able to scan for any of 10 positive items as rapidly as for any five or one by itself. These two studies suggest that parallel processing can occur when scanning for positive set items and that this processing appears to be relatively independent of the size of the memory set, <u>given enough practice</u>.

Sternberg's conclusions regarding the serial-exhaustive nature of the memory scanning process were based on data collected from memory scanning exercises. Neisser (1963), Neisser et al. (1963), Shaw (1969), Shaw and LaBerge (1971), and Shaw (1977) used visual search tasks. These and other procedural differences may help to account for the discrepancies.

DeRosa and Tkacz (1976) using a Sternberg memory scanning task varied the size of the memory sets, consisting of pictures, and used organization as an independent variable (varying the memory set's degree of organization). RT data from the study showed that when memory sets were disorganized, RT increased with memory set size suggesting a serial-type search process. When memory sets were organized, however, RT was independent of memory set size suggesting a parallel type search. The results of Derosa and Tkacz's study suggest that the type of search strategy adopted by subjects may be a function of the degree of organization of the positive set.

Neisser (1967) proposed a two part theory of perceptual processing which includes a parallel (attentive) and serial (focal attentive) processing stage. These perceptual stages occur in sequence with the preattentive stage first filtering out irrelevant stimuli allowing only those stimuli needing further processing to reach the attentive stage. The preattentive process is faster but less accurate than the focal attentive process.

Schneider and Shiffrin (1977) also developed a two stage theory of information processing which entails "controlled" and "automatic" processing stages. The theory suggests that controlled processing occurs when a memory set is first introduced. Controlled processing requires more attention and time than automatic processing, but a transition to automatic processing style occurs as the subject becomes more familiar with the memory set. Schneider and Shiffrin concluded that the transition is observed in both memory and display searches when the targets and distractors are consistently drawn from separate sets. This transition toward a more parallel type of processing provides one explanation of the decrease in RT observed in scanning procedures when practice is allowed with the same data set (Neisser, Novick & Lazar, 1963).

Hoffman (1979) proposed a two stage model which incorporates serial and parallel processing, and accounts for the effects of both memory and display size variables. In the first rapid stage, unlikely items are discarded through a parallel-type search process. More items are discarded in the initial stage when a) there are fewer items in the memory set and b) when targets and non-targets are dissimilar. In the second stage of Hoffman's visual search model the remaining candidates are studied more closely in a serial-type comparison with members of the memory set. The unique contribution of Hoffman's model to CRT research is its incorporation of both memory and display set sizes.

Other two-stage perceptual process theories similar to the three cited above do exist (Atkinson & Juola, 1973; Shiffrin & Geisler, 1973;). All of these two-stage theories employ both serial and parallel models of human perceptual processing.

Union-Intersection Decisions:

In all of the situations described above in which RT is being measured, the stimulus, whether it be a probe stimulus in Sternberg's memory scanning condition or a stimulus in a CRT situation, requires a decision to be made based on a union rule or, in other words, asks whether the target stimulus contains 'A' or 'B' or 'C' from the memory or positive set. Both Hick's Law and Sternberg's paradigm are founded upon searches, whether they are memory or visual searches, using union decisions. Many of our memory-reality comparisons in the real world involve conjunctive decisions, otherwise known as intersection decisions. An intersection decision requires that a choice be based on an intersection rule or, in other words, asks whether the target stimulus is 'A' and 'B' and 'C' from the positive set. For example, an air traffic controller considers a plane in good standing if, and only if, (a) the altitude is correct, and (b) the airspeed is correct, and (c) the heading is correct.

In a study by Treisman and Schmidt (1982) subjects were asked to make intersection decisions about a row of digits and letters in an effort to better understand the circumstances under which perceptual features may be incorrectly combined to form "illusory conjunctions". Although an intersection decision process was utilized in that study, the research was designed to measure and identify perceptual processes. Beckman and Coates (1992) examined the intersection decision process and its relation to RT.

It is known that requiring intersection decisions increases the complexity of the decision process, and, therefore increases the RT. What, however, is the relationship between RT and the number of items in the positive set in an intersection decision making process?

The relationship between union and intersection decisions and RT was investigated by Beckman and Coates (1992). Beckman and Coates (1992) used a 2 x 2 x 3 x 10 mixed model design employing two levels of decision making (union or intersection) combined factorially with three levels of difficulty (positive set size; 2, 3 or 4). Ten blocks of 24 trials and two trial types (positive or negative) were used as within-subject variables. A question driving the research of Beckman and Coates (1992) was whether a linear/logarithmic relationship, similar to Hick's law, exists between RT and the number of elements that are found in conjunction.

The method used by Beckman and Coates (1992) is almost identical to the method used by the present research. To avoid redundancy please refer to the method section, starting on page 34, for details on the method used in the Beckman and Coates (1992) study while being aware of the three following traits distinguishing the two method sections: (a) in the present research and independent variable (display set size) was added to the experimental design; (b) an extra positive set size (N=6) was added in the present research; and (c) the research by Beckman and Coates (1992) used a total of 36 subjects (six subjects per each of the six independent conditions). In the present research there is a total subject number of 96 (12 subjects per each of the eight independent conditions).

The RT data in the Beckman and Coates (1992) research was analyzed using a 3 x 2 x 2 x 10 (Positive Set Size x Type of Decision x Type of Trial x Block) mixed analysis of variance (ANOVA). The results of the ANOVA are summarized in Table 1.

The most interesting results of the Beckman and Coates (1992) research are contained in a significant three-way, positive set size x type of decision x type of trial, interaction. This interaction is illustrated in Figure 1.

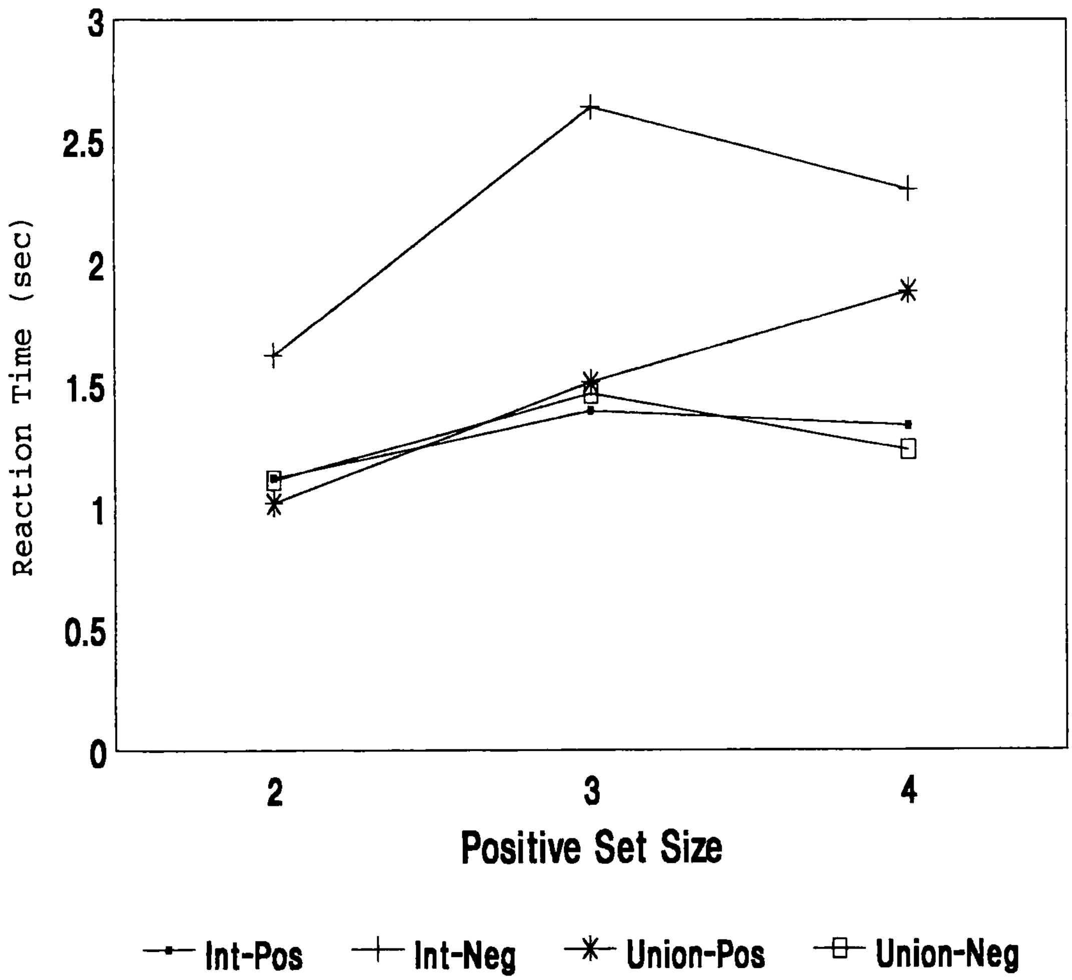


Figure 1. Positive Set Size x Type of Decision x Type of Trial

The RT's for the union-positive condition across the three levels of difficulty (positive set size) revealed a significant linear trend $F(1, 30) = 19.94$ $p<.05$, with no significant deviations from linearity. The RT's for the intersection-negative condition across the levels of difficulty yielded a significant curvilinear trend, $F(1, 30) = 20.43$ $p<.05$, with no significant deviations from this trend. Positive set size had no significant effect on RT for intersection-positive trials or union-negative trials.

Hick's law was founded upon searches using union decisions (Hick, 1952). The significant linear trend in the union-positive condition provides support for of Hick's law. Positive set size did not effect mean RT levels for union-negative trials. This result helps to define the scope and limits of Hick's law for predicting RT in CRT situations.

The mean RT's for both the union-negative and intersection-positive trials showed no significant differences between three positive set sizes and no significant trends across the three levels of difficulty. Therefore, in answer to the question raised earlier based on the results of the Beckman and Coates (1992) research, there does not appear to be a linear/logarithmic relationship similar to Hick's law between RT and the number of elements that are found in conjunction.

The significantly higher RT's observed in the intersection-negative condition across the three levels of positive set size suggest that the trials in this condition required a method of decision making different from the other three conditions. This curvilinear trend in the intersection-negative condition illuminates one area on which the current research has focussed.

The mean differences between the RT's of positive and negative trials in the intersection condition across the three positive set sizes were: N=2: 51 ms; N=3: 125 ms; N=4: 97 ms. The mean differences between the RT's of positive and negative trials in the union condition across the positive set sizes were: N=2: 9 ms; N=3: 5 ms; N=4: 65 ms. The difference between the RT for positive and negative trials for intersection decisions is of intrinsic interest in the realm of CRT research and communications theory.

A fast positive trial phenomenon has been reported in research using a modified version of the Sternberg high-speed memory scanning task and in research examining RT's associated with "same-different" judgments and matching tasks.

A small type of decision effect (positive or negative) was acknowledged by Sternberg (1975). He observed, "a roughly linear increase, the same rate for positive and negative responses, with the slope of the fitted function at about 38 ms/item and the zero intercept at about 400 ms". However he later quantified this positive/negative discrepancy stating that, "positive responses are produced about 40 ms faster than negatives, at each set size". He also noted that this phenomenon remains constant regardless of whether the positive set is fixed over a large number of trials or is varied from trial to trial. Sternberg hypothesized using his four stage RT model that during a trial a binary decision between responses may require a longer period for negative responses than positive.

Wickens, Moody and Dow (1981) researched the two types of RT (positive and negative) using Sternberg's memory scanning paradigm. Wickens et al. considered the discrepancy between the two types of RT insignificant and stated that in most cases the two are "very nearly coincidental." They reported differences between positive and negative trials varying from 15 ms to 40 ms which agree with Sternberg's (1975) findings.

Klatzky and Atkinson (1971) employing a modification of the Sternberg paradigm flashed the probe stimulus to the left or to the right of the fixation point in an effort to ascertain whether the left and right hemispheres behave serially. The researchers reported that "present" (or positive trials in which the probe stimulus was a member of the positive set) and "absent" (or negative trials in which the probe stimulus was not a member of the positive set) trials revealed equivalent slopes for different sizes of the memory set. Equivalent slopes such as these are what Sternberg heralds as evidence of an exhaustive search strategy occurring in the scan procedure as opposed to a self-terminating strategy. If a self-terminating strategy had been adopted, positive trials would have required only half the number of serial comparisons as negative trials and the slope of positive trials would be less steep than that of negative trials.

Almost a decade later Williams, Cooper and Hunter (1990) reexamined Klatzky and Atkinson's data and found a difference between the RT for present and absent trials that was neither reported nor tested for significance. Mean RT for present trials was on average 110 ms faster than absent trials. It appears that lateralization of the probe stimulus in the Sternberg memory scanning task results in a more pronounced discrepancy between RTs for positive and negative trials. Williams et al. felt this lateralization effect was worth replicating.

Williams et al. (1990) using the Sternberg memory scanning task presented the probe stimulus three degrees to the left or right and in another condition three degrees above or below the fixation point. Subjects were told not to anticipate the side of the fixation point the probe stimulus would occur. Two levels of stimuli were used in the experimental design: (a) digits and (b) symbols; and three memory set sizes were used: 2, 3, and 4. The slopes of the present and absent responses were approximately equal echoing Klatzky and Atkinson's results and providing evidence of exhaustive scanning for both types of response. Absent (negative) trials were, on average, 113 ms longer than present (positive) trials. This trial type effect was true for both digit and symbols, for all three memory sizes, and for both horizontal and vertical probe location conditions. A control condition, in which the probe stimulus occurred in its normal central position, revealed no significant response type effect which confirms the results of traditional Sternberg literature. These results agree closely with the latent findings extracted by Williams et al. from Klatzky and Atkinson's data.

Williams et al. offer one explanation for the enhanced response type effect found through the lateralization of Sternberg's probe stimulus. A positive probe stimulus will always have been preceded by a representation of itself in the positive set which is memorized before the first trial commences. Williams et al. suggest this prior exposure to the probe may have a priming effect on the positive probe stimulus and thus enhance the stimulus encoding of the probe. Such priming, Williams et al. suggest, must be more effective when the probe stimulus and the trace of the memory stimulus do not mask one another either forward or backward because of their separation in the visual field. Perhaps the small yet consistent fast positive response bias found in the traditional Sternberg memory scanning task is a function of the priming of masked positive set members.

Unless the negative set (those stimuli that would constitute a negative or absent trial) is equivalent in size to the positive set (2, 3, or 4 in size) and every stimulus, positive or negative, has an equiprobable chance of occurring, the positive characters would be displayed as probe stimuli more often than negative characters thus further enhancing the priming bias. This priming of the positive characters may help to account for the fast-"same" effect observed. This potential priming effect of positive characters should be considered in RT research using positive item(s) and a binary decision task.

Nickerson (1965) reported a response-type effect found in the RTs of subjects making "same-different" judgments. The same-different task involved the sequential presentation of two English letters and required subjects to respond as quickly as possible as to whether the second letter presented was the same or different as the first. Subjects made their responses by pressing one of two keys. On half of the 64 trials the second letter was the same as the first. On the other half of the trials the second "different" letter was randomly selected from a negative set of 15 letters. The pooled data between the subjects showed the mean difference between the two types of RT was 45 ms. When only the correct responses were considered, the mean difference between RTs jumped to 80 ms.

Bamber (1969) asked subjects to judge whether two sequentially presented rows of letters containing the same number of characters were identical (i.e. contained the same letters in the same order). The length of the character string was varied from one to four letters. The number of negative items in a trial varied from zero to one. In this experiment a decision could be made as soon as a character that was not a member of the initial character was encountered. Bamber found the "same" trial RTs to be well described by a serial-exhaustive search model. Different judgments were consistent with a self-terminating model. The mean RT for "same" trials, however, was still shorter or faster than the mean RT for "different" trials. Other research efforts using a similar same-different judgment paradigm with multidimensional stimuli have reported results supporting the conclusion that "same" judgments are faster than "different" judgments (Krueger, 1984; see review by Nickerson, 1972).

Bamber (1972) proposed a stimulus comparison model that explained the fast-"same" phenomenon reported in multidimensional stimulus comparison tasks. The model identifies two stimulus-comparison processors: one fast and one slow. In situations where the positive and display sets are the same (a positive trial) the fast processor is able to operate performing a simple comparison of physical characteristics. When the two sets are different, in the case of a negative trial, the fast processor is not able to operate thus defaulting to the slow processor resulting in higher RT. This model helps to explain why, when RT data from positive trials are accurately described by a serial-exhaustive comparison model and the RT data of negative trials are accounted for by using a serial self-terminating model, the mean RT for positive trials is still shorter.

In an experiment testing Bamber's model, Bamber and Paine (1973) forced subjects to evaluate both positive and negative trials using a serial self-terminating model. They achieved this forced processor choice by requiring comparison of stimuli on a nominal basis (Bamber assumes that the fast processor is unable to make nominal judgments). Analysis of subjects' RT data showed that "same" judgments were still faster than "different" judgments even though both positive and negative trials were well described using a serial-self-terminating model. The results of Bamber and Paine's experiment used to evaluate Bamber's RT model casts light on fast-"same" phenomenon and casts doubt on Bamber's model.

Krueger (1983) tested three explanations of why "same" trials are faster than "different" judgments in same-different judgment tasks. The first explanation, the internal-noise principle, is based on the noisy-operator theory (Krueger, 1978) which contends that internal noise can make two identical letters appear different but will rarely make two different letters appear the same. Letters that appear different, according to the theory, will tend to be rechecked where perceived matches rarely will be rechecked. RTs will consequently be greater on "different" trials. The internal-noise theory also predicts more errors on "same" pairs in the form of a false-"different" responses. Some "same"-pair trials resulted in false-"different" responses. Krueger (1978) attributed this margin of error to impatience with the rechecking process and subjects' willingness to accept a 4% margin of error. The general rule underlying this theory's fast-"same" prediction is that internal noise will produce more false mismatches than matches thus reducing the confidence in "different" judgments and revealing more false-"different" decisions with "same" pairs.

Krueger's second explanation of the fast-"same" effect, the priming principle, was discussed earlier in the review of research by Williams et al. (1990). The priming principle contends that the processing of the first stimulus of a pair of identical stimuli will enhance or quicken the encoding of the second occurrence of the stimulus. The priming effect, Krueger (1984) also suggests, biases the subject with a tendency to err by depressing the "same" button.

The third explanation tested by Krueger (1984), the relative-frequency principle, is based on the fact that when the size of the positive and display sets are greater than one, the number of unique "different" pairs will be greater than the number of unique "same" pairs and that unique "same" pairs will occur more often that unique "different" pairs. The theory suggests that the longer RT associated with different pair judgments is a result of the lower relative frequency of occurrence of different pairs.

Krueger had subjects engage in a multi-stimulus "same-different" matching task in which the type of presentation (simultaneous or sequential) and the size of the display pairs were varied. The results of the study provided strong support for the noisy-operator theory, a small amount of support for the priming explanation, and no support for the relative frequency explanation. More errors as well as faster correct judgments on "same" pairs, as predicted by the noisy-operator theory, were found. The priming explanation which predicted faster processing of repeated letters was, in fact, inhibited by the repetition of letters between trials and thus the priming explanation was not fully supported. The frequency explanation was not confirmed since stimulus set size did not affect the speed advantage of same-pairs.

Contradictory findings in one condition of Krueger's experiment point toward the use of a self-termination strategy. When only one letter was varied in the multi-stimulus comparison, the usual fast-"same" effect was observed for short-string length (1-3) but a fast-

"different" effect was found for longer string lengths (5-6). This fast-"different" effect was found only when both strings were simultaneously present. This reversal of the fast-"different" RT discrepancy suggests the action of an analytical type process with a self-termination factor in stimulus comparison with long strings and simultaneous presentation. This self-termination conclusion was also supported by a greater standard deviation found in the RT for "different" judgments.

Soler and Algarabel (1988) in response to Krueger's (1984) atypical data supporting a fast-"different" effect designed a multi-stimulus matching task in which subjects were forced to exhaustively scan the display set items. Subjects were required to find the number of common elements between the display and comparison set thus forcing an exhaustive search strategy. The results Soler and Algarabel's research showed RTs for all "same" responses were on average 90 ms faster than "different" responses. The fast-"same" effect was observed for both sequential and simultaneous presentation of test and comparison sets. RT and the disparity between same-different judgments increased with increases in set size. The forced exhaustive search strategy produced results that contrast with those reported by Krueger (1984). The findings of Soler and Algarabel support those of other studies (Algarabel, Soler & Pitarque, 1987; Pachella & Miller, 1976).

The fast-"same" judgment phenomenon is well established in the realm of same-different judgments. Although no significant response-type effect has been found with the Sternberg memory-scanning paradigm, lateralization of the probe stimulus increased the positive-negative trial discrepancy (Williams et al., 1990).

Haygood and Johnson (1983) investigated the conditions under which subjects would switch focus in Sternberg's memory search task. Sternberg (1975) reported that negative set size has no effect on RT for either positive or negative type trials. This lack of negative set effect seems counterintuitive when subjects that are given a large positive set and a small negative set fail to adopt the more efficient approach of scanning the negative set. Haygood and Johnson (1983) suggest that this poor choice of search strategy may be a result of the task instructions which encourage a strong positive set focus. In Haygood and Johnson's first experiment, using a Sternberg type task, the contents of the negative set were made explicit and subjects consequently did shift focus to the negative set when it was efficient to do so (when the negative set was smaller than the positive set). In their second experiment the size of the positive set was increased systematically. This increase forced a shift in the focus of the subjects to the negative set.

Another variable that will be investigated through the present research will be the effect of display set size on RT. In a literature review, Tiechner and Krebs (1974) concluded that a positive relationship exists between display size and search time. Schneider and Shiffrin (1977) found that when display sizes are small this effect decreases with practice. With regards to parallel processing, Fisher (1982) concluded that parallel processing is limited to situations which have a display size no greater than six.

The present experiment was designed to test the following hypotheses stated in the form of predictions:

(1) Mean RT in response to intersection-negative trials is significantly different from mean RT produced by intersection-positive trials. It seems reasonable to predict that intersection-positive trials will require less time than intersection-negative trials complementing the fast-"positive" trial effect reported in previous research for union decisions (Sternberg, 1975; Wickens, Moody & Dow, 1981; Williams, Cooper & Hunter, 1990). The prediction of a fast-"positive" trial effect for intersection decisions also conforms with the fast-"same" trial effect reported in previous research using "same-different" judgement tasks (Nickerson, 1965; Bamber, 1969; Bamber & Paine, 1973; Soler & Algarabel, 1988).

(2) There is a significant linear\logarithmic relationship between RT and the positive set size in intersection-positive trials. This hypothesis is based on the prediction that a function similar to Hick's Law will be found between RT and the number of items that are found in conjunction (Hick, 1952; Hyman, 1953).

(3) A shift of focus to the negative set will occur in the 6-6 (positive set=6; display set=6) intersection decision condition resulting in a significantly lower mean RT relative to the 4-6, 3-6, and 2-6 conditions. Sternberg (1975) reported that negative set size has no effect on RT for either positive or negative type trials. Haygood and Johnson (1983) made the contents of the negative set explicit to subjects performing a Sternberg memory search task and found that the subjects shifted focus to the negative set when it was efficient to do so. It seems reasonable to predict that subjects in the current experiment will shift focus to the negative set in the 6-6 condition in which adoption of a negative set focus strategy would be clearly practical. If the subjects were to adopt a negative set focus strategy in the 4-6 condition, which would entail a search for two members in the display set that do not belong as opposed to four members that do belong, then one would expect the mean RT in the 4-6 condition to be less than that in the 3-6 condition and

equal to the mean RT in the 2-6 condition and greater than the mean RT in the 6-6 condition. If the subjects adopt a negative set focus strategy when it is practical to do so as outlined above, then a curvilinear trend of mean RT for intersection-negative trials across the four positive set size conditions would result. This would constitute a continuation of the curvilinear trend observed in the intersection-negative condition within the positive set size x type of decision x type of trial interaction of the Beckman and Coates (1992) study (see Figure 1).

(4) An increase in display set size increases the amount of stimulus information in a CRT task and consequently increases RT. It is expected that a main effect of display set size will be found and that mean RT in response to trials using a display set size of 8 will be significantly greater the mean RT associated with trials employing a display set size of 6. This prediction of a display set size effect supports previous research (Schneider & Shiffrin, 1977; Fisher, 1982)

(5) A significant relationship exists between the location of the probe stimulus in the display set and RT for union-positive trials. This prediction does not conform to the exhaustive component of the cognitive search model advocated by Sternberg (1969b). If subjects employ an exhaustive

search strategy for union trials, then there would be no relationship between the location of the probe stimulus and RT since each trial would involve a complete search of the display set regardless of the probe stimulus location. The present hypothesis that a relationship will be found supports previous research which challenge Sternberg's conclusions about the exhaustive nature of the memory scanning process (Shaw, 1977; Neisser, 1963; Neisser, Novick & Lazar, 1963).

Method

This study used a 2 x 2 x 2 x 2 x 4 x 10 mixed model design involving two levels of decision making (Union and Intersection) and a gender variable combined factorially with four levels of difficulty (positive set size: 2, 3, 4, or 6). Two display set sizes (6 or 8), two trial types (positive and negative), and 10 blocks of 48 responses were used as within-subject variables. There were two main conditions. In the first condition, Union Decision Condition, subjects were required to decide whether any member of the positive set was represented in the display set. In the union-positive trials one member of the positive set was contained in the display set. In the union-negative trials no member of the positive set was represented in the display set. In the second condition, Intersection Decision Condition, subjects were required to decide whether all of the members of the positive set were represented in the display set. In the intersection-positive trials all of the members of the positive set were contained in the display set. In the intersection-negative trials less than all of the members in the positive were contained in the display set.

The response set for all trials and all conditions contained two possibilities: (a) a positive response or (b) a negative response. Subjects made a positive response by depressing the "1" key on the numeric keypad and a negative response by depressing the "2" key. The number of characters in the positive set (2, 3 ,4, or 6) determined the level of difficulty where a two member positive set constituted the easiest condition and a six member set was the most difficult. Subjects responded to visually presented upper case letters. Each subject completed 240 trials with a display set of six characters and 240 trials with a display set of eight characters.

<u>Subjects</u>

Subjects were 96 undergraduate students (48 male and 48 female) chosen from introductory psychology classes at Old Dominion University. 12 subjects (6 male and 6 female) occupied each of the 8 independent conditions. The only criterion affecting the selection of subjects from this pool was a requirement of 20/20 corrected vision. The American Psychological Association ethical principles nine and ten governing human subjects were observed.

Apparatus

Stimuli were standard upper case letters presented on a 12 inch monochrome monitor driven by an IBM-compatible computer. Viewing distance was approximately 24 inches. The stimuli were white presented against a black background. The responses were made, as described above, by depressing the appropriate key on a numeric key pad which is part of a standard computer keyboard.

Stimulus Selection

The display set was presented at the center of the screen in a single row with no spaces separating the characters. The display set was randomly selected and different for each trial. As a memory aid, the positive set appeared at the bottom of the screen on the far left with single spaces separating each character. The positive set, consisting of 2, 3, 4, or 6 characters from the 26 character alphabet, was randomly selected and different for each subject.

Each subject participated in 480 stimulus-response trials. Reaction time in milliseconds was measured for each of the trials. The trials for each subject were broken into 10 blocks with each subject's display set being randomly generated within each block of 48 trials. Each of the 10 blocks for all conditions contained 24 positive response trials and 24 negative response trials. The first five blocks were based on a display set size of 6 or 8, and the other five were based on a display set size of 6 or 8 such that each subject completed 240 trials with each display set size. The sequence of presentation of the display set size variable followed a counterbalancing schedule.

Within the union decision condition a member of the positive set could occur in any one of the six or eight positions of the display set. Only one member of the positive set could occur within the display set during a given trial. To control for position effects within the union decision condition a positive set item occurred in each display set character position no more than four times during a given block in the six item display set condition and no more than three times in the eight item display set condition.

Within the intersection decision condition, members of the positive set could occur in any position and in any sequence within the display set. For the 24 positive response situations within each block of 48 trials, all of the positive set's members were represented within the display set. For the 24 negative response situations within each block of 48 trials, none or less than all of characters in the positive set were represented in the display set. Members of the positive set in the intersection decision conditions were randomly positioned within the display set. With a constant set number of 26 characters (A to Z) for all conditions, the number of characters in the negative set covaried inversely with the number of items in the positive set.

The positive set remained constant and visible at the bottom left corner of the computer monitor during the 480 trials each subject had to complete. The display set, presented with each trial, remained visible at the center of the screen until a response was made by the subject.

Procedure

Each of the 96 subjects served once in one of the eight independent conditions. Subjects were randomly assigned to conditions. The experiment was conducted in a small windowless and sound attenuated room.

Subjects were read a set of formalized instructions. Instructions for the intersection and union decision conditions differed accordingly. The instructions described the nature the task they were being asked to perform and informed them of the dependent variable (RT) without revealing the hypothesis of the study. Subjects were asked to respond as quickly as possible with no more than 5% errors. Verbatim text of the instructions are presented in Appendices A and B.

After the instructions were read, subjects were given a break during which they could ask any questions they had before starting the 10 blocks of 48 trials. The subjects were then left alone in the room to complete the experimental procedure. Subjects were able to respond with the preferred hand (right or left).

Each subject completed the 480 trials consecutively with a short 60 second break which commenced after the completion of the first 240 trials. During this short break the display set size variable changed from 6 to 8 or 8 to 6 depending on the counterbalancing schedule of that within-subject variable. The display set size (6 or 8) that subjects started with was counterbalanced such that six of the 12 subjects in each of the eight independent conditions completed the first 240 trials with a display set size of six and of those six, three were females and three were males. Each response by a subject was followed by an approximately two second interstimulus interval which preceded the presentation of the next display set. A white noise generator produced background noise at an intensity of 70 decibels during the experimental procedure to mask extraneous noise. Following the 480 trials each subject underwent a short debriefing.

Results

The RT data were analyzed with a 4 x 2 x 2 x 2 x 2 x 10 (Positive Set Size [2,3,4 or 6] x Gender x Type of Decision [Intersection or Union] x Type of Trial [Positive or Negative] x Display Set Size [6 or 8] x Block) mixed analysis of variance. Another dependent variable, percent correct, was also analyzed with an identical 4 x 2 x 2 x 2 x 2 x 10 mixed analysis of variance. The percent correct (PC) variable is the proportion of total trials in a condition that received a correct response. The results of the RT ANOVA are summarized in Table 2. The results of the PC ANOVA are summarized in Table 3.

REACTION TIME DATA

Using an overall alpha of .05, five main effects, seven two-way interactions, six three-way interactions, and three four-way interactions achieved statistical significance.

Main Effects (RT)

Positive Set Size. A main effect of Positive Set Size (2, 3, 4, or 6) was found. Figure 2 illustrates this main effect. A Tukey post-hoc test revealed that the mean RT in the two-character stimulus condition was significantly shorter than the mean RT in the four-character and six-character stimulus conditions. The mean RT for trials with a positive set size of six was significantly longer than the mean RT in the three-character and four-character stimulus conditions. A test for trend revealed a significant linear effect, $F(1, 80) = 850.202$ $p<.05$; $r^{2*} = 0.972$, with no significant deviations from linearity.

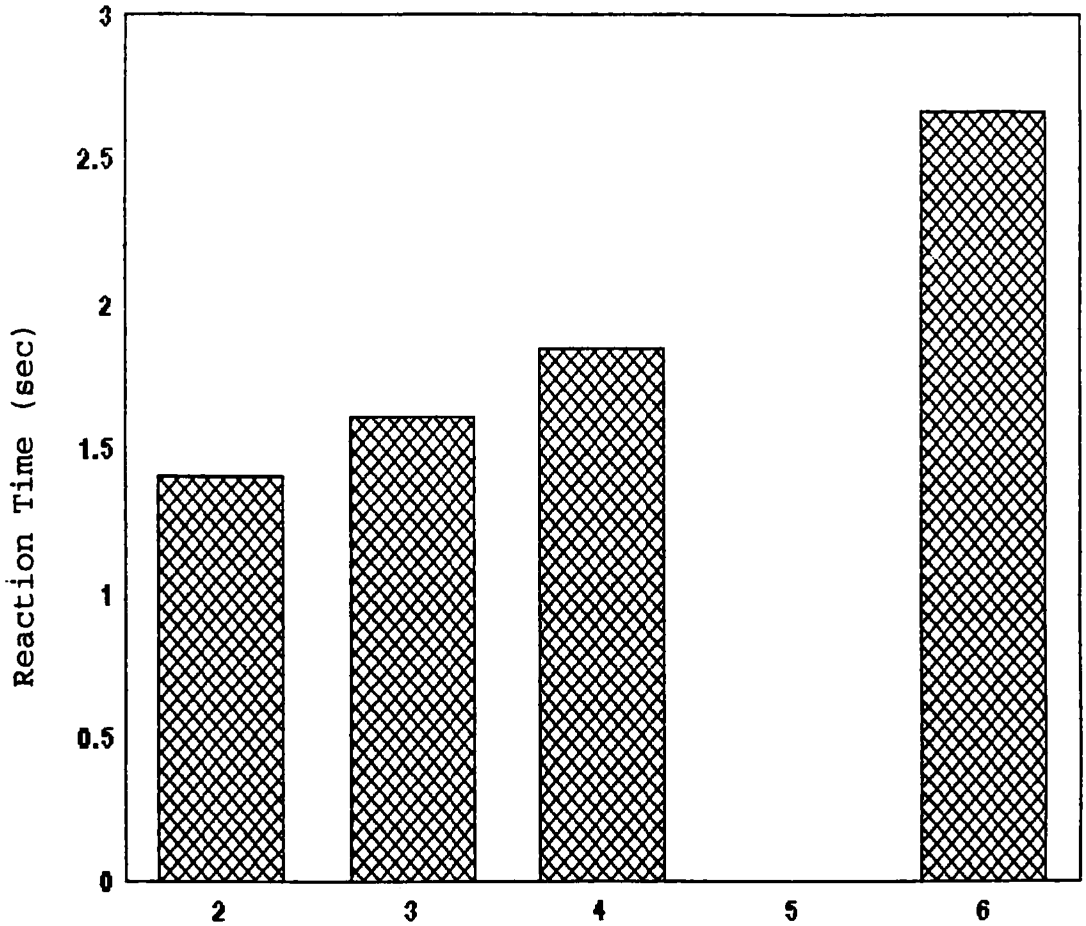


Figure 2. Positive Set Size

Type of Decision. A main effect of decision type (intersection or union) revealed that the mean RT for subjects making union decisions was significantly longer than the mean RT for subjects making intersection decisions, 2.025 sec. and 1.730 sec., respectively.

Type of Trial. A main effect of trial type (positive or negative) was obtained. The mean RT for positive stimulus trials was significantly shorter than the mean RT for negative stimulus trials, 1.491 sec. and 2.560 sec., respectively.

Display Set Size. The display set size variable produced a main effect. An increase in display set size from six to eight resulted in a significant increase in mean RT, 1.621 sec. and 2.134 sec., respectively.

Block. A main effect of block demonstrated a learning effect. Figure 3 illustrates this main effect. A Tukey post-hoc test revealed that the mean RT for block one was significantly greater than the mean RT for the proceeding nine blocks. Block two was significantly greater than blocks five, eight, nine, and ten. Blocks three and four were significantly greater than blocks nine and ten. Block ten was significantly less than blocks five, six and seven.

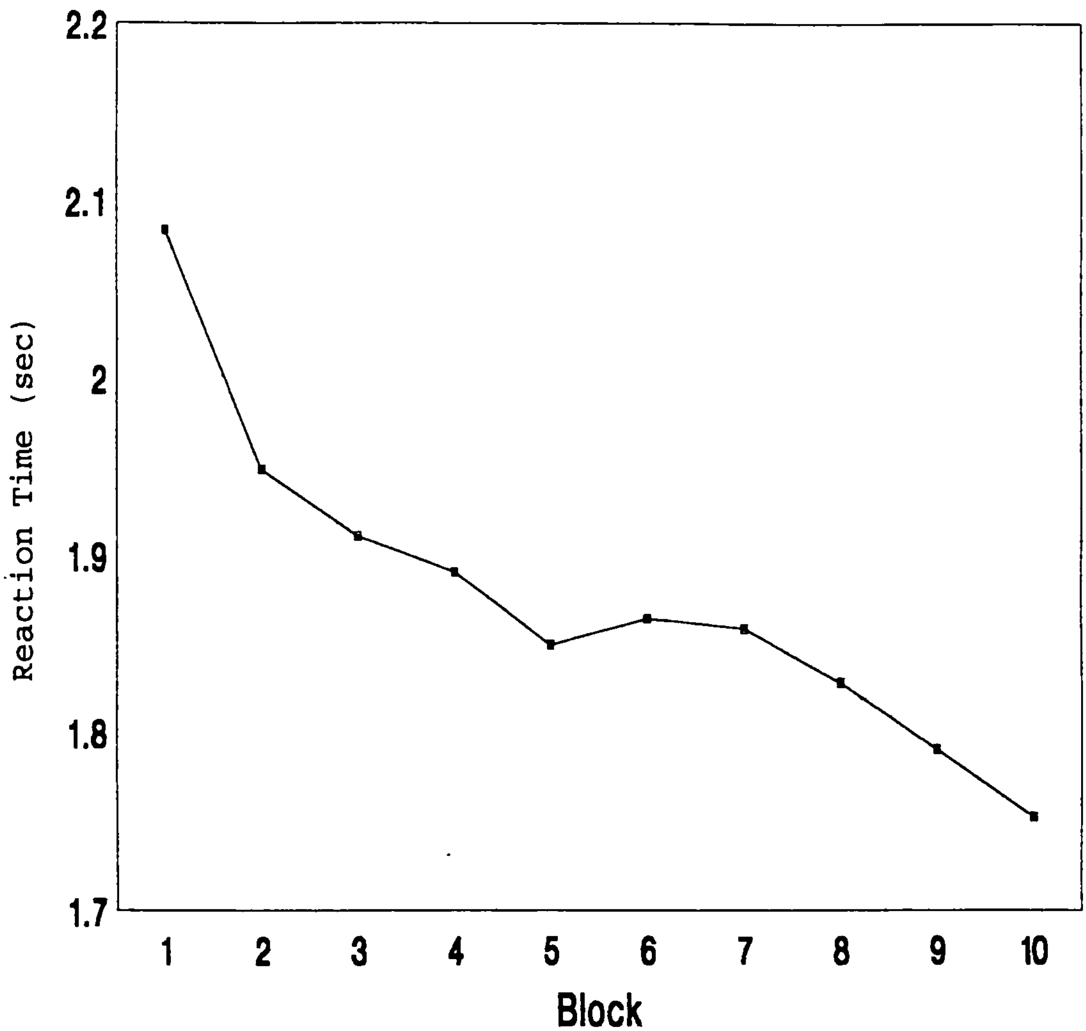


Figure 3. Block

Two-Way Interactions

Positive Set Size x Type of Trial. A significant two-way interaction (Positive Set Size x Type of Decision) was obtained. This interaction is illustrated in Figure 4. An examination of the simple effects of positive set size within the union decision condition showed that the positive set size had a significant effect for union decisions, $F(3, 80) = 21.044$, $p<.05$ (Winer, 1991). A Tukey post-hoc test revealed that for union decisions, the mean RT at positive set size six was significantly greater than the mean RT measured at levels two, three and four. No other differences were significant. A test for trend in the union condition across the four levels of difficulty revealed a significant linear effect, $F(1, 80) = 59.904$, $p<.05$; $r^2 = 0.949$, with no significant deviations from linearity. The relationship found between RT and the positive set size for union decisions is best described by the following equation:

$$RT = 0.452 + 0.419(\text{Positive Set or N})$$

A second test for trend in the union condition across the four $\log_2 N$ values (log to the base(2) of positive set size) also revealed a significant linear effect, $F(1, 80) = 53.640$, $p<.05$; $r^2 = 0.850$, with significant deviations from linearity, $F(2, 80) = 4.745$, $p<.05$.

Simple effects of positive set size for intersection decisions showed that the positive set size had a significant effect, $F(3, 80) = 5.468$, $p<.05$. A Tukey post-hoc test revealed that for intersection decisions the mean RT at positive set size six was significantly greater than the mean RT measured at levels two and three. There were no other significant differences. A test for trend for the intersection condition across the four levels of difficulty revealed a significant linear trend, $F(1, 80) = 15.984$, $p<.05$; $r^2 = 0.974$, with no significant deviations from linearity. The relationship found between RT and the number of members in the positive set for intersection decisions is best described by the following equation:

$$RT = 0.917 + 0.217(N)$$

A second test for trend in the intersection condition across the four $\log_2 N$ values also revealed a significant linear trend, $F(1, 80) = 15.371$, $p<.05$; $r^2 = 0.937$, with no significant deviations from linearity.

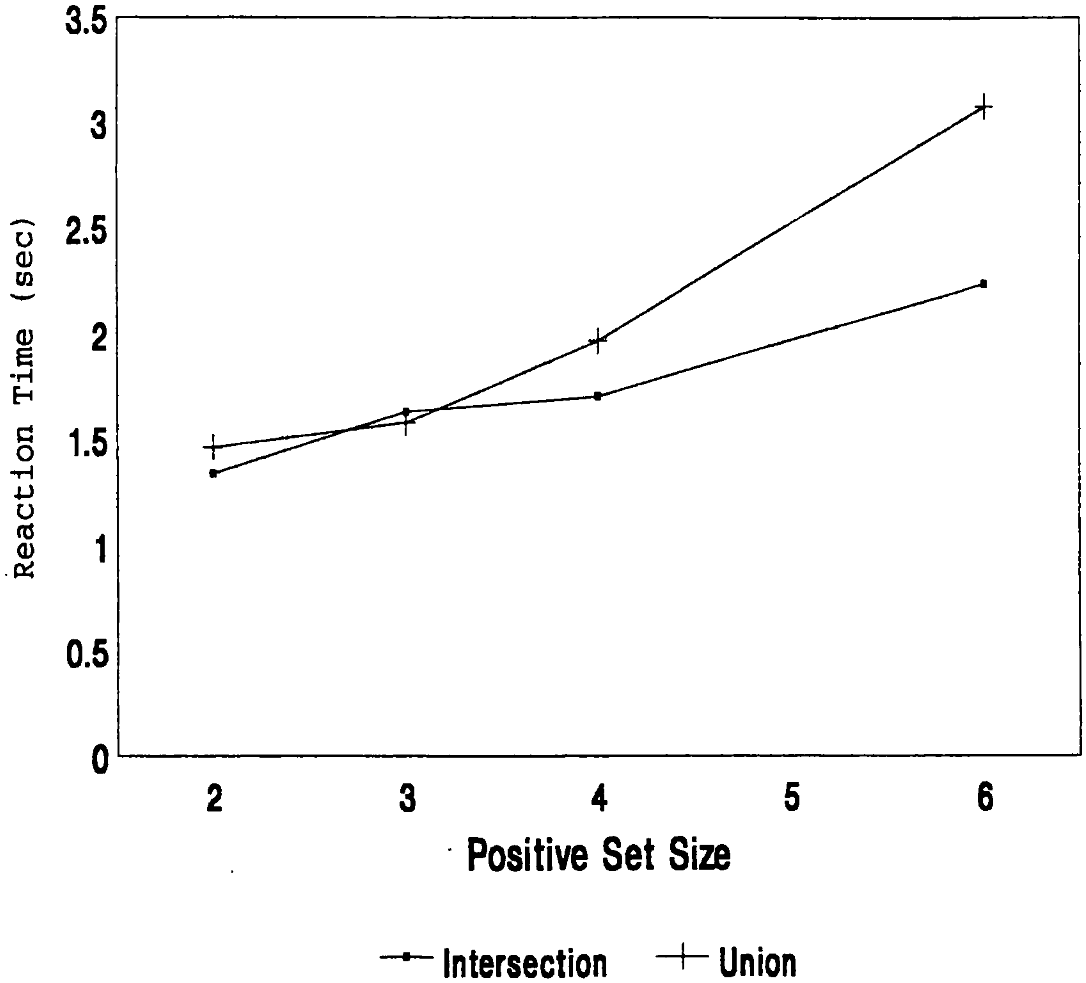


Figure 4. Positive Set Size x Type of Decision

Positive Set Size x Display Set Size. A significant two-way interaction (Positive Set Size x Display Set Size) was obtained. This interaction is illustrated in Figure 5. An examination of the simple effects of positive set size with a display size of eight revealed that the positive set size had a significant effect, $F(3, 80) = 131.337$, $p<.05$. A Tukey post-hoc test showed that for decisions made with a display size of eight, the mean RT at the positive set size of two was significantly less than the mean RT measured at positive set sizes of three, four, and six. The mean RT for trials with a display set size of eight across the four levels of N (positive set size) revealed a significant linear trend, $F(1, 80) = 383.569$, $p<.05$; $r^2 = 0.973$, with significant deviations from linearity, $F(2, 80) = 5.221$, $p<.05$. A second test for trend for trials with a display set size of eight across four $\log_2 N$ values (log to the base(2) of N) revealed a significant linear trend, $F(1, 80) = 353.186$, $p<.05$; $r^2 = 0.896$, with significant deviations from linearity, $F(2, 80) = 20.413$, $p<.05$.

Further examination of the simple effects of the positive set size when the display set size was six revealed that the positive set size had a significant effect, $F(3, 80) = 131.337$, $p<.05$. A Tukey post-hoc test revealed that for decisions made with a display set size of six, the mean RT at positive set size two was significantly less than the mean RT at levels four and six. The mean RT at level six was significantly greater than levels three and four. A test for trend for trials with a display set size of six across the four levels of N (Positive Set Size) revealed a significant linear trend, $F(1, 80) = 90.596$, $p<.05$; $r^2 = 0.968$, with no significant deviations from linearity. The mean RT for trials with a display set size of six examined across four $\log_2 N$ values (log to the base(2) of N) revealed a significant linear trend, $F(1, 80) = 82.578$, $p<.05$; $r^2 = 0.882$, with significant deviations from linearity, $F(2, 80) = 5.526$, $p<.05$.

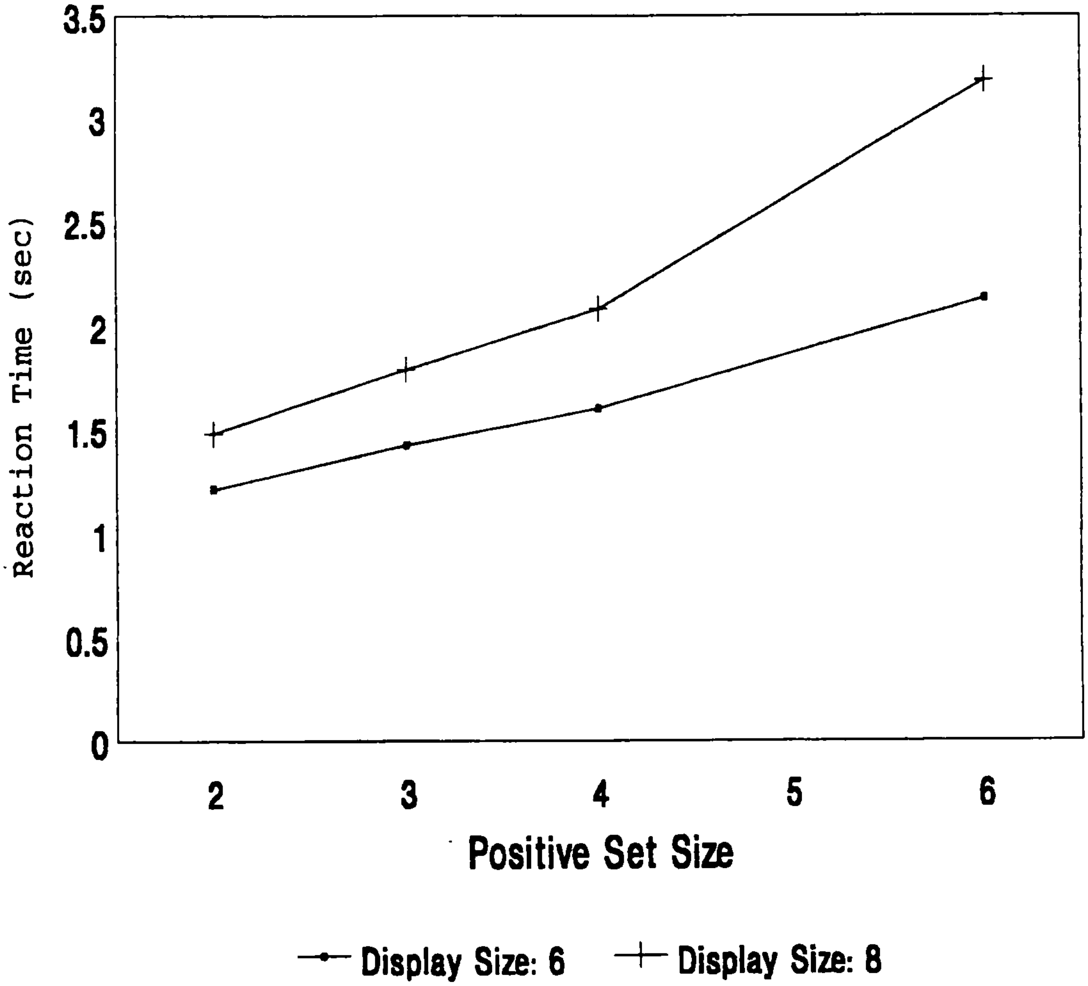


Figure 5. Display Set Size x Positive Set Size

Type of Decision x Type of Trial. A significant two-way type of decision (union or intersection) x type of trial (positive or negative) interaction, illustrated in Figure 6, was obtained. In the positive trial condition, the mean RT for subjects making union decisions was significantly less than subjects making intersection decisions, $F(1, 80) = 114.413$, $p<.05$. The type of decision making (union or intersection) had a significant effect on RT in the negative trial condition, $F(1, 80) = 247.114$, $p<.05$. For negative stimulus trials, union decisions required significantly more time than intersection decisions. Looking at this interaction from another angle, the effect of trial type was significant for intersection decisions, $F(1, 80) = 52.629$, $p<.05$. Positive trials took significantly more time than negative trials for intersection decisions. Positive trials, however, required significantly less time than negative trials for union decisions, $F(1, 80) = 242.911$, $p<.05$.

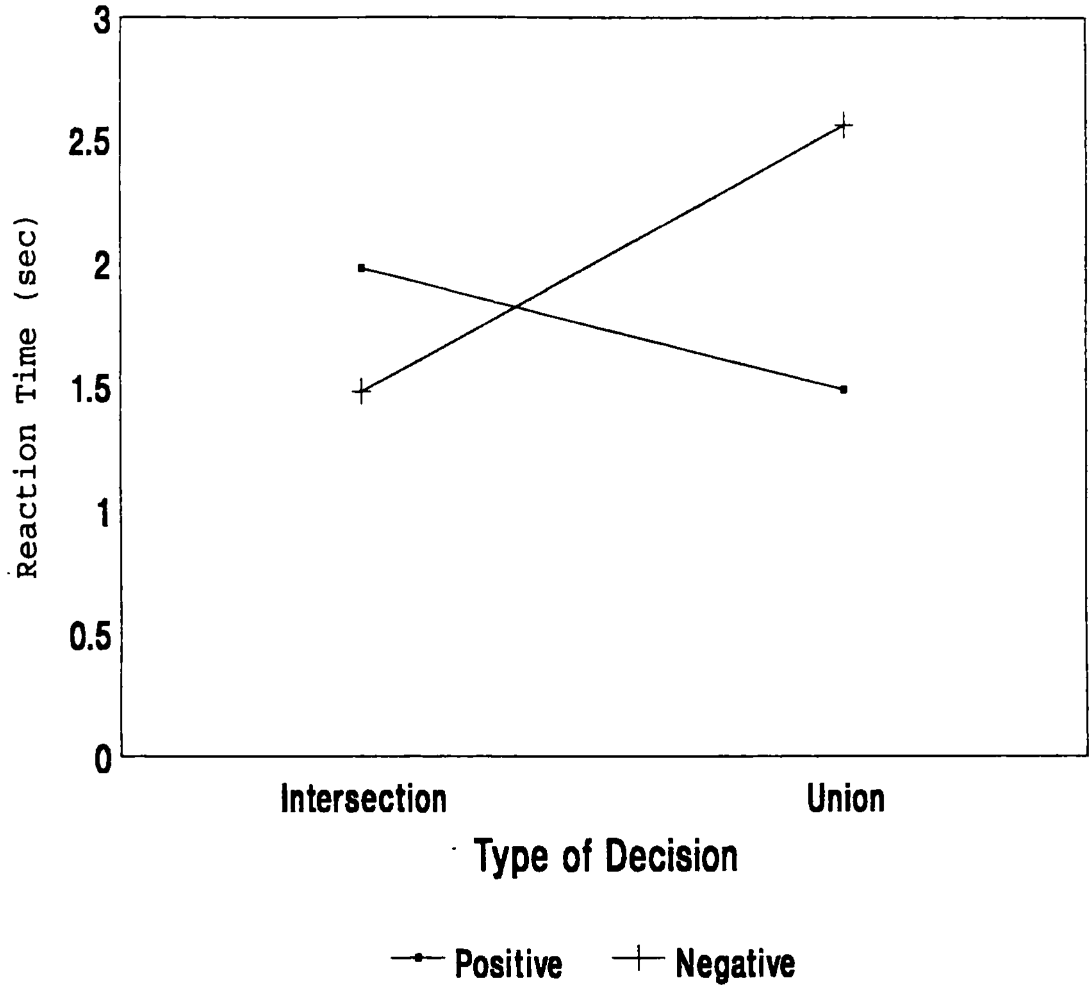


Figure 6. Type of Decision x Type of Trial

Type of Decision x Display Set Size. A significant two-way type of decision (union or intersection) x display set size interaction was obtained. This interaction is illustrated in Figure 7. In those trials employing a six character display set, union decisions required significantly more time than intersection decisions, $F(1, 80) = 38.176$, $p<.05$. Decision type had a significant effect on RT in trials using an eight character display set, $F(1, 80) = 8.637$, $p<.05$. For those trials, union decisions required significantly more time than intersection decisions. Looking at this interaction from another angle, display set size had a significant effect for both intersection decisions, $F(1, 80) = 91.154$, $p<.05$, and union decisions, $F(1, 80) = 39.785$, $p<.05$. Decisions based on a display size of eight required significantly more time than decisions based on a display size of six for both intersection and union decisions.

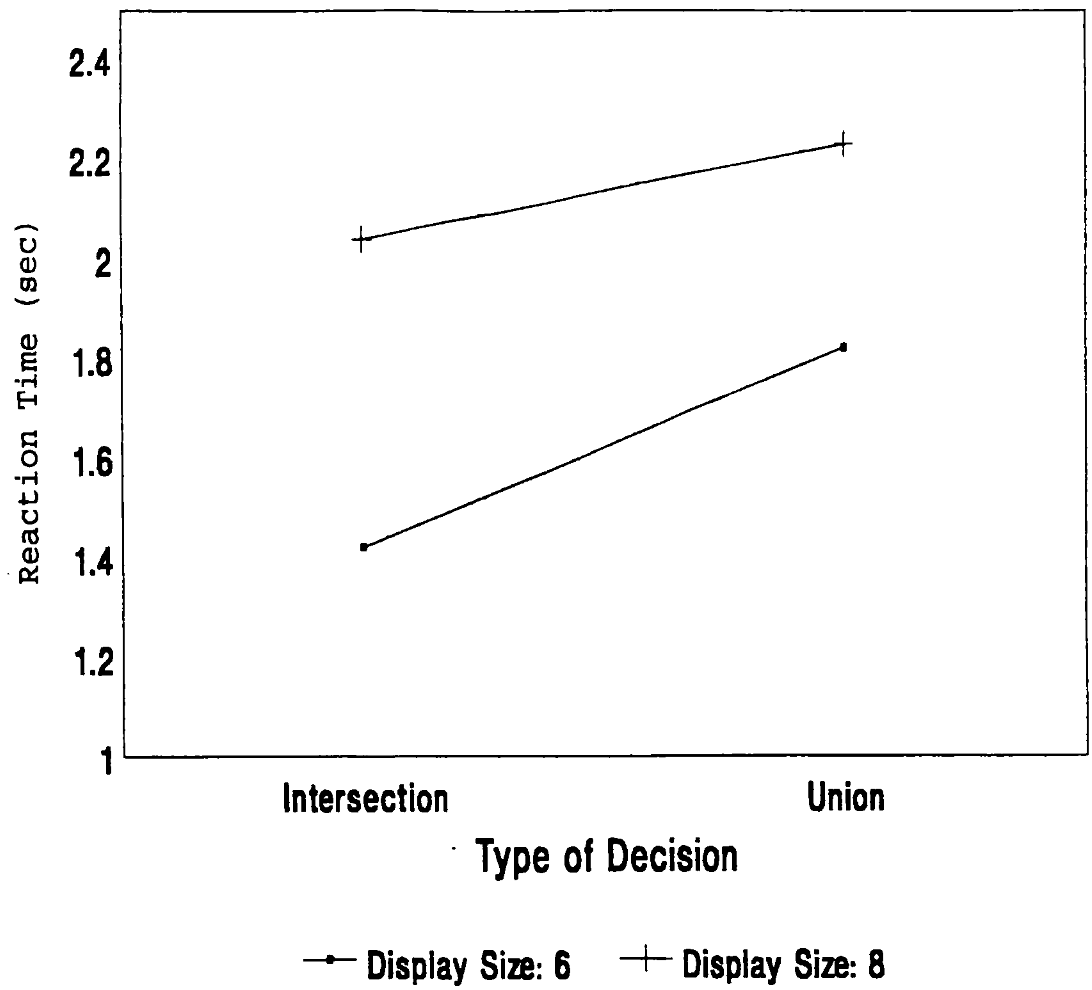


Figure 7. Display Set Size x Type of Decision

Three-Way Interactions

Positive Set Size x Type of Decision x Type of Trial. The three-way positive set size x type of decision (union or intersection) x type of trial (positive or negative) interaction yielded significance. This interaction is illustrated in Figure 8. A breakdown of this three-way interaction into its simple effects revealed that for intersection decisions, positive set size had a significant effect, $F(3, 80) = 29.936$, $p<.05$, trial type had a significant effect, $F(1, 80) = 52.629$, $p<.05$, and the interaction between positive set size and trial type was also significant, $F(3, 80) = 24.606$, $p<.05$. A closer look at the positive set size x trial type interaction for intersection decisions revealed that the positive set size had a significant effect for positive trials, $F(3, 80) = 54.150$, $p<.05$, but had no effect for negative trials. A Tukey post-hoc test showed that the mean RT for intersection-positive trials with a positive set size of two was significantly less than those trials with positive set sizes of three, four, and six. The mean RT for intersection-positive trials with a positive set size of three was significantly less than those trials employing a six-character positive set. The mean RT for the intersection-positive condition across the four levels of difficulty revealed a significant linear trend, $F(1, 80) = 160.774$, $p<.05$; $r^2 = 0.990$, with no significant deviations from linearity.

Further examination of the simple effects showed that for union decisions, positive set size had a significant effect, $\underline{F}(3, 80) = 115.024$, $\underline{p}<.05$, trial type had a significant effect, $\underline{F}(1, 80) = 242.911$, $\underline{p}<.05$, and the interaction between positive set size and trial type was also significant, $\underline{F}(3, 80) = 18.951$, $\underline{p}<.05$. A closer look at the positive set size x trial type interaction for union decisions revealed that the positive set size had a significant effect for both positive trials, $\underline{F}(3, 80) = 20.335$, $\underline{p}<.05$, and negative trials, $\underline{F}(3, 80) = 113.640$, $\underline{p}<.05$. A Tukey post-hoc test showed that the mean RT for subjects responding to union-positive trials with a six-member positive set was significantly greater than those trials with positive set sizes of two, three, and four. The mean RT for the union-positive condition across the four levels of difficulty revealed a significant linear trend, $\underline{F}(1, 80) = 58.073$, $\underline{p}<.05$; $\underline{r}^2 = 0.952$, with no significant deviations from linearity.

For union-negative trials, all mean RT differences between the positive set sizes were significant except between the RT associated with the two and three-member positive set conditions. The RT's for the union-negative condition across the four levels of difficulty revealed a significant linear trend, $\underline{F}(1, 80) = 322.912$, $\underline{p}<.05$; $\underline{r}^2 = 0.947$, with significant deviations from linearity, $\underline{F}(2, 80)$

= 9.005, $p<.05$.

Regression analyses were performed on each of the three significant linear trends (intersection-positive, union-positive, and union-negative trials across the four positive set sizes) within the positive set x type of decision x type of trial interaction. Two models were tested for each trend, one using N (the number of members in the positive set) as a predictor and the second using $\log_2 N$ (log to the base[2] of N) as a predictor. These models are outlined below:

A) Int-Pos trials: $RT = 0.420 + 0.416(N)$ $r^2 = .990$

Int-Pos trials: $RT = 0.118 + 1.039(\log_2 N)$ $r^2 = .948$

B) Un-Pos trials: $RT = 0.554 + 0.250(N)$ $r^2 = .952$

Un-Pos trials: $RT = 0.407 + 0.604(\log_2 N)$ $r^2 = .855$

C) Un-Neg trials: $RT = 0.350 + 0.589(N)$ $r^2 = .947$

Un-Neg trials: $RT = 0.010 + 1.422(\log_2 N)$ $r^2 = .847$

In all three cases the former equation provided the best fit for the data.

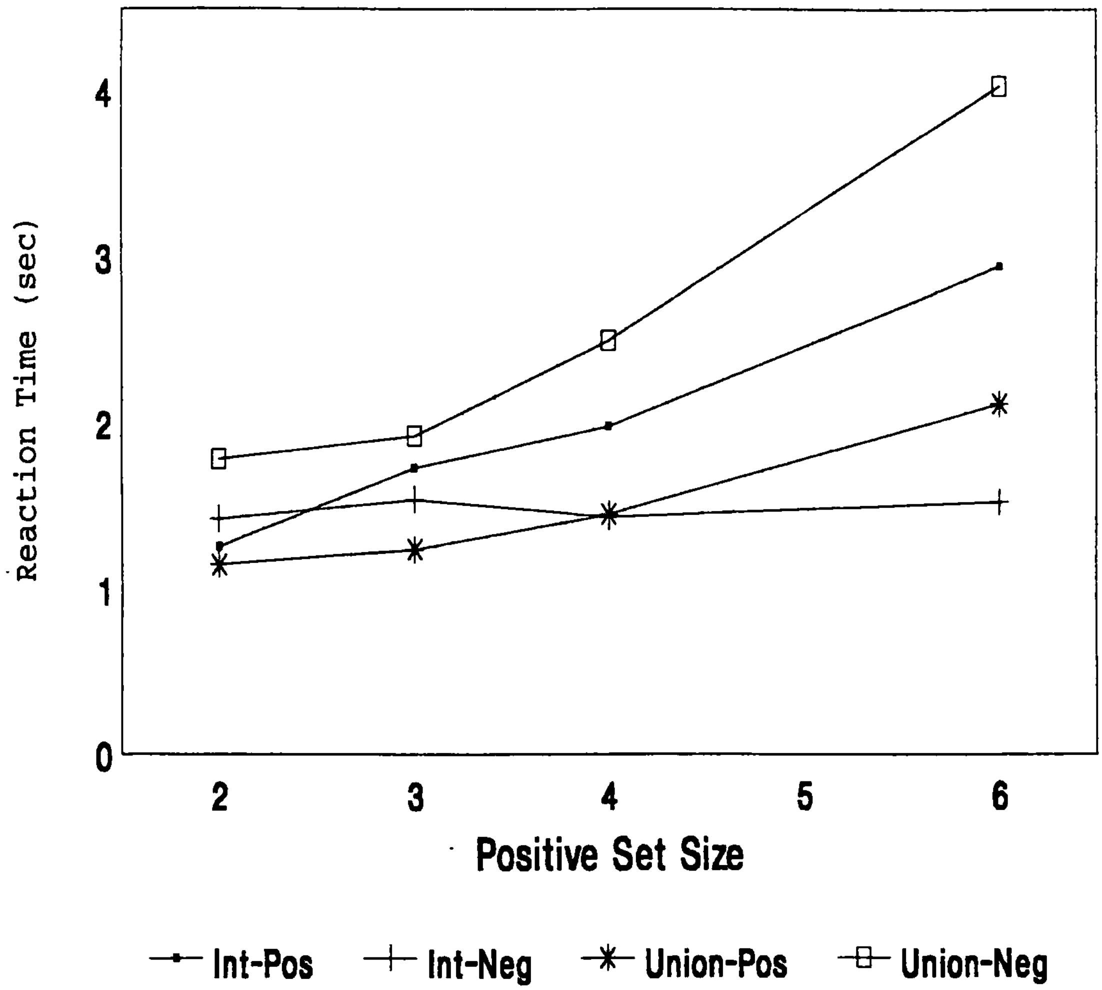


Figure 8. Positive Set Size x Type of Decision x Type of Trial

Positive Set Size x Type of Trial x Display Set Size.

The three-way positive set size x type of trial x display set size interaction yielded significance. This interaction is illustrated in Figure 9. A breakdown of the interaction into its simple effects revealed that for decisions based on a display set size of six, positive set size had a significant effect, $F(3, 80) = 172.460$, $p<.05$, trial type had a significant effect, $F(1, 80) = 84.420$, $p<.05$, and the positive set size x trial type interaction was also significant, $F(3, 80) = 4.395$, $p<.05$. A closer look at the positive set size x trial type interaction for decisions based on a display set size of six revealed that the positive set size had a significant effect for both positive trials, $F(3, 80) = 77.597$, $p<.05$, and negative trials, $F(3, 80) = 99.262$, $p<.05$. A Tukey post-hoc test showed that the mean RT for positive trials with a display set size of six and a positive set size of two was significantly less than the RT at positive set sizes of three, four, and six. The mean RT for trials with three positive set members in this condition was significantly less than levels four and six, and the mean RT for level four was significantly less than level six. The mean RT for the positive trials using a display size of six produced a significant linear trend across the four levels of difficulty, $F(1, 80) = 232.635$, $p<.05$; $r^2 = 0.999$, with no significant deviations from linearity.

A Tukey post-hoc test showed that the mean RT for negative trials with a display set size of six and a positive set size of six was significantly greater than the RT at positive set sizes of two, three, and four. The mean RT for trials with four positive set members in this condition was significantly greater than the RT at level two. The mean RT for the negative trials using a display size of six produced a significant linear trend across the four levels of difficulty, $\underline{F}(1, 80) = 268.684$, $\underline{p}<.05$; $\underline{r}^2 = 0.893$, with no significant deviations from linearity.

Simple effects of positive set size and trial type for decisions based on a display set size of eight, showed that positive set size had a significant effect, $\underline{F}(3, 80) = 263.670$, $\underline{p}<.05$, trial type had a significant effect, $\underline{F}(1, 80) = 48.680$, $\underline{p}<.05$, but there was no significant interaction between positive set size and trial type. Negative decisions, based on a display set size of eight, required significantly more time than positive decisions. A Tukey post-hoc test was used to compare the mean RT differences within the positive set size effect. The mean RT for trials with an eight-member display set and a positive set size of two was significantly less than the RT at sizes three, four, and six. Positive set size produced a significant linear trend for trials with a display set size of eight, $\underline{F}(1, 80) = 2119.606$, $\underline{p}<.05$; $\underline{r}^2 = 0.893$, with significant deviations from linearity, $\underline{F}(2, 80) = 28.850$.

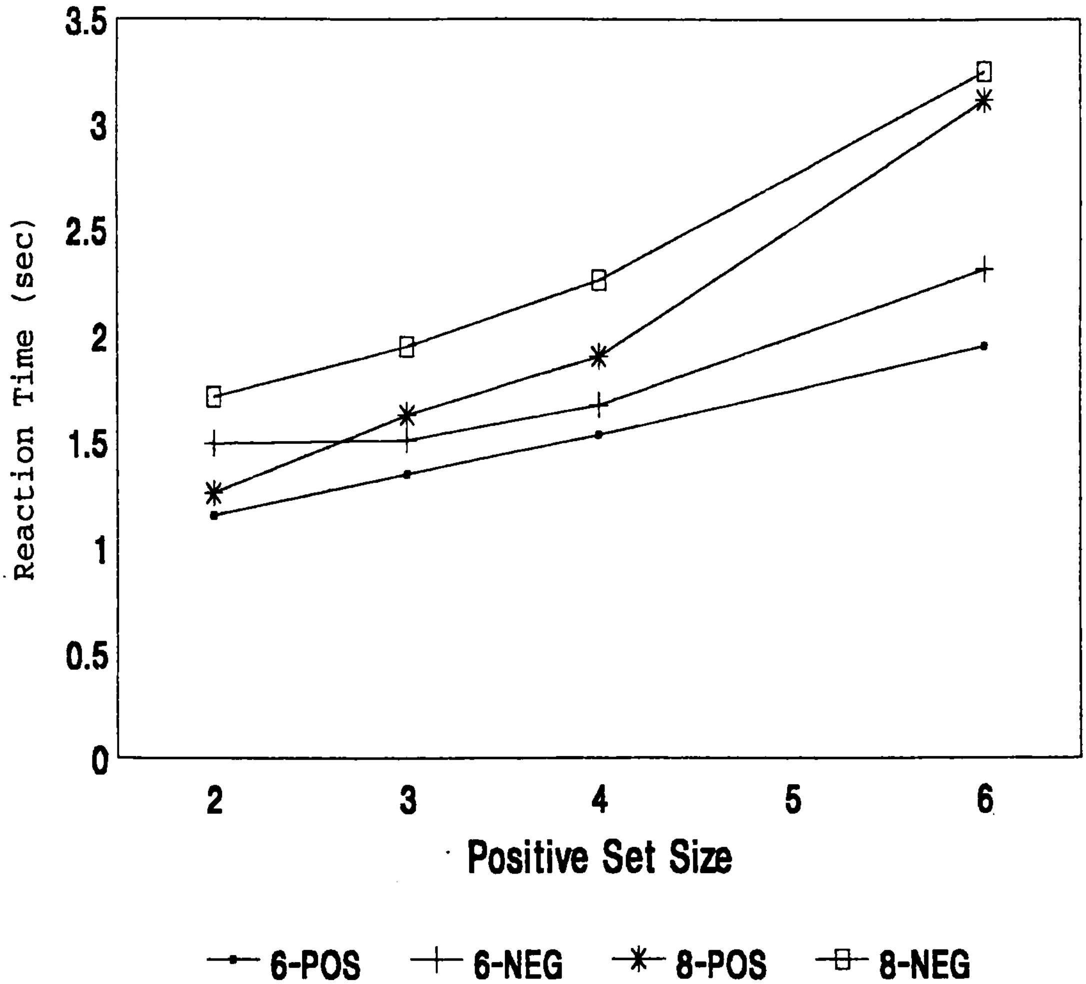


Figure 9. Positive Set Size x Type of Trial x Display Set Size

Positive Set Size x Type of Decision x Display Set Size. The three way interaction positive set size x type of decision (union or intersection) x display set size was significant. This interaction is illustrated in Figure 10. A breakdown of the interaction into its simple effects revealed that for decisions based on a display set size of six, positive set size had a significant effect, $F(3, 80) = 31.204$, $p<.05$, decision type had a significant effect, $F(1, 80) = 38.175$, $p<.05$, and the interaction between positive set size and decision type was also significant, $F(3, 80) = 19.731$, $p<.05$. A closer look at the positive set size x decision type interaction revealed that positive set size had a significant effect for union trials, $F(3, 80) = 49.697$, $p<.05$, but had no effect for intersection trials. A Tukey post-hoc test showed that the mean RT for union trials with a display set size of six and a positive set size of six was significantly greater than those with positive set sizes of two, three, and four. The mean RT for union trials using a display size of six revealed a significant linear trend across the four levels of difficulty, $F(1, 80) = 137.567$, $p<.05$; $r^2 = 0.923$, with significant deviations from linearity, $F(2, 80) = 5.761$, $p<.05$.

Simple effects of positive set size and decision type for trials based on a display set size of eight, showed that positive set size had a significant effect, $F(3, 80) = 87.890$, $p<.05$, decision type had a significant effect, $F(1,$

80) = 8.637, $p<.05$, and the interaction between positive set size and decision type was also significant, $F(3, 80) = 3.175$, $p<.05$. A closer look at the positive set size x decision type interaction revealed that the positive set size had a significant effect for union trials, $F(3, 80) = 52.581$, $p<.05$, and intersection trials, $F(3, 80) = 81.972$, $p<.05$. A Tukey post-hoc test showed that the mean RT for union trials with a display set size of eight and a positive set size of two was significantly less those trials with positive set sizes of four and six. The mean RT for trials with three positive set members in this condition was significantly less than levels four and six. The mean RT at level four was significantly less than the mean RT at level six. The mean RT for the union trials using a display size of eight produced a significant linear trend across the four levels of difficulty, $F(1, 80) = 237.246$, $p<.05$; $r^2 = 0.965$, with significant deviations from linearity, $F(2, 80) = 4.335$, $p<.05$. A Tukey post-hoc test showed that the mean RT for intersection trials with a display set size of eight and a positive set size of two was significantly less those trials with positive set sizes of three, four and six. The mean RT for trials with a six member positive set in this condition was significantly greater than the mean RT for levels three and four. The mean RT for the intersection trials using a display size of eight produced a significant linear trend across the four levels of difficulty, $F(1, 80)$

= 151.154, $p<.05$; $r^2 = 0.958$, with significant deviations from linearity, $F(2, 80) = 3.295$, $p<.05$.

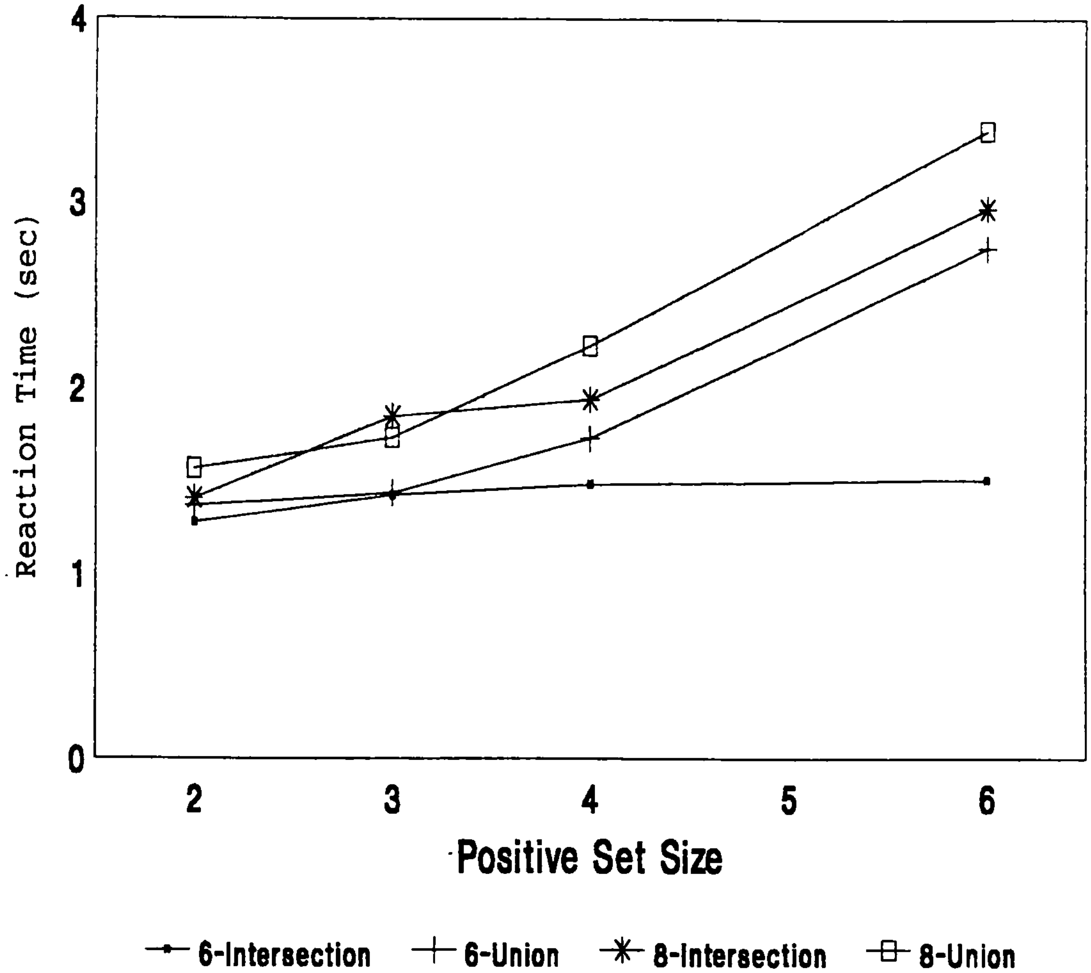


Figure 10. Display Set Size x Positive Set Size x Type of Decision

Type of Trial x Type of Decision X Display Set Size. The three way type of trial (positive or negative) x type of decision (intersection or union) x display set size interaction yielded significance. This interaction is illustrated in Figure 11. A breakdown of the interaction into its simple effects revealed that for decisions based on a display set size of six, trial type had a significant effect, $F(1, 80) = 210.963$, $p<.05$, decision type had a significant effect, $F(1, 80) = 84.420$, $p<.05$, and the trial type x decision type interaction was also significant, $F(1, 80) = 563.123$, $p<.05$. Intersection-positive trials using a display set size of six took significantly longer than intersection-negative trials using a display set size of six. Union-positive trials based on a display set size of six required significantly less time than union-negative trials based on a display set size of six

Simple effects of trial type and decision type for decisions based on a display set size of eight, showed that trial type had a significant effect, $F(1, 80) = 47.726$, $p<.05$, decision type had a significant effect, $F(1, 80) = 133.996$, $p<.05$, and the trial type x decision type interaction was also significant, $F(1, 80) = 1101.924$, $p<.05$. Intersection-positive trials based on a display set size of eight required significantly more time than intersection-negative trials based on a display set size of eight. Union-positive trials based on a display set size of eight required significantly less time than union-negative trials.

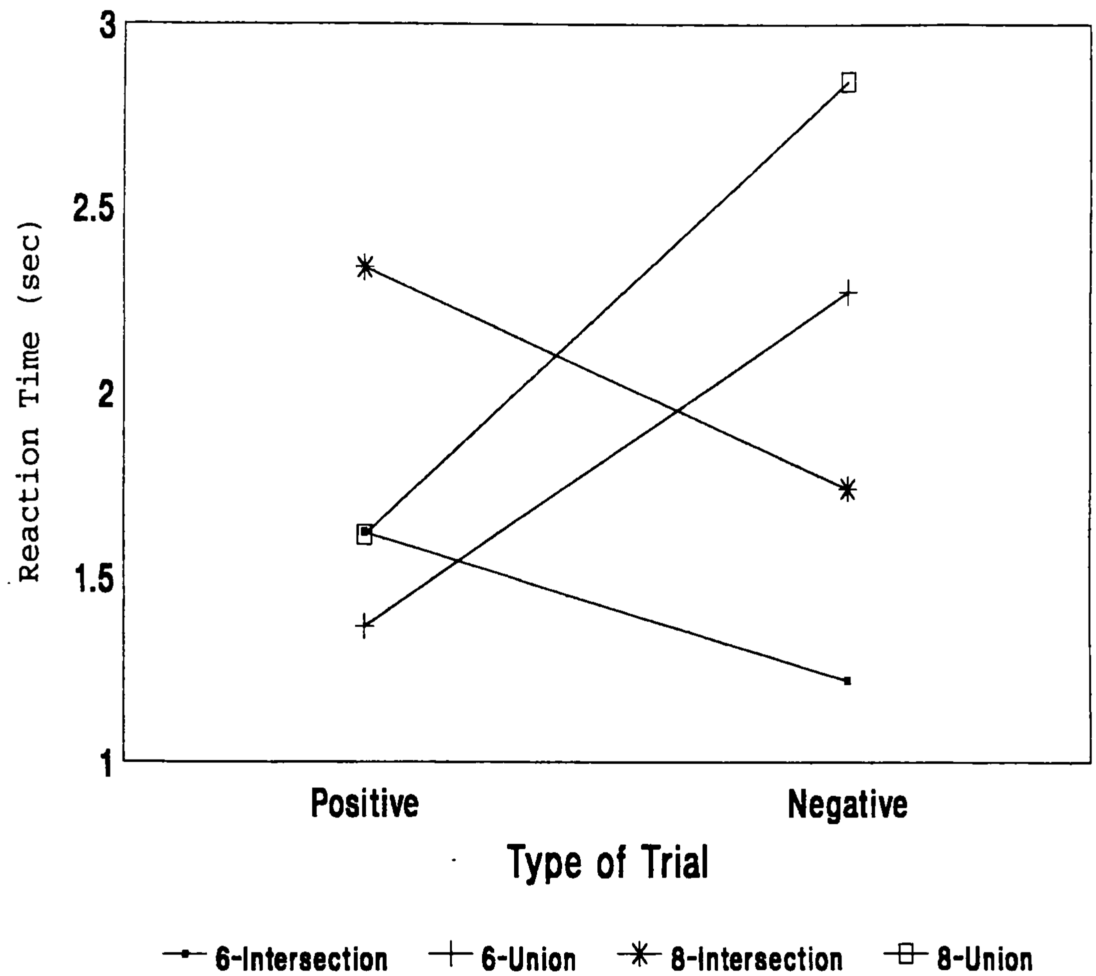


Figure 11. Display Set Size x Type of Decision x Type of Trial

Four-Way Interactions

Two four-way interactions reached statistical significance. The statistical design used in this research possessed a large amount of power and consequently many interactions reached statistical significance at the $p<.05$ level. Using eta², it was determined that each of the following two four-way interactions accounted for less than one percent of the total variance. For this reason these interactions will not be considered in the detail that the previous interactions were examined. Readers interested in obtaining more detailed information about these interactions should contact the author.

Positive Set Size x Type of Trial x Type of Decision x Display Size. This interaction illustrated in Figure 12, shows the differential effects of display set size on the Positive Set Size x Type of Decision x Type of Trial interaction.

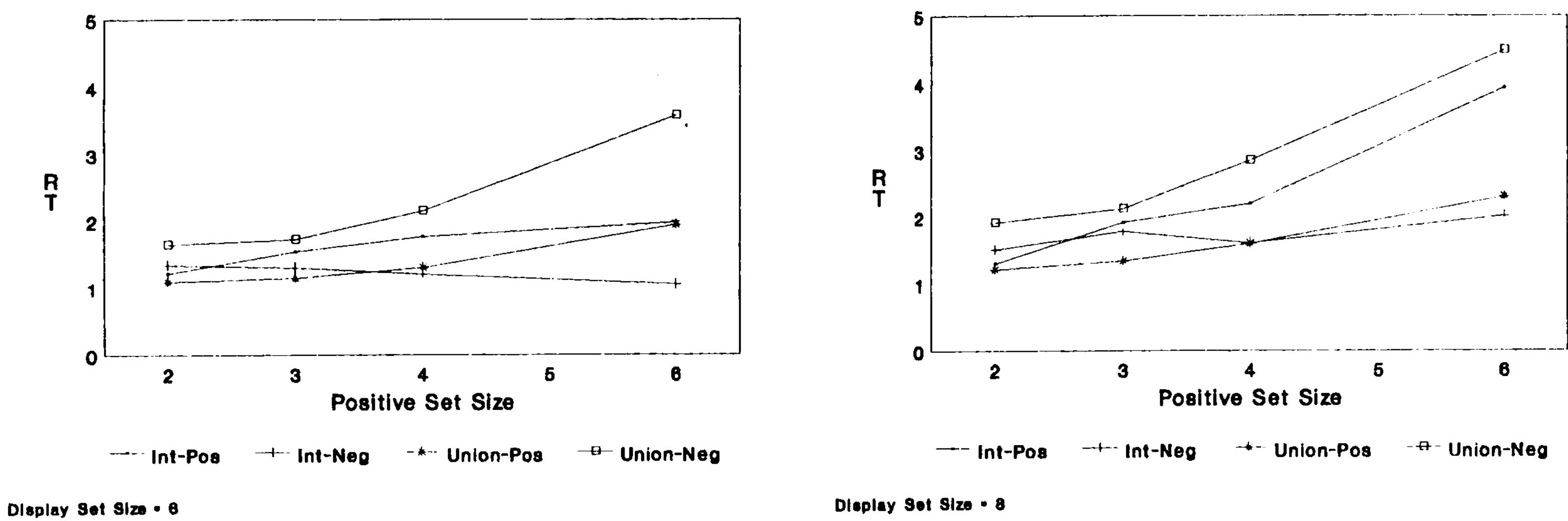
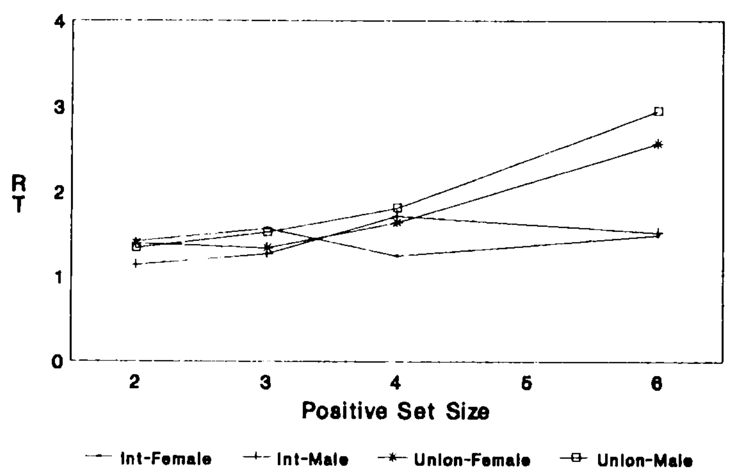
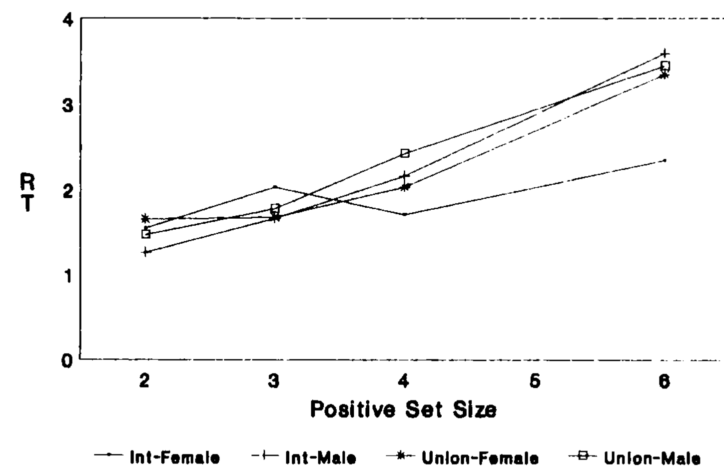


Figure 12. Display Set Size x Positive Set Size x Type of Decision x Type of Trial

Positive Set Size x Type of Decision x Display Size x Gender. This interaction, illustrated in Figure 13, shows the differential effects of display set size on the Positive Set Size x Type of Decision x Gender interaction.



Display Set Size = 6



Display Set Size = 8

Figure 13. Display Set Size x Positive Set Size x Type of Decision x Gender

Interactions with Block.

The Block variable interacted significantly with a number of other variables resulting in three two-way interactions, two three-way interactions, and one four-way interaction. The main effect of Block, described above and illustrated in Figure 3, accounted for less than one percent of the total variance as indicated by an eta^2 value of 0.0064. Each of the significant interactions with the Block variable possessed eta^2 values even smaller than that associated with the main effect of Block. For this reason these interactions will not be considered in the detail that the previous interactions were examined. The interactions with the Block variable are outlined below.

Display Size x Block. This interaction, illustrated in Figure 14, shows the differential effects of display set size on RT across the ten blocks of trials. Using Tukey post-hoc tests it was determined that at each level of block the RT based on trials with a display set size of eight was significantly greater than the RT based on trials with display set size of six. An examination of the simple effects of block showed that the block had a significant effect for decisions based on a display set size of six, $F(9, 720) = 4.112$, $p<.05$. A Tukey post-hoc test revealed that the mean RT for block one was significantly greater than the mean RT for the proceeding nine blocks excluding block two.

Further examination of the simple effects of block revealed that the block also had a significant effect for decisions based on a display set size of eight, $F(9, 720) = 22.097$, $p<.05$. A Tukey post-hoc test showed that block one was significantly greater than the proceeding nine blocks. Block ten was significantly less than blocks two, three, four, five, six and seven. Blocks nine and eight were significantly less than blocks two, three, and four.

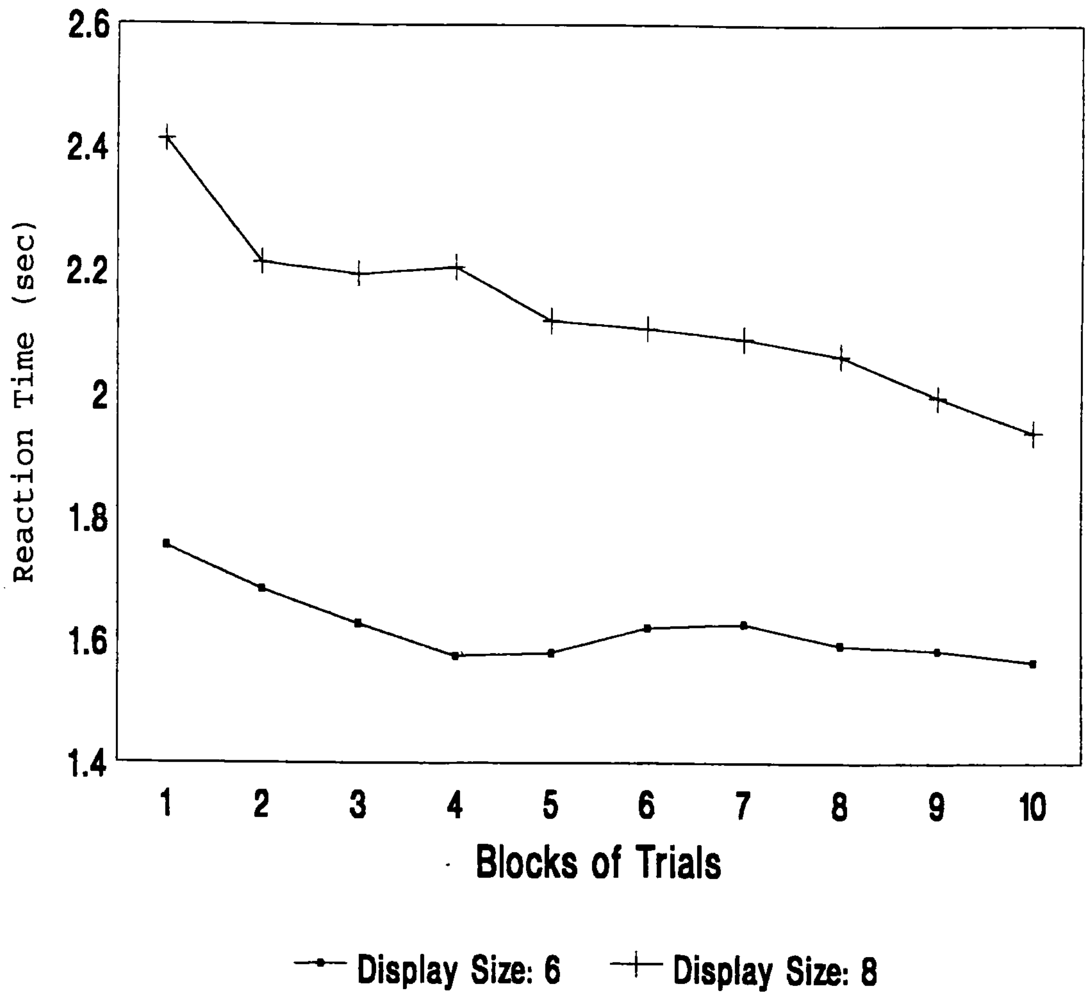


Figure 14. Display Set Size x Block

<u>Positive Set x Block</u>. This interaction, displayed in Figure 15, illustrates the differential effects of display set size on RT across the ten blocks of trials. Increases in display set size had additive effects on RT within each of the ten blocks.

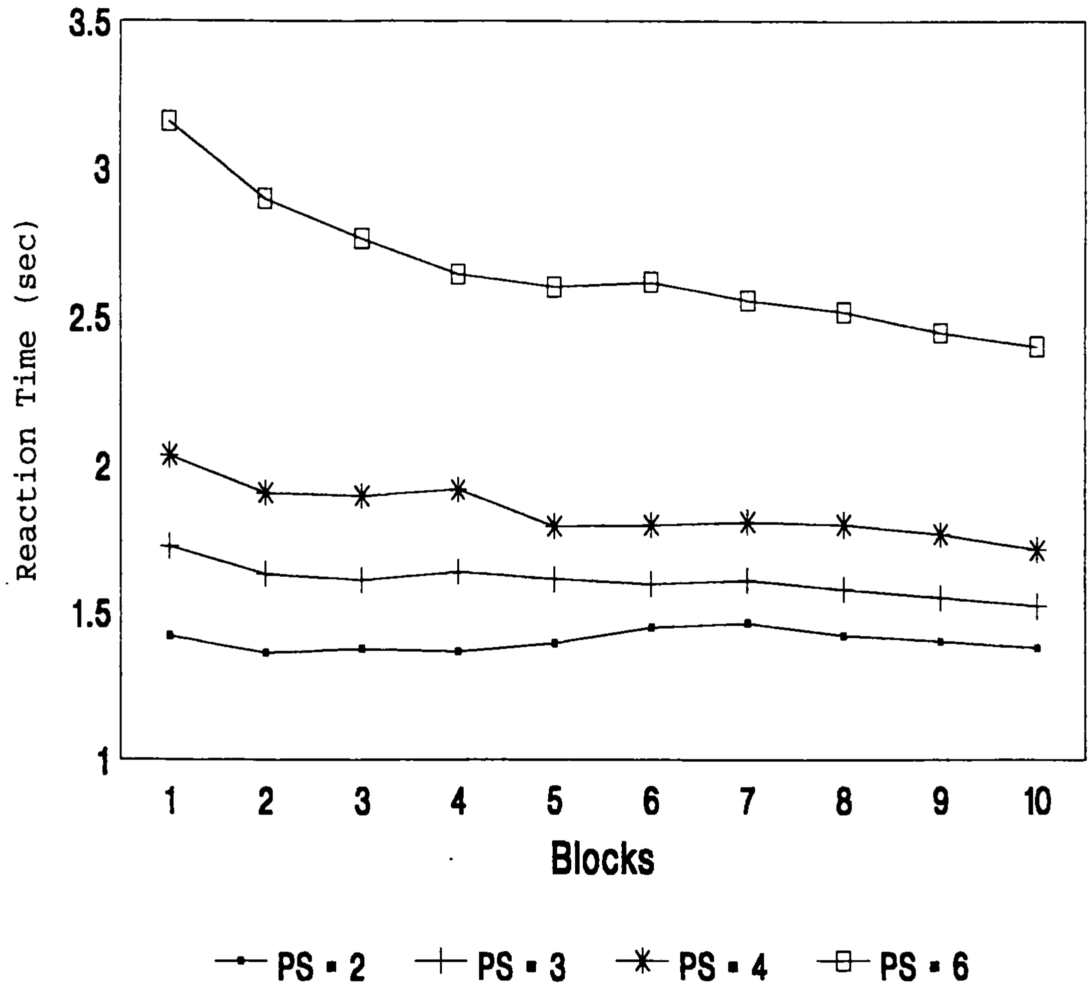


Figure 15. Positive Set Size x Block

Type of Trial x Block. This interaction is illustrated in Figure 16. The type of trial x block interaction shows the differential effects of trial type on RT throughout the course experimental procedure. Negative trials required more time than positive trials at each level of the block variable.

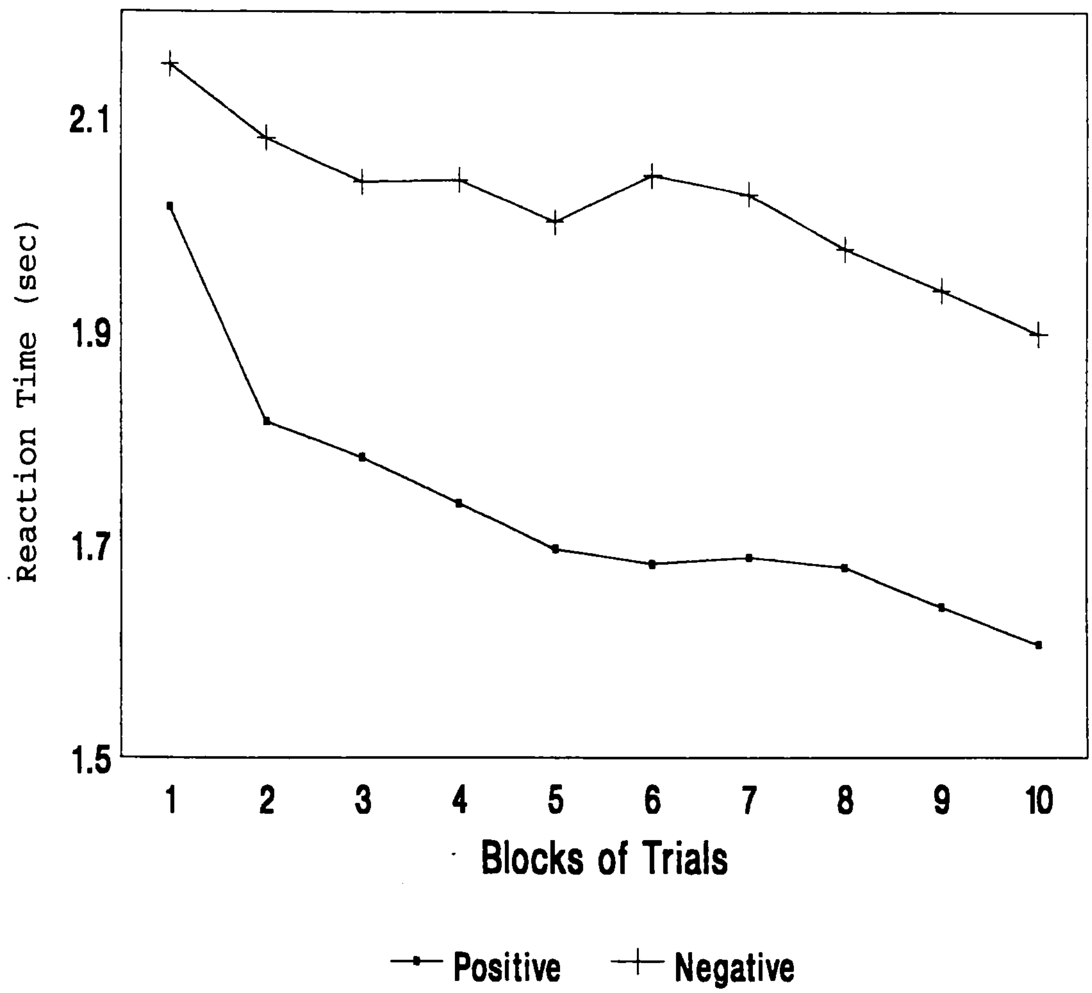


Figure 16. Type of Trial x Block

Positive Set x Type of Trial x Block. This three-way interaction, illustrated in Figure 17, shows the differential effects of positive set size and trial type on RT as the subjects gained more experienced with the task and progressed through the 480 trial procedure. Increases in positive set size had additive effects on RT. The effect of trial type on RT is illustrated for each positive set size as subjects gained experience with the task.

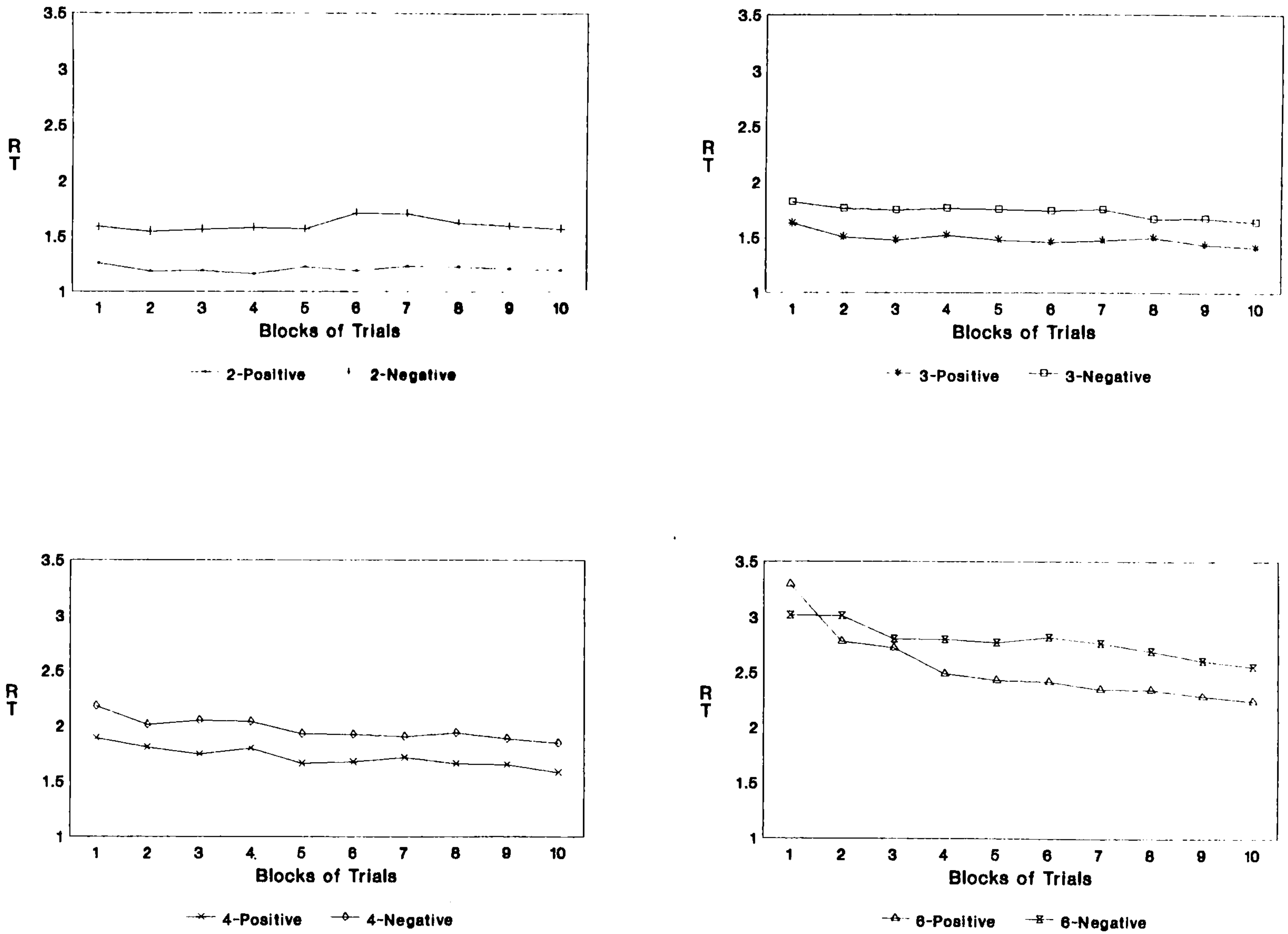


Figure 17. Positive Set Size x Type of Trial x Block

<u>Display Size x Positive Set Size x Block</u>. In this three-way interaction, illustrated in Figure 18, the effect of positive set size and display set size on RT can be compared as the subjects progress through the ten blocks of 48 trials. The positive relationship between display set size and RT is relatively constant across the ten blocks of trials at each positive set size level. The difference in RT in response to trials using the different display set sizes tends to increase as positive set size increases.

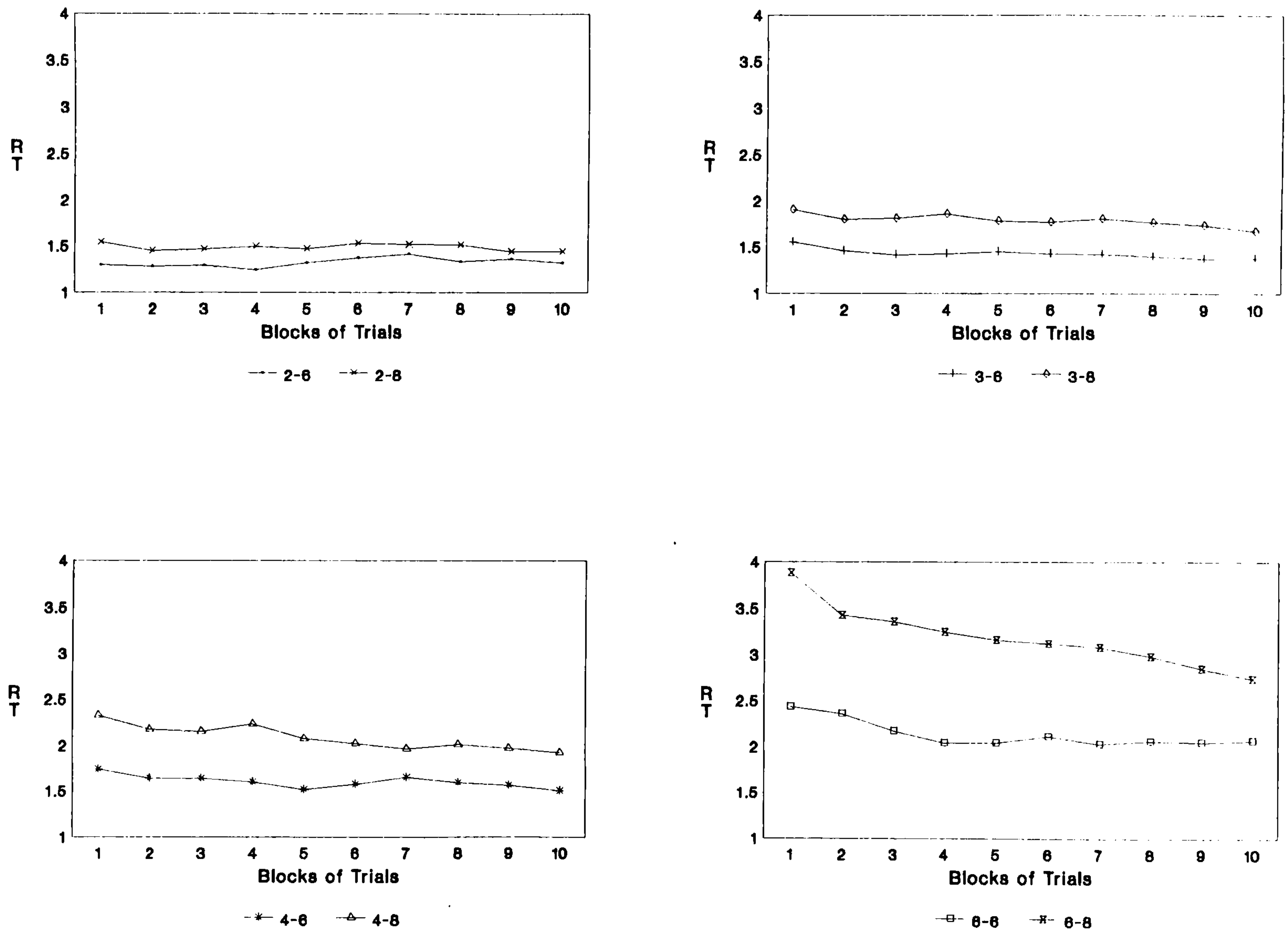


Figure 18. Display Set Size x Positive Set Size x Block

Positive Set x Type of Trial x Display Size x Block. This four way interaction, illustrated in Figure 19, shows the differential effects of positive set size on the type of trial and display set size variables across the ten blocks of trials.

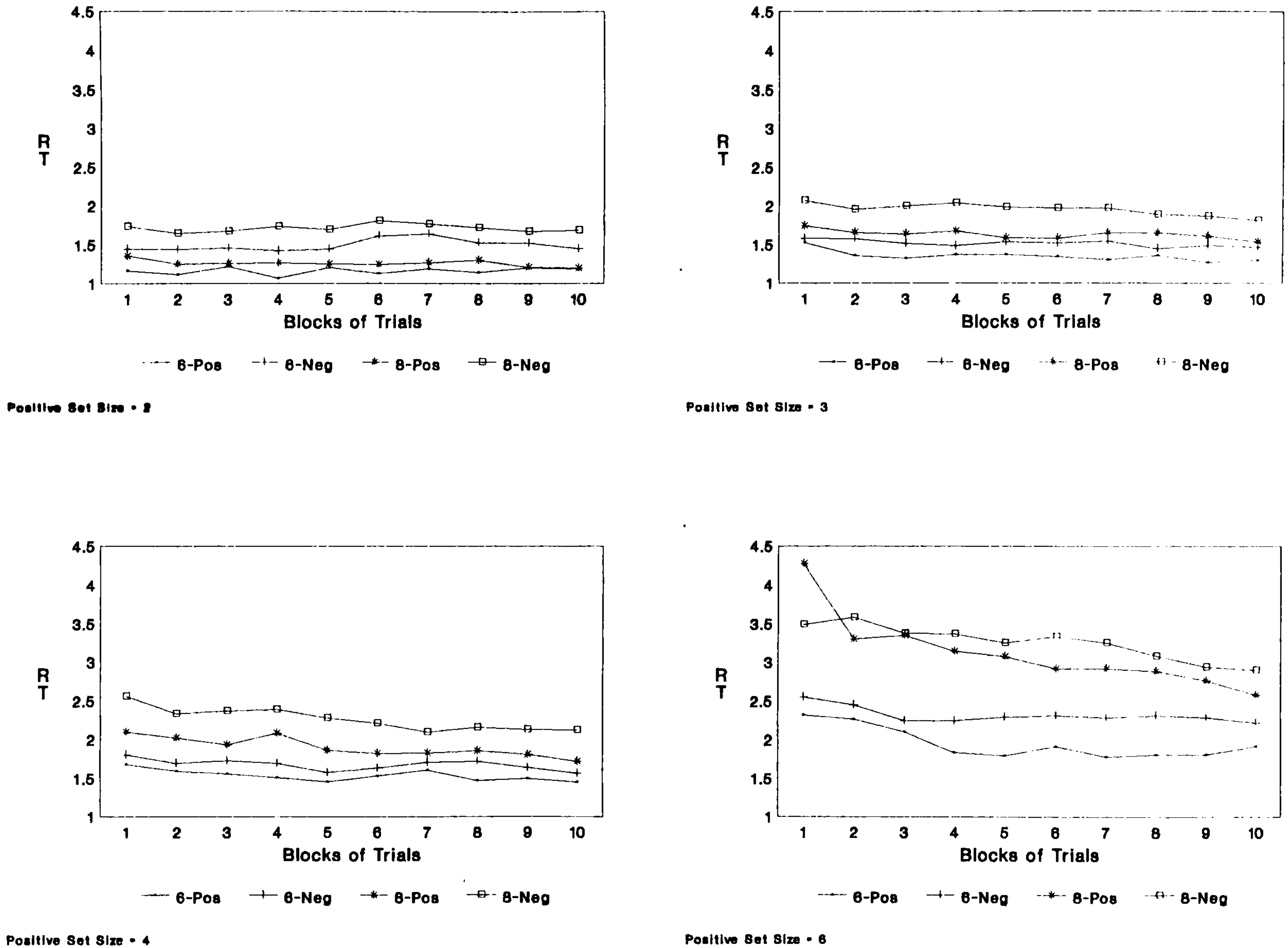


Figure 19. Positive Set Size x Type of Trial x Display Set Size x Block

Position Effects

A significant position effect of the probe stimulus within the display set was found for the union-positive trials. Figure 20 shows the mean RT for union-positive trials with a display set size of 8 or 6, according to the position of the probe stimulus within the display set. The position effect for trials with a display set size of 6 produced a significant linear trend, which is best described by equation D below. The position effect for trials with a display set size of 8 also produced a significant linear trend, which is best described by equation E below.

D) 6 CONDITION: $RT = 1.158 + 0.052(POSITION)$ $r^2 = 0.045$

E) 8 CONDITION: $RT = 1.350 + 0.060(POSITION)$ $r^2 = 0.045$

A Tukey post-hoc test was used to compare the RT means of the union-positive trials associated with the different positions of the probe stimulus in the positive set for trials employing a display set size of six. The RT at the first position was significantly less than the RT at positions two, four, five, and six. The RT at the second position was significantly less than the RT at positions four, five, and six. The RT at position three was significantly less than the RT at positions four, five and six. The RT at position four was significantly less than the RT at positions five and six. No other RT differences were significant.

A Tukey post-hoc test was used to compare the RT means of the union-positive trials associated with the different positions of the probe stimulus in the positive set for trials employing a display set size of eight. The RT at the first position was significantly less than the RT at all other positions. The RT at position two was significantly less than the RT at positions six, seven, and eight. The RT at position three was significantly less than the RT at positions six, seven, and eight. The RT at position four was significantly less than the RT at positions six, seven, and eight. The RT at position five was significantly less than the RT at position seven.

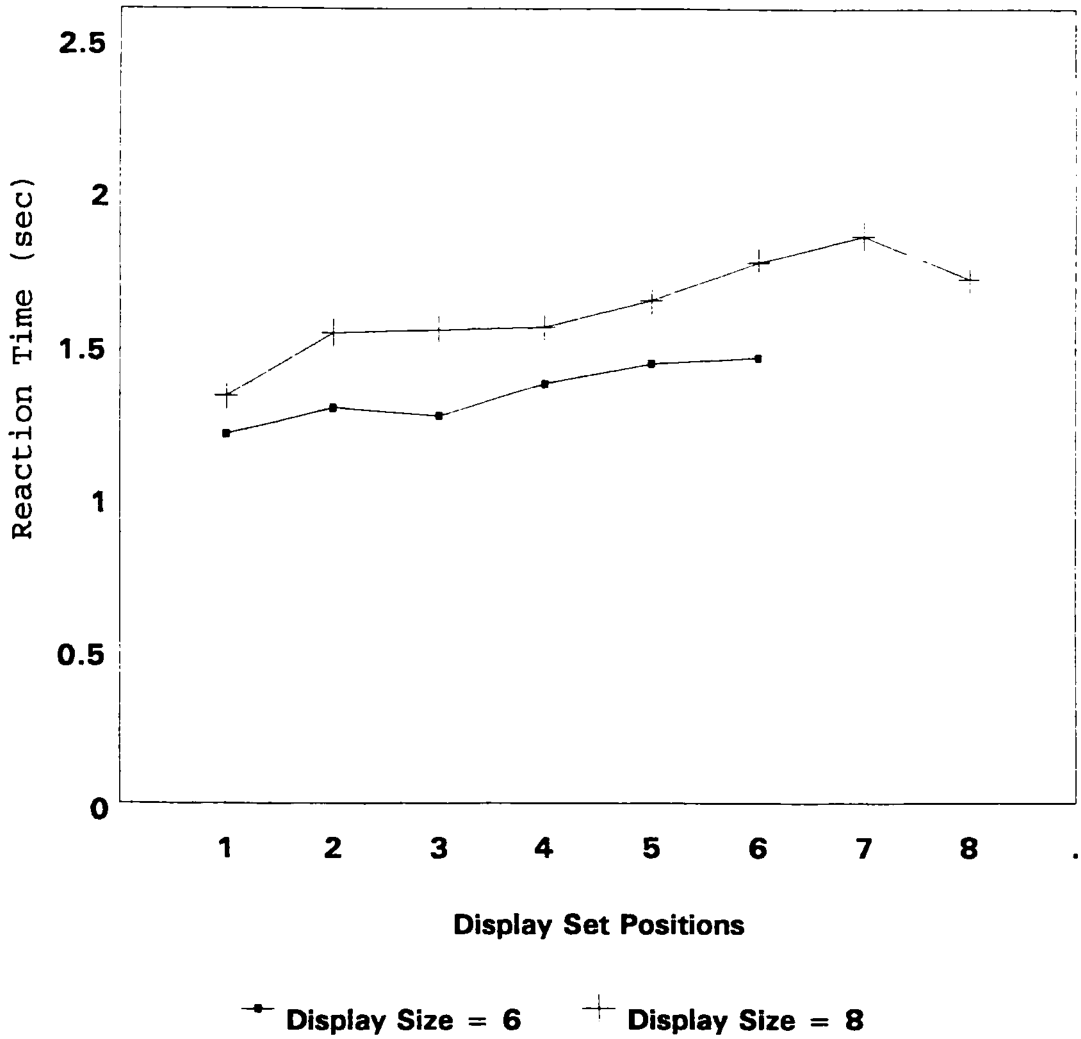


Figure 20. Position Effects for Union-Positive Trials

PERCENT CORRECT DATA

Using an overall alpha level of .05, five main effects, six two-way interactions, five three-way interactions, and three four-way interactions achieved statistical significance.

Main Effects

Gender. A main effect of gender was found. Male subjects provided significantly more correct responses than female subjects, 95.62 % and 93.95 %, respectively.

Positive Set Size. A main effect of the positive set size (2, 3, 4, or 6) was found. Figure 21 illustrates this main effect. A Tukey post-hoc test revealed that the PC in the two-character stimulus condition was significantly greater than the PC in the three-character and six-character stimulus conditions. The PC for trials with a positive set size of four was significantly greater than the PC for the six-character stimulus condition.

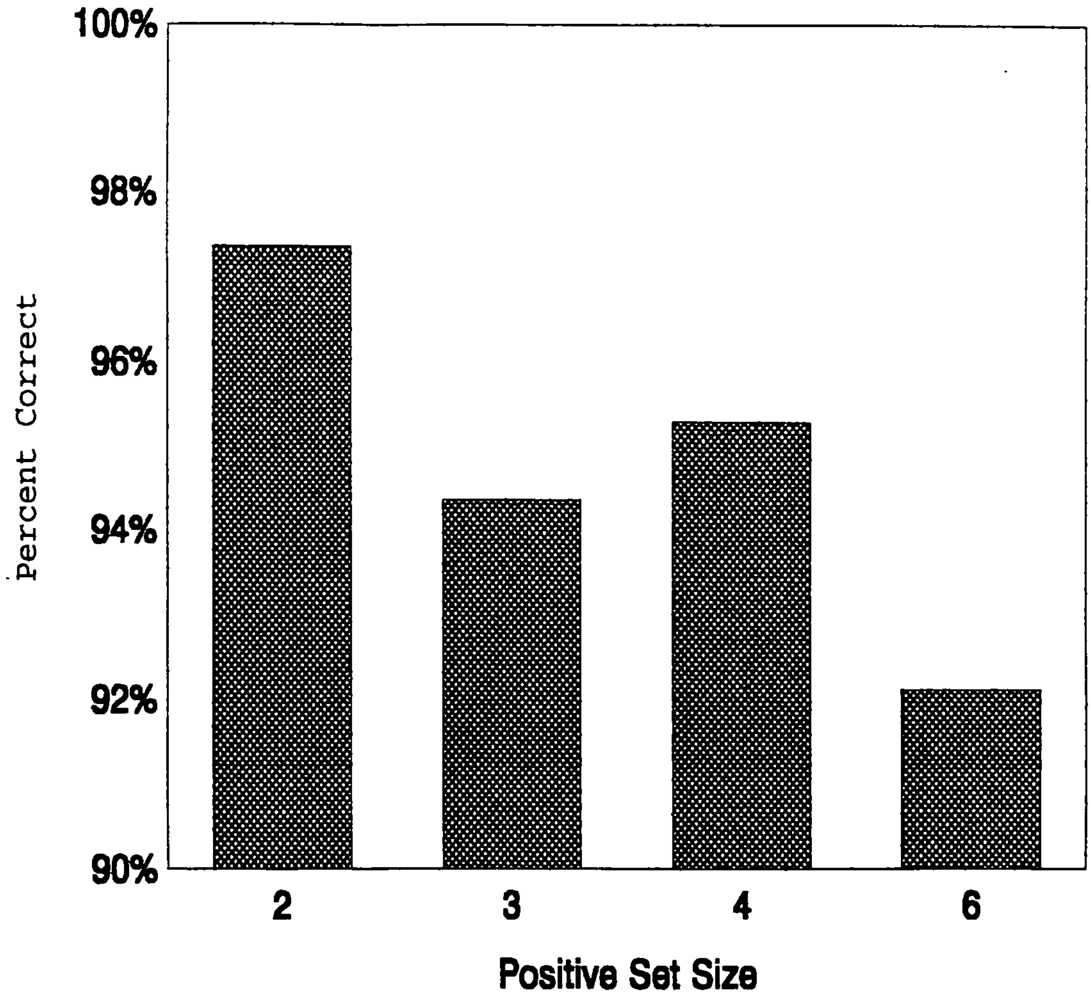


Figure 21. Positive Set Size

Type of Decision. A main effect of decision type (union or intersection) was found. The PC for subjects making intersection decisions was significantly greater than the PC for subjects making union decisions, 96.56 % and 93.02 %, respectively.

Type of Trial. A main effect of trial type (positive or negative) revealed that PC for positive stimulus trials was significantly less than the PC for negative stimulus trials, 96.56 % and 99.09 %, respectively.

Block. A main effect of block was found. Figure 22 illustrates this main effect. A Tukey post-hoc test revealed that the PC for block one was significantly less than the PC for the proceeding nine blocks.

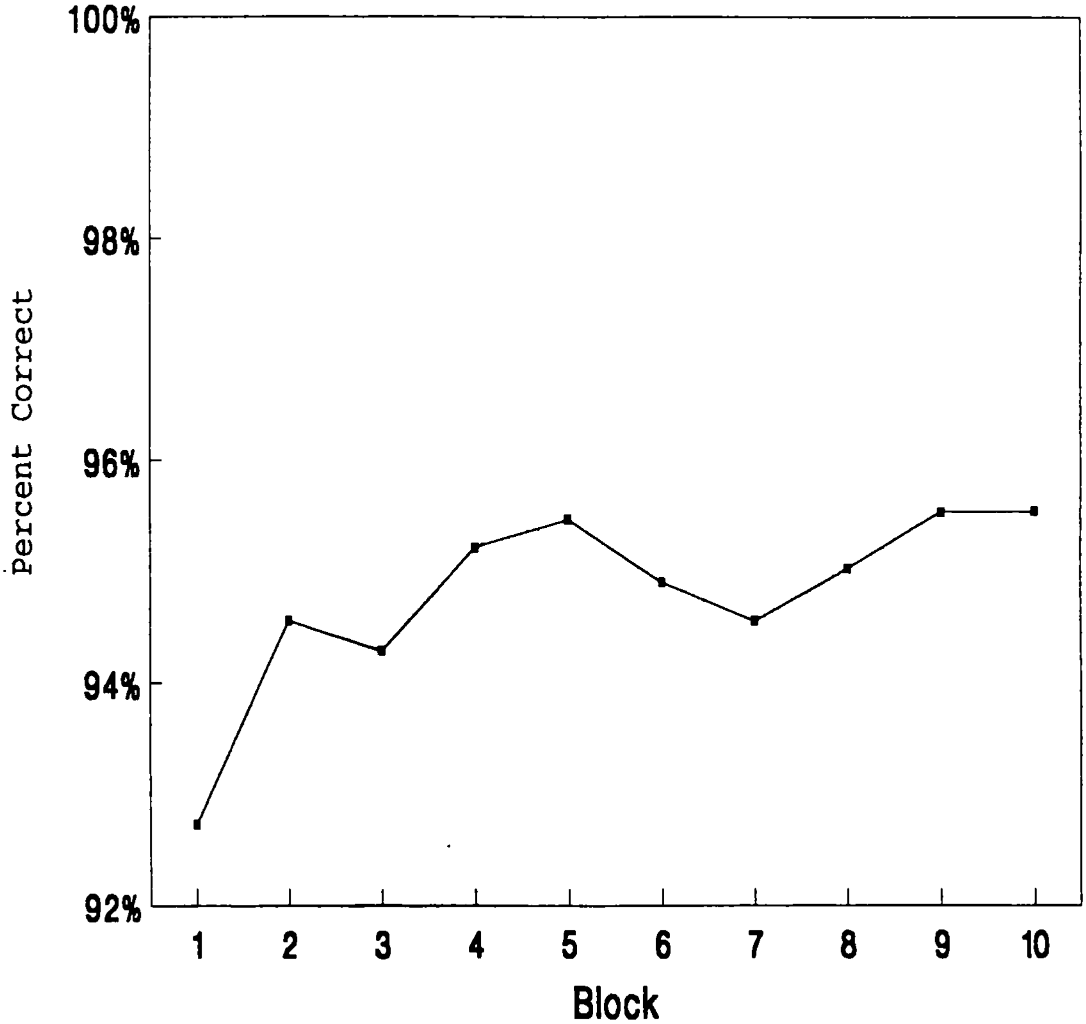


Figure 22. Block

Two-Way Interactions.

Gender x Type of Trial. A significant two-way gender x type of trial interaction, illustrated in Figure 23, yielded significance. A test of the simple effects revealed that for male subjects, the PC for positive trials was significantly less than that for negative trials, $F(1, 80) = 48.933$, $p<.05$. The same trend was observed for females. The PC for positive trials was significantly less than the PC for negative trials, $F(1, 80) = 108.904$, $p<.05$. Considering gender differences of PC for positive trials, the mean PC obtained by males was significantly higher than the mean PC obtained by females, $F(1, 80) = 13.731$, $p<.05$. There was no gender difference for PC in response to negative trials.

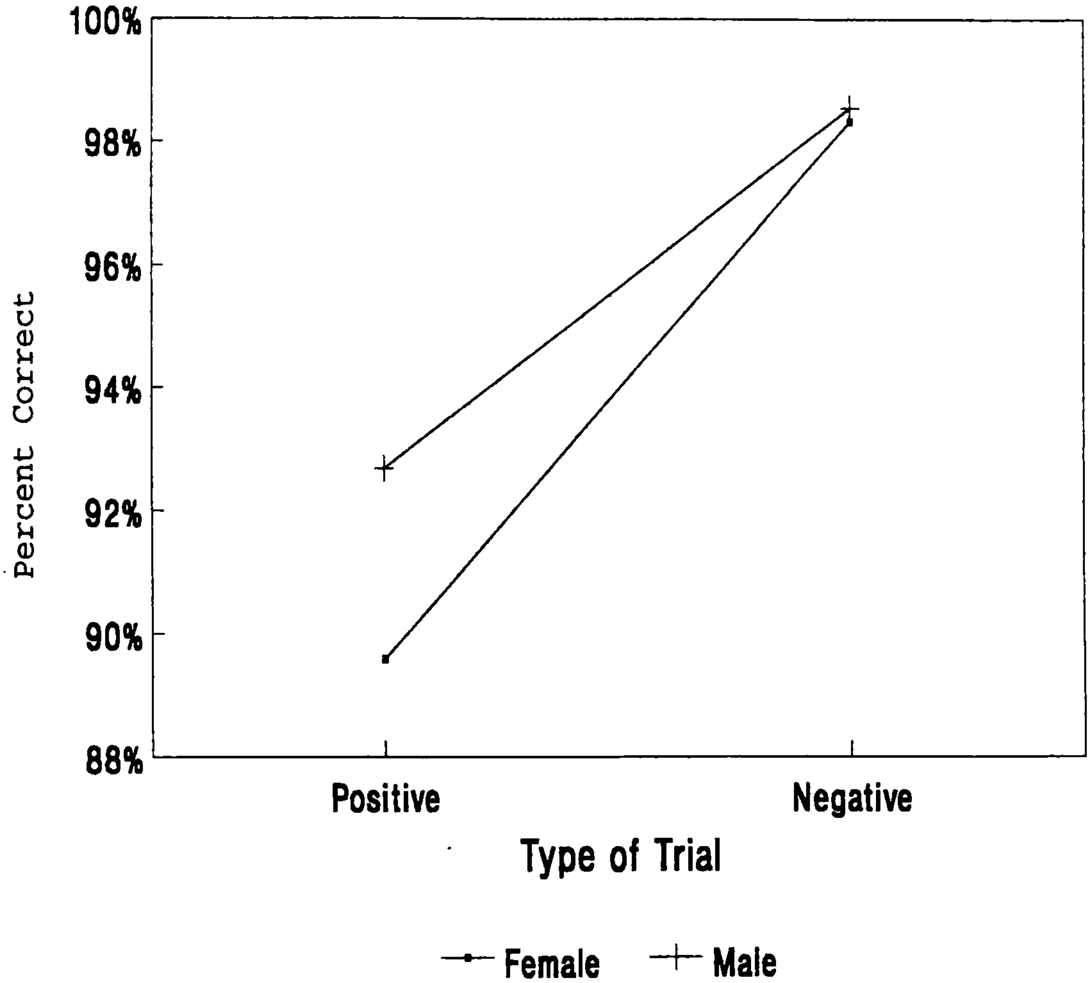


Figure 23. Gender x Type of Trial

Positive Set x Type of Decision. A significant two-way interaction (Positive Set Size x Type of Decision) was obtained. This interaction is illustrated in Figure 24. An examination of the simple effects demonstrated that the positive set size had a significant effect for union decisions, $F(3, 80) = 8.957$, $p<.05$. A Tukey post-hoc test revealed that for union decisions, the PC at positive set size two was significantly greater than the PC at levels three and six. The positive set size also had a significant effect for intersection decisions, $F(3, 80) = 3.234$, $p<.05$. A Tukey post-hoc test revealed that for intersection decisions the PC at positive set size six was significantly less than the PC at levels two and three.

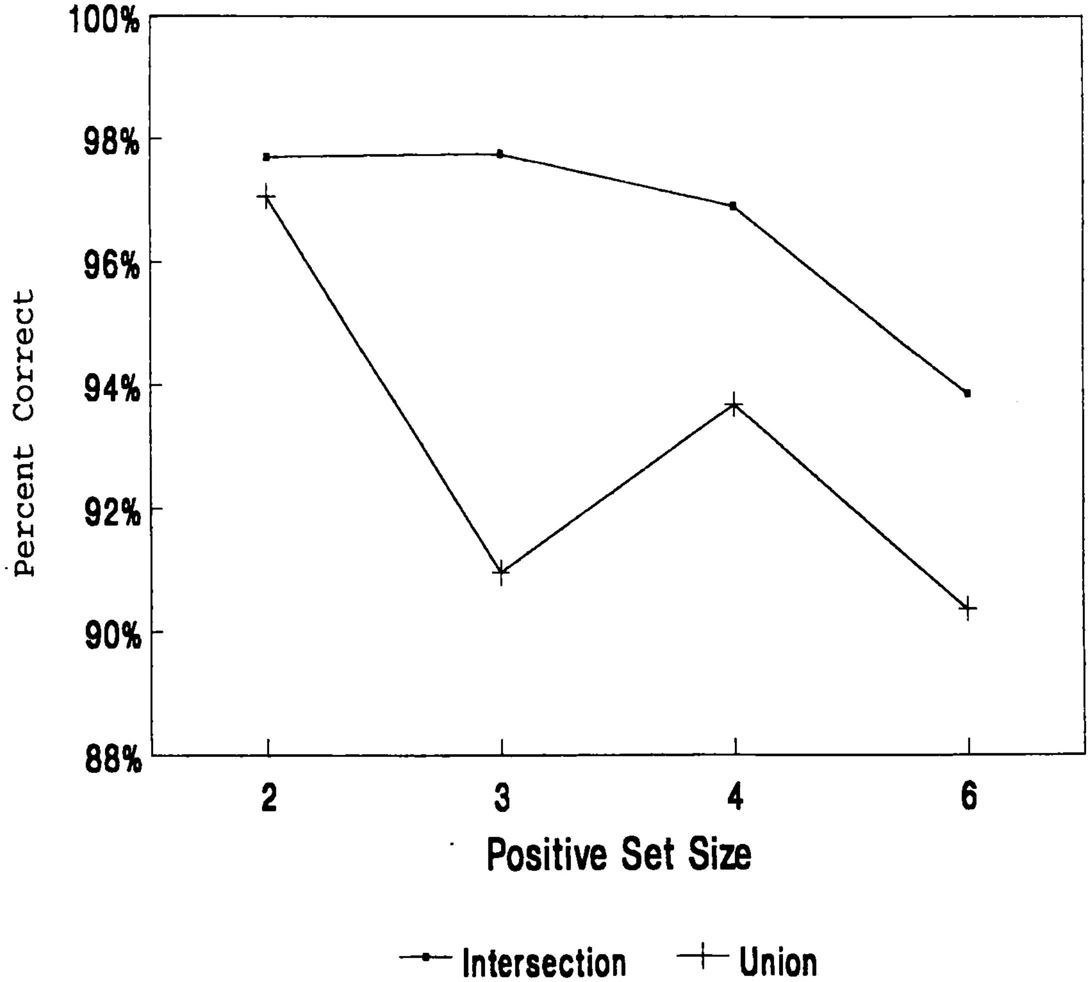


Figure 24. Positive Set Size x Type of Decision

Positive Set x Type of Trial. The two-way interaction (Positive Set Size x Type of Trial) achieved significance. This interaction is illustrated in Figure 25. An examination of the simple effects demonstrated that the positive set size had a significant effect for positive trials, $F(3, 80) = 22.615$, $p<.05$, but had no effect for negative trials. A Tukey post-hoc test established that for positive decisions the PC at positive set size two was significantly greater than the PC at levels three, four and six. The PC for positive trials at positive set size six was found to be significantly less than the PC at positive set sizes three and four.

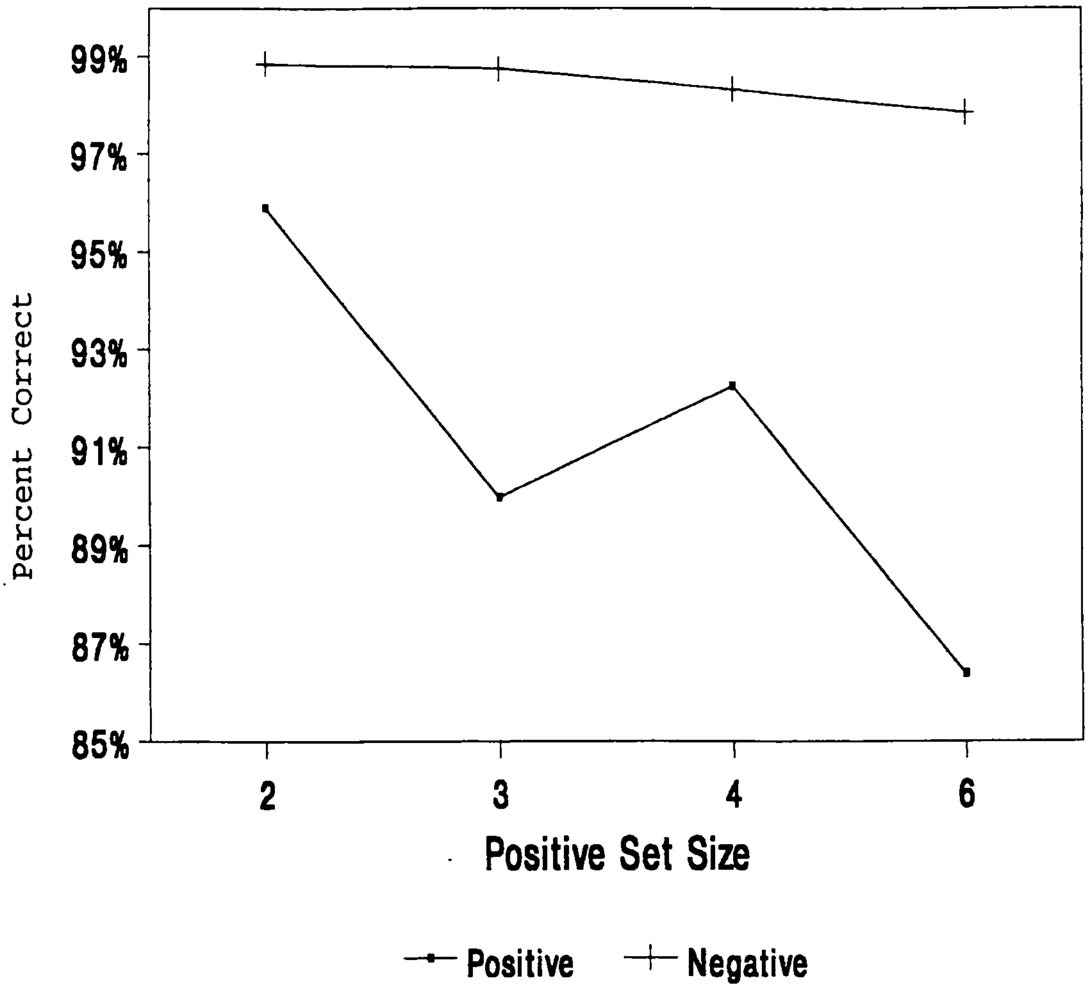


Figure 25. Positive Set Size x Type of Trial

<u>Type of Decision x Type of Trial</u>. A significant two-way (Type of Decision x Type of Trial) interaction was obtained. Figure 26 illustrates this interaction. For intersection decisions, positive trials yielded significantly more mistakes than negative trials. More mistakes were also made in union-positive trials than in union-negative trials, $F(1, 80) = 209.530$, $p<.05$. The type of decision produced a significant effect for positive trials, $F(1, 80) = 99.566$, $p<.05$, but decision type had no effect for negative trials. Significantly more mistakes were made within positive-union trials than positive-intersection trials.

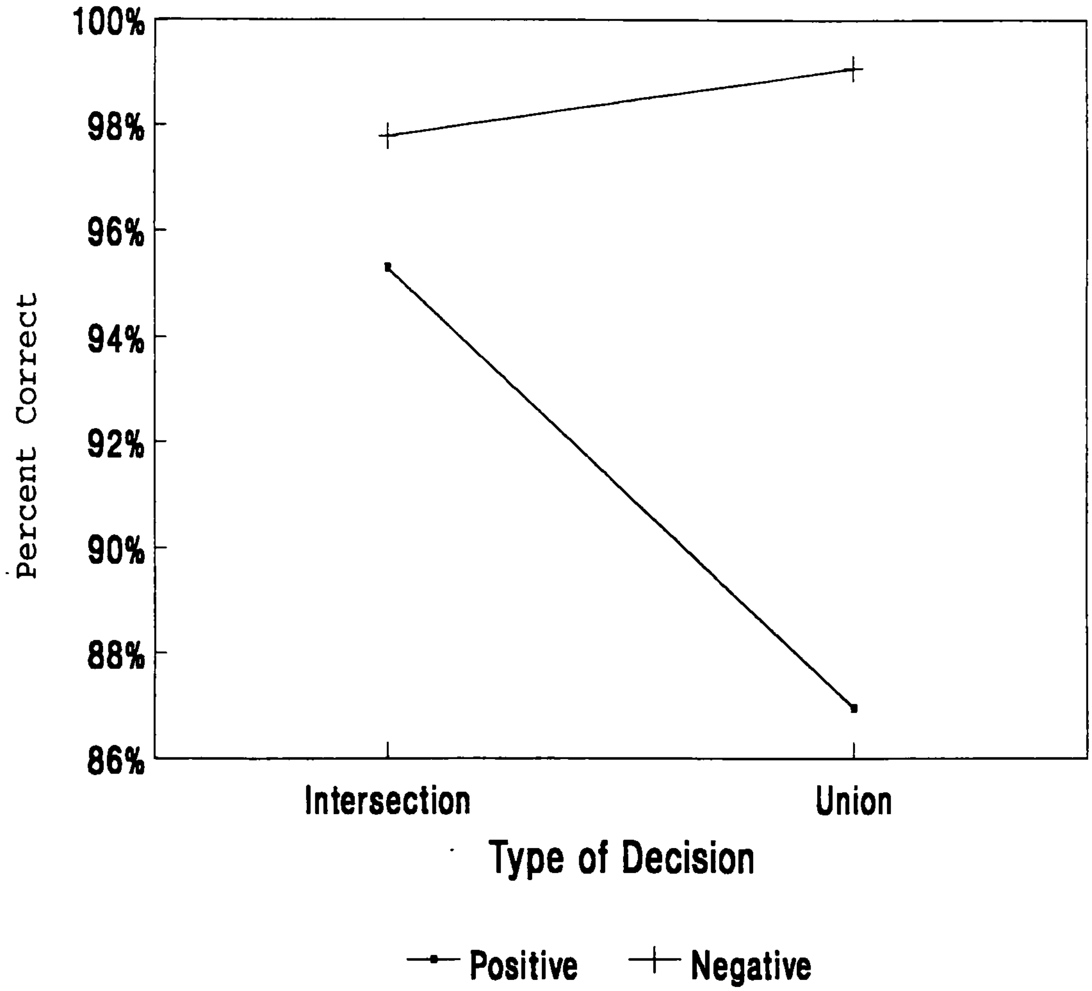


Figure 26. Type of Decision x Type of Trial

Three-Way Interactions.

Positive Set Size x Type of Decision x Type of Trial. The three way (Positive Set Size x Type of Decision x Type of Trial) interaction yielded significance. This interaction is illustrated in Figure 27. A breakdown of the three-way interaction into its simple effects showed that for intersection decisions, positive set size had a significant effect, $F(3, 80) = 4.772$, $p<.05$, trial type had a significant effect, $F(1, 80) = 8.737$, $p<.05$, but the interaction between positive set size and trial type was not significant. Using a Tukey post-hoc test and averaging across trial type, it was found that the PC at level six was significantly less than the PC at levels two and three.

Further examination of the simple effects revealed that for union decisions, the positive set size had a significant effect, $F(3, 80) = 13.220$, $p<.05$, trial type had a significant effect, $F(1, 80) = 209.529$, $p<.05$, and the interaction between positive set size and trial type was also significant, $F(3, 80) = 12.208$, $p<.05$). A closer look at the positive set size x type of trial interaction for union decisions revealed that the positive set size had a significant effect for positive trials, $F(3, 80) = 25.405$, $p<.05$, but had no effect for negative trials. A Tukey post-hoc test showed that the PC for union-positive trials with two members in the positive set was significantly greater than those trials with positive set sizes of three, four, and six. It was also shown that the PC for union-positive trials with a positive set size of six was significantly less than the PC at positive set size four.

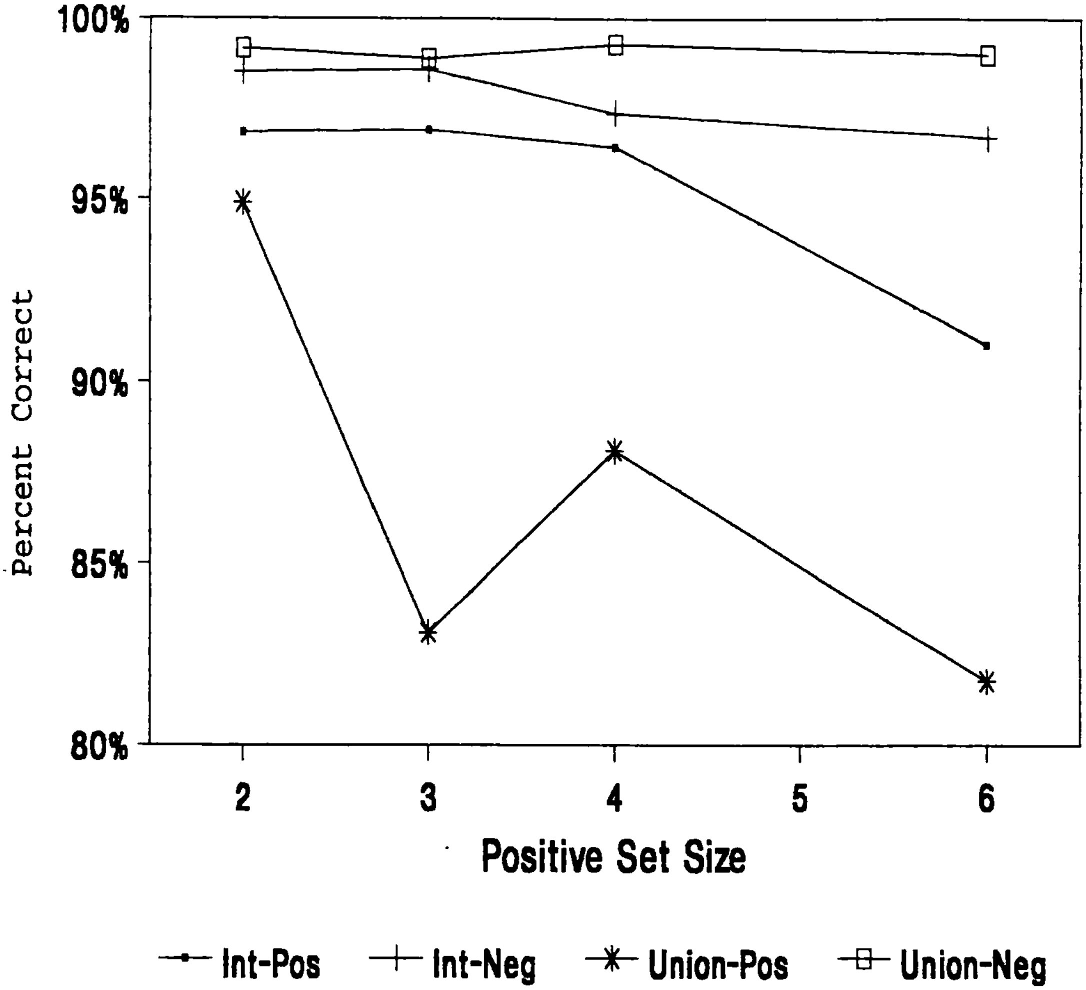


Figure 27. Positive Set Size x Type of Decision x Type of Trial

Gender x Type of Decision x Type of Trial. The three way (Gender x Type of Decision x Type of Trial) interaction yielded significance. Figure 28 illustrates this interaction. A breakdown of the interaction into its simple effects revealed that for union decisions, gender had a significant effect, $F(1, 80) = 10.091$, $p<.05$, trial type had a significant effect, $F(1, 80) = 209.529$, $p<.05$, and the gender x trial type interaction was also significant, $F(1, 80) = 11.029$, $p<.05$. The PC for male subjects making union decisions was significantly higher for negative trials than for positive trials, $F(1, 80) = 62.208$, $p<.05$. Female subjects making union decisions also produced more correct responses for negative trials than for positive trials, $F(1, 80) = 158.349$, $p<.05$. Male subjects made significantly less errors for union-positive trials than female subjects did, $F(1, 80) = 21.110$, $p<.05$. There was no gender effect of PC for union-negative trials.

Further examination of the simple effects showed that for intersection decisions, trial type had a significant effect, $F(1, 80) = 8.737$, $p<.05$, but gender had no effect and the gender x trial type interaction was also not significant. Intersection-negative trials produced significantly less errors than intersection positive trials.

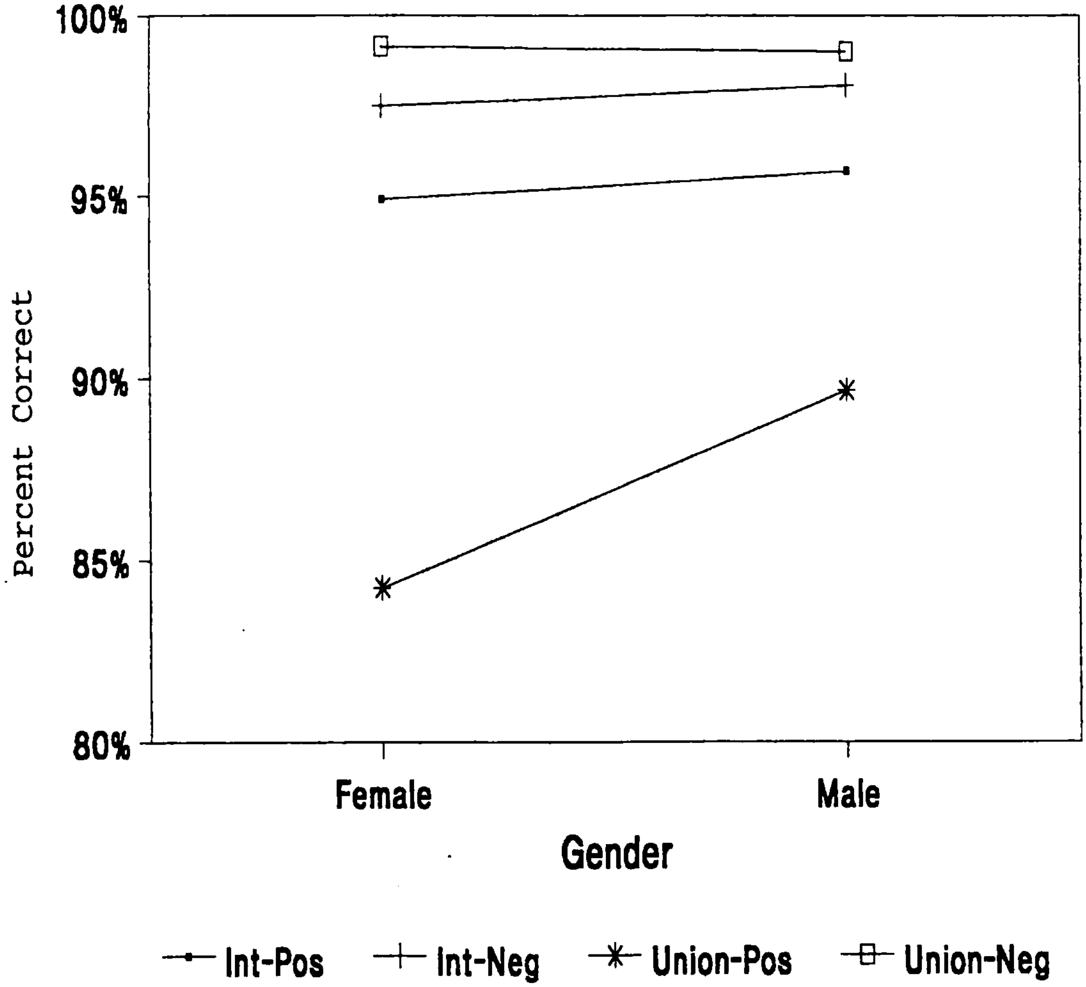


Figure 28. Gender x Type of Decision x Type of Trial

Interactions with Block.

The block variable for the PC data interacted significantly with a number of other variables resulting in two two-way interactions, three three-way interactions, and three four-way interactions. The main effect of block, described above and illustrated in Figure 22, accounted for less than one percent of the total variance as indicated by an eta^2 value of 0.0067. Each of the significant interactions with the block variable had eta^2 values smaller than the eta^2 associated with the main effect of block. These interactions with the block variable are outlined below.

Type of Decision x Block. In this interaction, illustrated in Figure 29, the differential effects of decision type on the error rate can be seen as the subjects progressed through the ten blocks of trials.

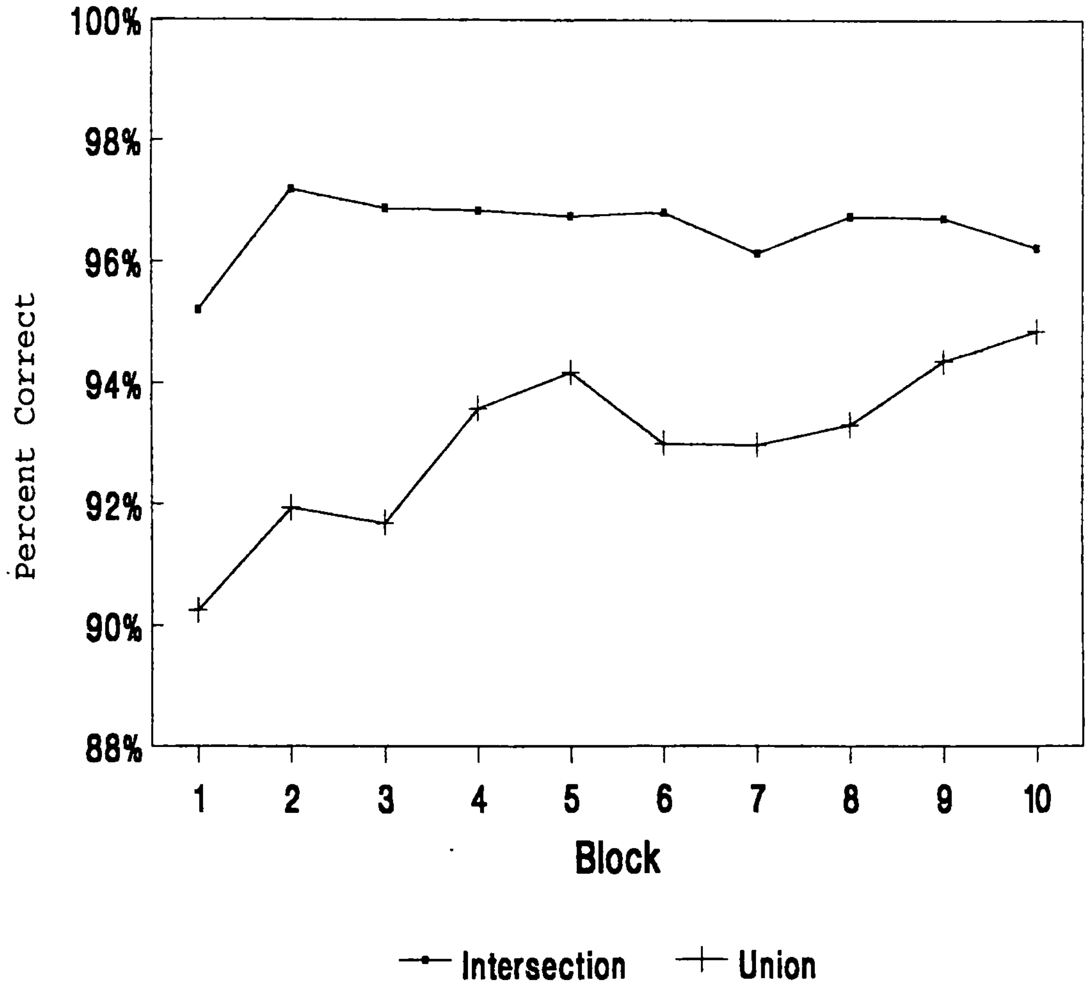


Figure 29. Type of Decision x Block

Type of Trial x Block. In this interaction, illustrated in Figure 30, the differential effects of trial type on the error rate can be seen as the subjects progressed through the ten blocks of trials.

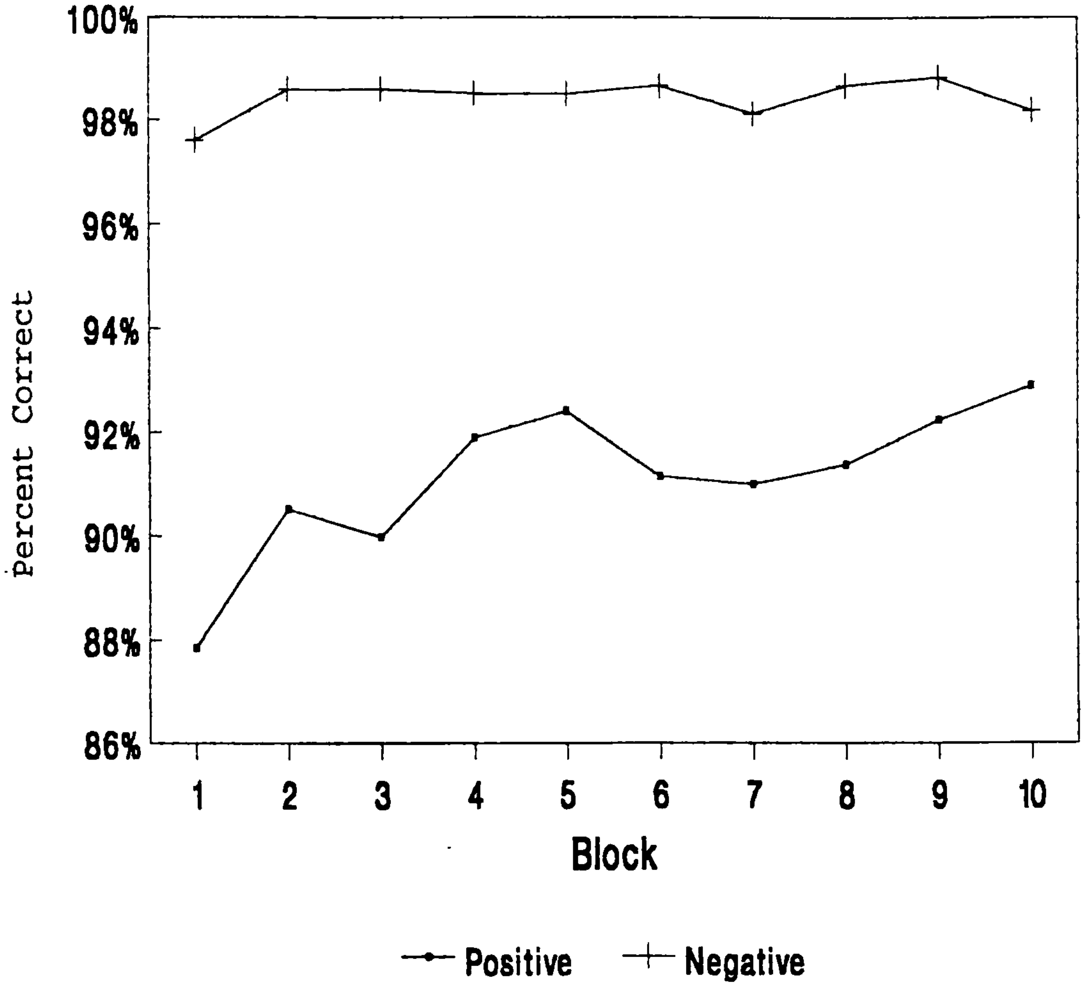


Figure 30. Type of Trial x Block

Display Size x Type of Decision x Block. In this three-way interaction, illustrated in Figure 31, the differential effects of display set size and decision type on error rates can be compared in light practice effects.

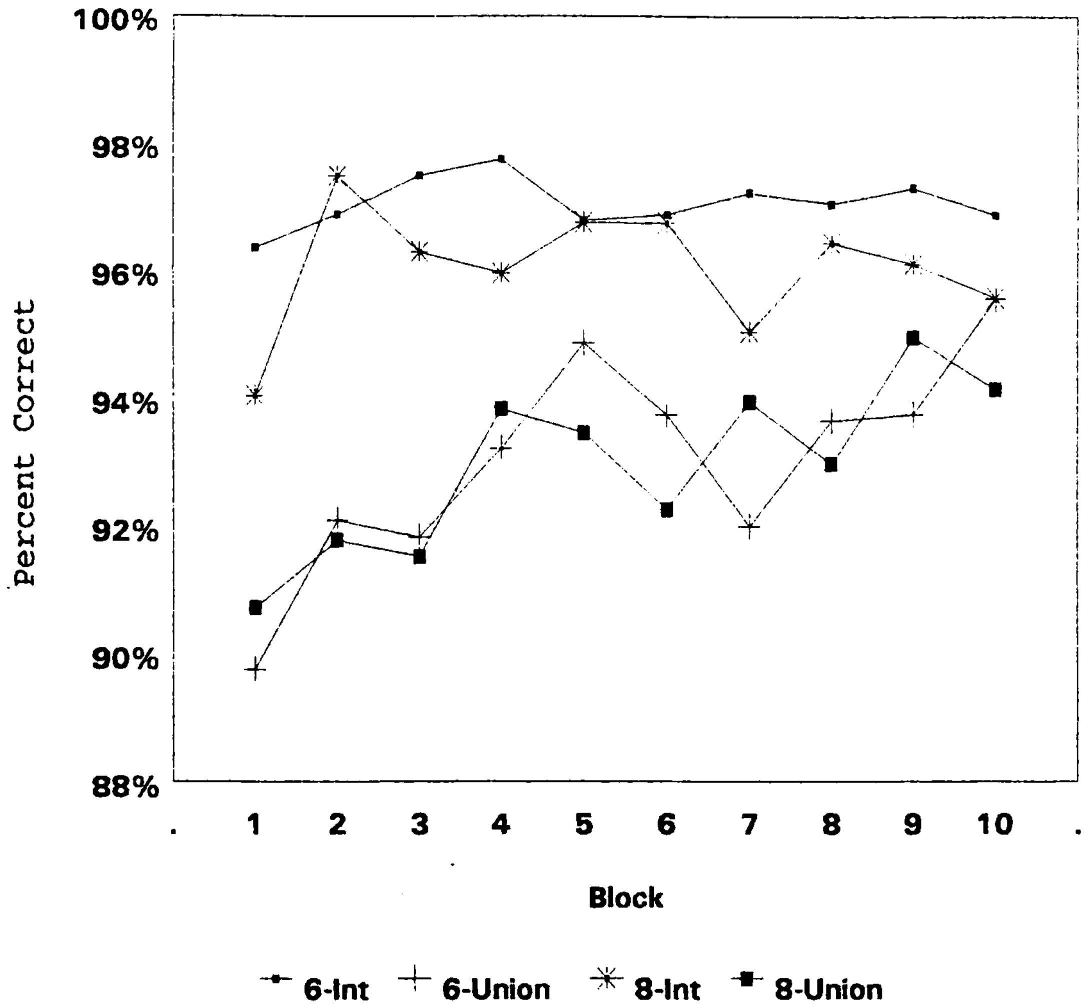


Figure 31. Display Set Size x Type of Decision x Block

<u>Positive Set x Type of Decision x Block</u>. This interaction, illustrated in Figure 32, shows the effects of positive set size and type of decision on error rates across the ten blocks of trials.

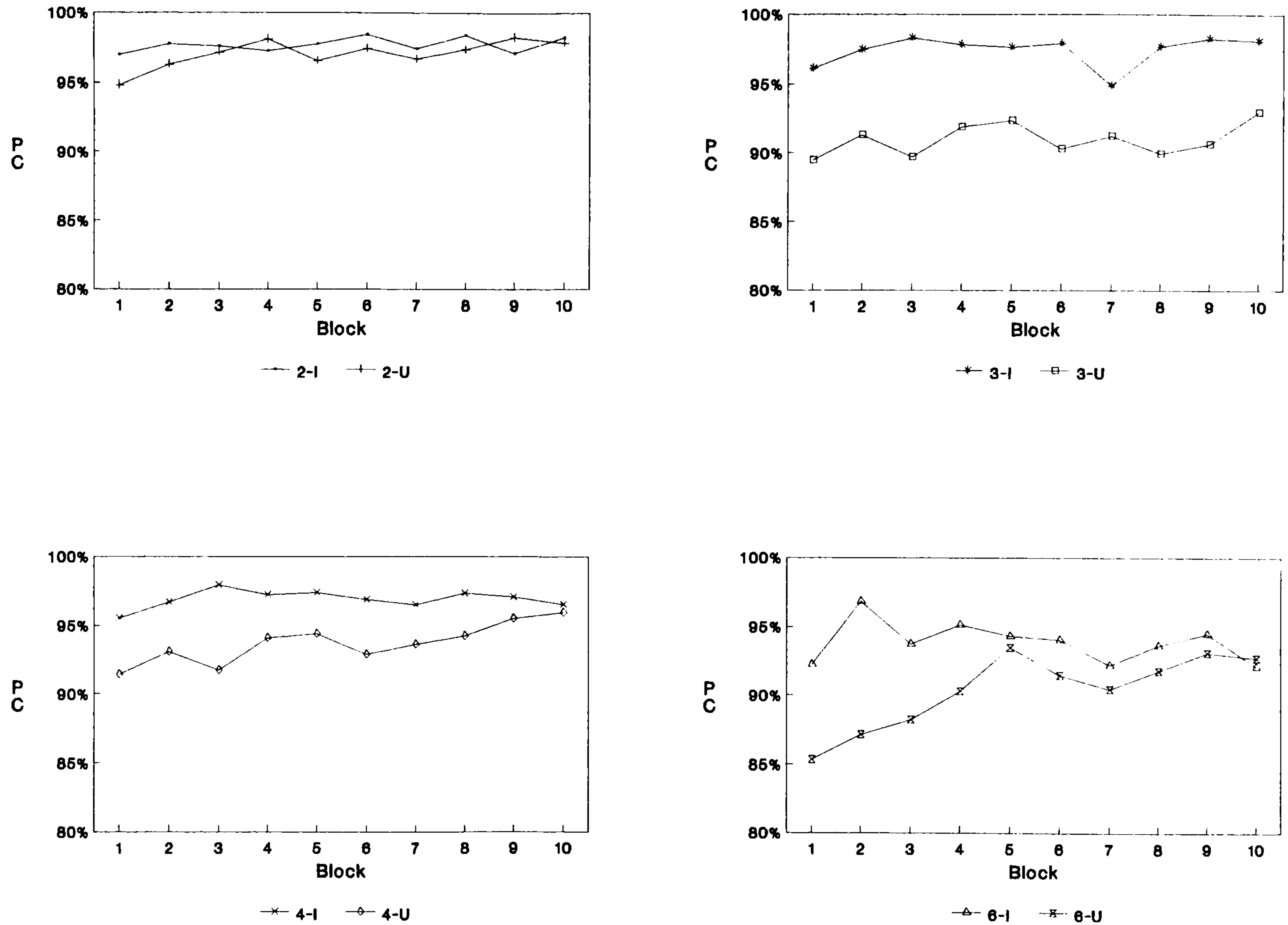


Figure 32. Positive Set Size x Type of Decision x Block

Type of Decision x Type of Trial x Block. In this three-way interaction, illustrated in Figure 33, the differential effects of decision type and trial type on error rates can be compared in light practice effects.

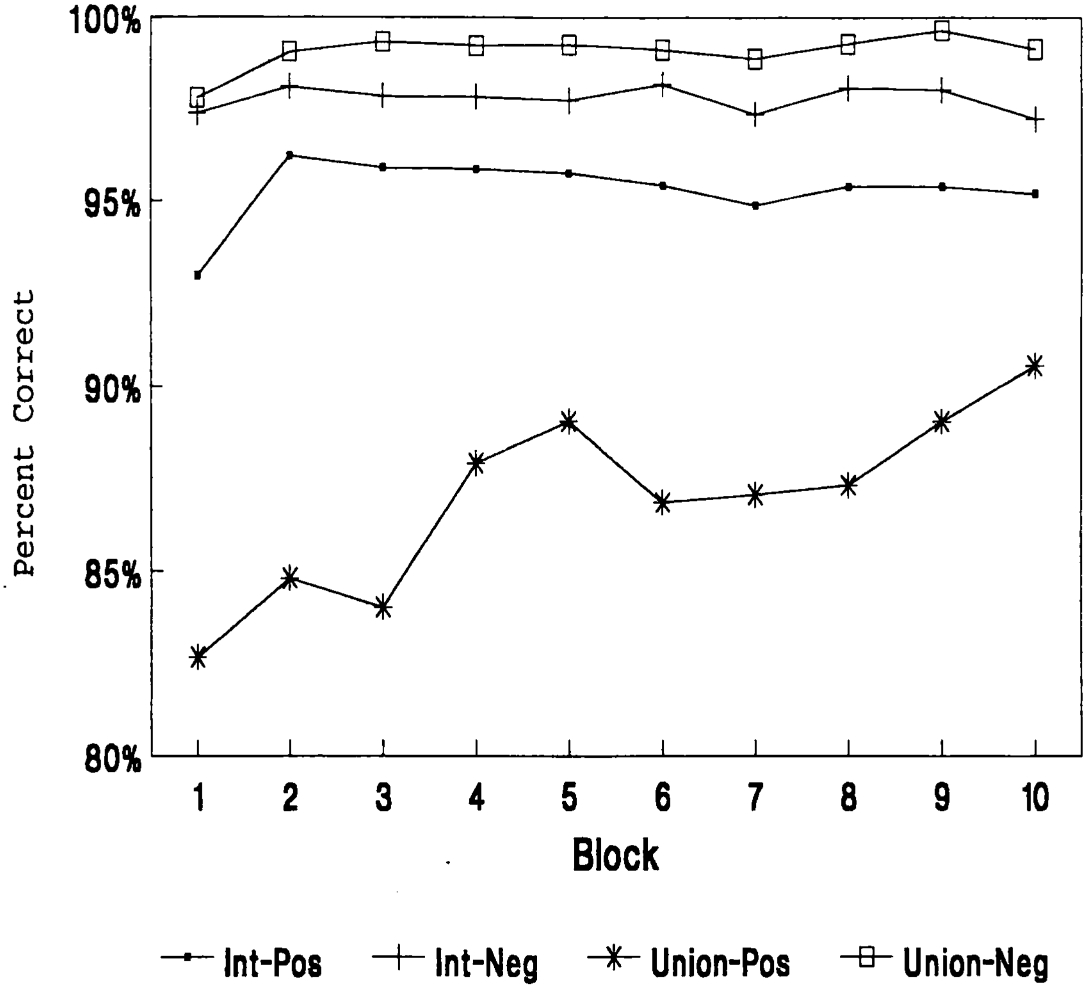


Figure 33. Type of Decision x Type of Trial x Block

Positive Set x Type of Trial x Display Size x Block. This four-way interaction, illustrated in Figure 34, shows the differential effects of trial type and display set size on error rates throughout the ten blocks of trials. The error rates for negative trials for both display set sizes and all levels of positive set size are relatively low and stable across the ten blocks of trials. As positive set size increases from two to six the error rates for positive trials at both display set size levels tend to decrease and become more erratic throughout ten blocks of trials.

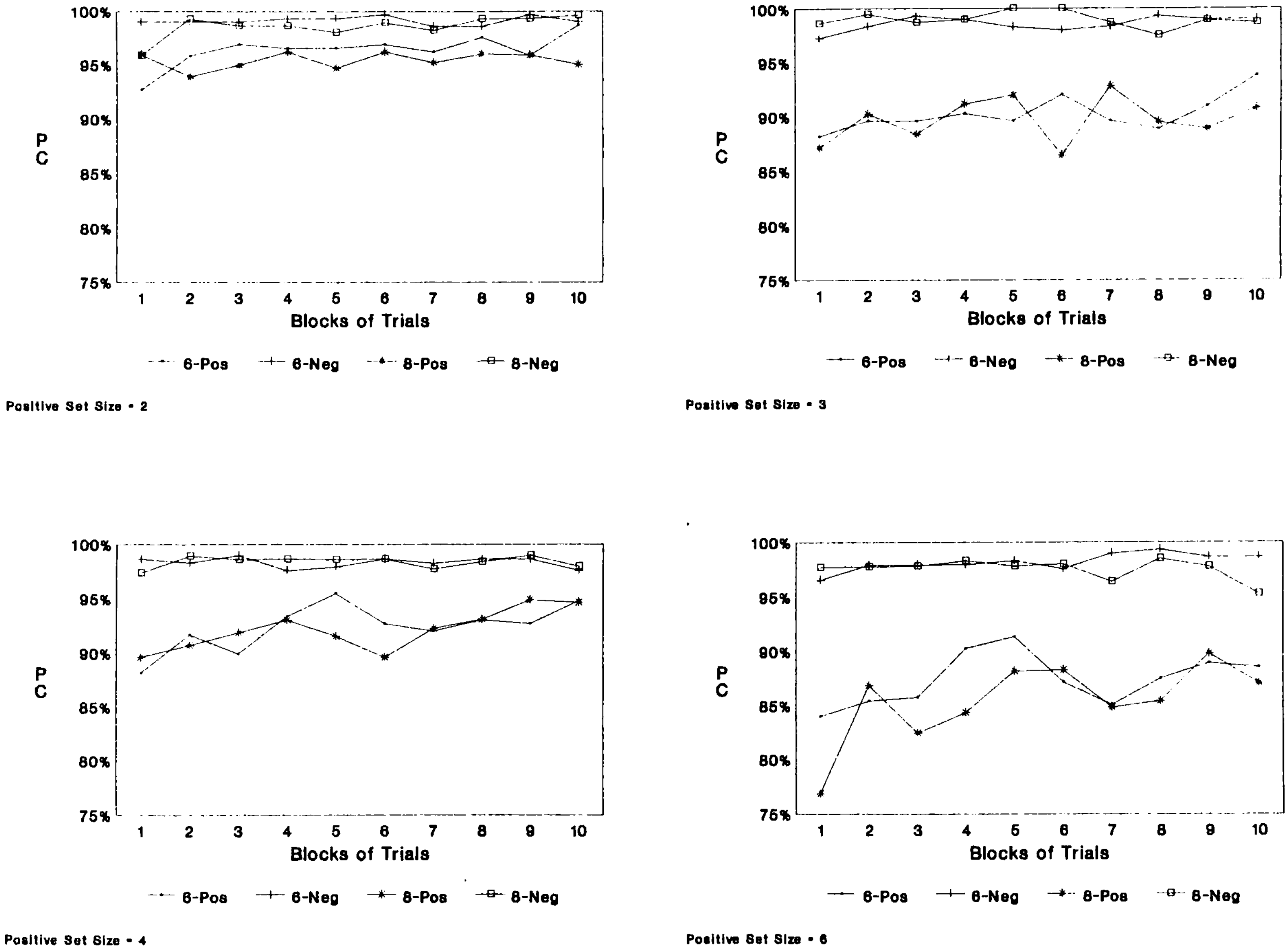


Figure 34. Positive Set Size x Type of Trial x Display Set Size x Block

<u>Positive Set x Type of Trial x Gender x Block</u>. In this interaction, illustrated in Figure 35, the effects of positive set size, trial type, and gender on response accuracy can be compared across the course of the experimental procedure. Negative trials for both males and females at all set size levels had relatively low PC rates, remaining within the 5% error bracket, at each level of block. The error rates for positive trials increased as positive set size increased from two to six. At the positive set size levels of three and four, female error rates for positive trials tended to be higher than the error rates for males.

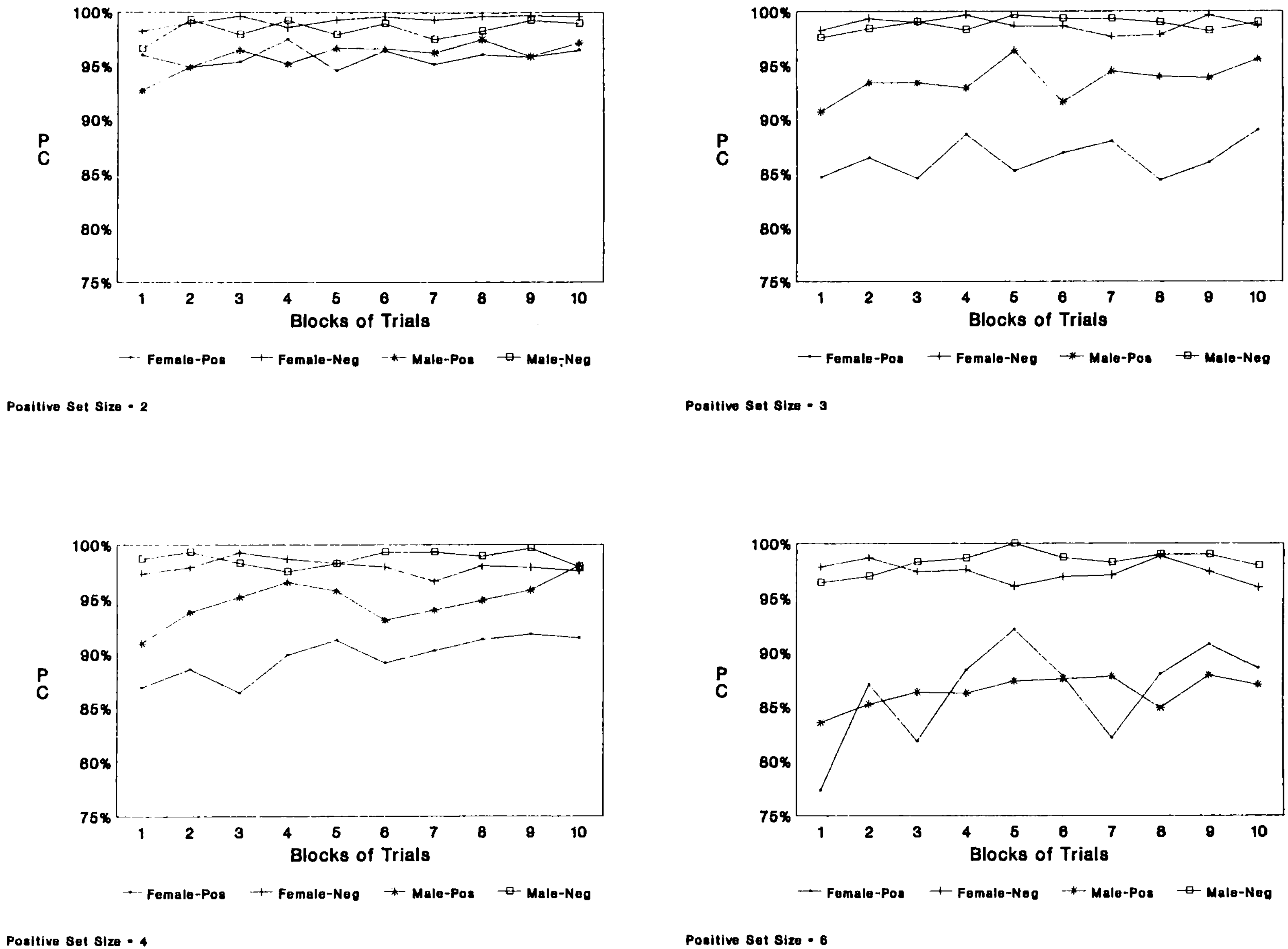


Figure 35. Positive Set Size x Type of Trial x Gender x Block

Type of Trial x Type of Decision x Display Size x Block. This interaction, illustrated in Figure 36, shows the differential effects of display set size, decision type, and trial type on response accuracy throughout the course of the ten block experimental procedure.

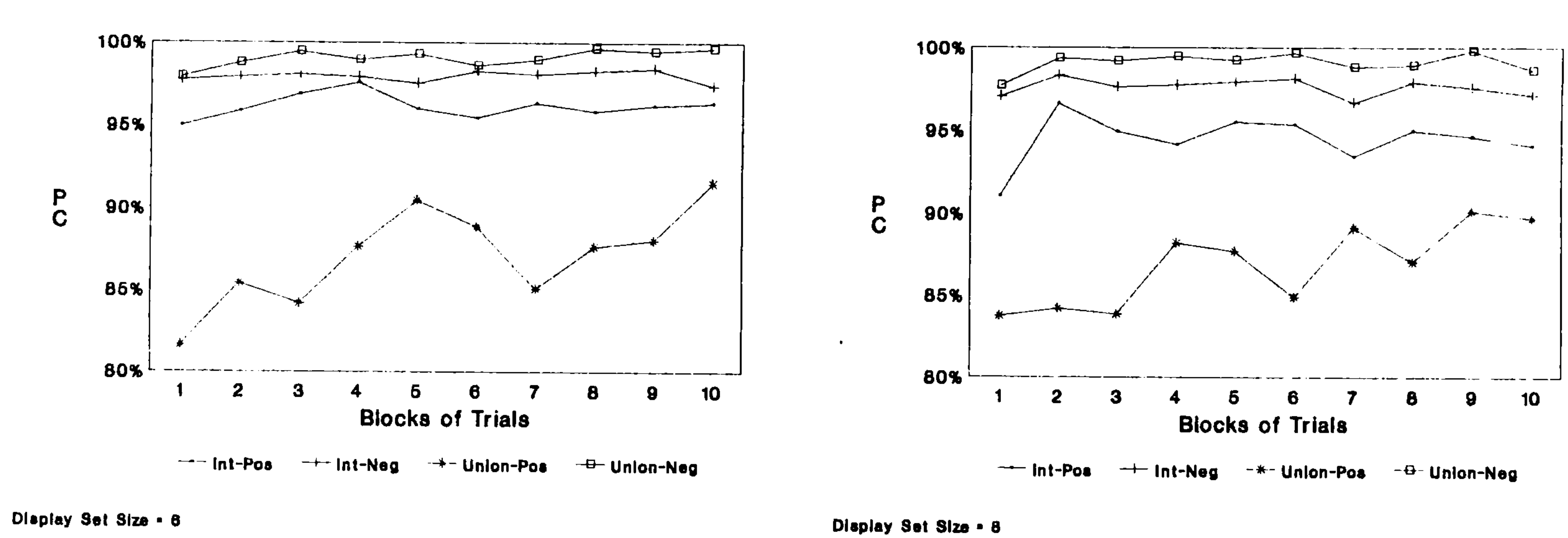


Figure 36. Display Set Size x Type of Decision x Type of Trial x Block

DISCUSSION

This research was designed to test a number of hypotheses regarding the relationship between decision making, reaction time and error rates. These hypotheses, stated as predictions, can be found at the end of the introduction (pp. 31-33). Some of these predictions were confirmed by the results of the present research. The present research makes a number of contributions towards the understanding of the relationship between decision making, reaction time, and error rates. These contributions are considered through the closer examination of some of the significant effects found for the RT and PC data. The hypotheses outlined in the introduction are discussed in the process.

Reaction Time Data

Positive Set Size. This main effect is illustrated in Figure 2. The significant linear trend produced by this main effect [RT = 0.685 + 0.318(Positive Set); r^2 = .972] confirms one of the earliest conclusions regarding decision making and RT which is that a significant relationship exists between RT and the number of alternative stimuli or the positive set size in a CRT situation (Donders, 1969; Hick, 1952; Hyman, 1953; Woodworth, 1938). An increase in positive set size can be thought of as an increase in the complexity of a S-R ensemble. This main effect of positive set size accounted for a substantial 19.3% of the overall variance as indicated by eta^2.

<u>Display Set Size</u>. The main effect of display set size revealed that the increase of display set size from six to eight members resulted in a significant increase in RT. The effect of display set size on RT observed in this research parallels the findings of Tiechner and Krebs (1974).

<u>Block</u>. Mowbray and Rhoades (1959), Newell and Rosenbloom (1981), and Seibel (1962) concluded that RT decreases as a function of practice. Their conclusion was supported by the results of the present research. The main effect of block revealed significant decreases in RT as the number of trials completed increased from block one to block ten. Blocks six and seven constitute a deviation from this general decreasing trend in mean RT. This slight deviation could be attributed to the break given to each subject following the completion of the first five blocks or 240 trials. The temporary increase in RT recorded within blocks six and seven may constitute a reacclimation to the CRT task following the 60-second break, an adjustment to the new display set size, and/or an adjustment to the new characters in the display set. The largest drop in RT occurred early in the sequence of trials between blocks one and two which reflects findings of Mowbray and Rhoades (1959).

<u>Positive Set Size x Display Set Size</u>. This interaction is illustrated in Figure 5. An increase in display set size

from six to eight characters had an additive effect on RT. This effect was relatively consistent at each level of positive set size. The RT for those decisions based on a display set size of eight are, at each positive set size level, significantly greater than the corresponding decisions based on a display set size of six.

Type of Decision x Type of Trial. This interaction is illustrated in Figure 6. Intersection-negative trials resulted in a mean RT that was significantly less than the mean RT for intersection-positive trials. This two-way interaction accounted for a relatively large portion of the overall variance, $eta^2=.1297$. The fast-"negative" trial effect for intersection decisions runs counter to the positive response-type effect reported by Sternberg (1975), Klatzky and Atkinson (1971), and Williams et al. (1990). Their conclusions were based on RT data gathered from subjects performing Sternberg's memory scanning paradigm or, in the case of Williams et al., a modification of the Sternberg paradigm. The fast-"positive" trial effect found by Sternberg (1975), Klatzky and Atkinson (1971), and Williams et al. (1990) was based on the RT data collected from subjects completing union decision tasks. The reversal of this trial-type bias for intersection decisions found in the present experiment can be tentatively attributed to the difference of decision type.

The slow "positive" trial effect found for intersection decisions may be better understood through the closer examination of the conditions that must be met in order for a subject to decide the correct response to a given trial. Intersection decisions are based on an "and" rule. A subject determines for each trial whether every member of the positive set is contained within the display set. Intersection-positive trials require that the subject compare each letter in the positive set with the corresponding positive members in the display set. The search within intersection-negative trials does not need to be as extensive. Once the subject encounters a member of the positive set that is absent from the display set, the search may be terminated. Thus the searches within intersection-negative trials would not be as thorough as the searches within intersection-positive trials and would require, on average, less time. A self-terminating strategy within intersection-negative trials may be responsible for the fast-"negative" effect found in the present research.

This type of trial (positive/negative) by type of decision (intersection/union) interaction also revealed a significant difference between the mean RT for positive-union and negative-union trials. A fast-"positive" trial effect was observed for union trials. This fast-"positive" trial effect supports similar findings by Sternberg (1975), Klatzky and Atkinson (1971), and Williams et al. (1990). Two of Krueger's (1983) explanations for the fast-"same" trial effect observed in "same-different" judgment tasks can be used to understand the fast-"positive" trial effect found for union decision trials in the present experiment.

Krueger's first explanation is based on the noisy-operator theory which contends that internal noise can make two identical letters appear different but rarely make two different letters appear the same (Krueger, 1978). The general rule underlying this theory's fast-"same" prediction is that internal noise produces more false mismatches than matches, thus reducing the confidence in "different" judgments and revealing more false-"different" decisions with "same" pairs. This attenuation of confidence means that perceived mismatches, not perceived matches, are rechecked and consequently negative trials require a longer response time.

The internal-noise principle can be generalized to the results of the present research and can be used to understand the fast-"positive" trial effect found for union decisions. In terms of Krueger's (1978) noisy operator theory, the transition from a "same-different" judgment task to a union decision task represents a change from making a paired comparison to making multiple paired comparisons within a single trial. The only characteristic differentiating positive from negative union trials is the presence or absence of a probe stimulus, or a character from the positive set, in the display set. Using the multiple paired comparison model for union decisions, the difference in RT between positive and negative trials can be attributed to subjects' differential responses to the presence or absence of a probe stimulus.

If the union decision making process is conceptualized as a series of paired comparisons between members of the positive set and members of the display set subjects' responses to not finding a match between any of the paired stimuli in the comparison process, in the case of a negative trial or a false-negative trial, may have resulted in a rechecking of the positive set and display set stimuli and an increase in the mean RT for negative trials. Thus, Krueger's (1983) first explanation of the fast-"same" effect can be used to conceptualize the fast-"positive" trial effect for union decisions.

Krueger's (1983) second explanation of the fast-"same" effect, based on the priming principle, asserts that the processing of the first stimulus in a pair of identical stimuli enhances or quickens the encoding of the second occurrence of the same stimulus. In a union decision trial, multiple comparisons must be made between members of the positive set and members of the display set. The presence or absence of a probe stimulus, the common member between the positive and display sets, differentiates positive and negative-union decision trials. The significance of a RT difference that a priming effect could produce for the one "same" comparison in positive trials on the overall trial RT is questionable. The priming principle may not account for a significant amount of the observed discrepancy between the RT for union-positive and union-negative trials although its potential contribution to the difference should not be ruled out. This conclusion, regarding the priming principle, supports the views expressed by Krueger (1983).

Type of Decision x Display Set Size. This two-way interaction is illustrated in Figure 7. This interaction provides some insight concerning the differential effects of display set size on the two types of decision making. The increase in display set size from six to eight characters resulted in a significant increase in RT for both intersection and union decisions. Intersection decisions required significantly less time than union decisions at both levels of display set size although the difference between the RT for intersection and union decisions at the display set size level of six is greater.

Positive Set Size x Type of Decision x Type of Trial. Figure 8 illustrates this interaction. This three-way interaction accounted for a notable portion of the observed variance, eta^2=.0641. The significant linear effect produced by the union-positive trials across the positive set size levels provides a close approximation of Hick's law (Hick, 1952). This linear trend found in the intersection-positive condition across the positive set sizes is best described by the following equation:

$$RT = 0.420 + 0.416(\text{Positive Set}) \quad \underline{r}^2 = .990$$

Based on the value of $\underline{r}^2$, it was determined that the positive set size, rather than $\log_2$ positive set size as in Hick's equation, was a better predictor of RT for intersection-positive trials and provided a better fit to the data. The data suggest that RT is a linear, not a logarithmic, function of positive set size for union decisions.

Hick's law is based on the assumption of error free performance. The PC for union-positive trials at each level of positive set size is significantly lower than that of union-negative trials. This inflated error rate for union-positive trials can be seen in the positive set size x type of decision x type of trial interaction which is illustrated in Figure 27. Clearly the performance on the union-positive trials was not free of errors. This may account for the better linear fit to the union-positive trial data over a logarithmic fit as suggested by Hick (1952) in the case of error free performance.

Union negative trials required significantly more time than union-positive trials at each level of positive set size. This fast-"positive" trial effect for union decisions supports research findings reported by Klatzky and Atkinson, (1971) Sternberg (1975), and Williams et al. (1990). Again, based on the values of $\underline{r}^2$, it was determined that for union-negative trials the positive set size, rather than $\log_2$ positive set size, was a better predictor of RT.

There was no continuation of the curvilinear trend found in the Beckman and Coates (1992) study for intersection-negative trials (see Figure 1). It was predicted in the introduction that the mean RT for the 6-6 intersection-negative condition would be significantly lower than the 4-6, 3-6, and 2-6 conditions. Sternberg (1975) reported that negative set size has no effect on RT for either positive or negative trial types. Positive set size had no effect on intersection-negative trials. There were no significant differences of RT found between the positive set size levels for the intersection-negative trial condition. This lack of trend contrasts with the curvilinear effect observed in the Beckman and Coates (1992) study. One possible explanation for the curvilinear effect observed in the Beckman and Coates (1992) study is that the number of negative set members in the display set for intersection-negative trials was not counterbalanced. The number of negative set members was counterbalanced in the program used to generate the CRT tasks for the present research and this control may have eliminated the curvilinear trend found in the research by Beckman and Coates (1992).

If subjects had employed the negative set in the decision process when it was efficient to do so, as outlined by Haygood and Johnson (1983), it would be reasonable to expect a curvilinear trend to develop. This prediction, outlined above, assumes that a serial type search process would be employed (Sternberg, 1975). RT was unaffected by positive set size for the intersection-negative trials. This lack of positive set size effect provides evidence of parallel processing. It is not clear whether, in this apparent instance of parallel processing, subjects utilized the positive set or some combination of the positive and negative sets in the decision process. Positive set size had a significant effect on RT for intersection-positive trials, producing a linear trend across the levels of positive set size. This linear effect provides evidence of serial processing. Future research may focus on this difference in processing styles for positive and negative intersection trials.

Union-negative trials took on average 1.0687 sec. longer than union-positive trials. This fast-"positive" response-type effect for union decisions has been noted in other research (Bamber, 1969; Nickerson, 1965; Sternberg, 1975). It is interesting to note the reversal of the fast-"positive" response-type effect in the union trials to a fast-"negative" response-type effect in the intersection trials for positive set sizes four and six. Although positive and negative intersection trials at levels two and three do not differ, the response-type effect exhibited at levels four and six provide evidence of a reversal of the fast-"positive" response type effect to a fast-"negative" effect for larger positive-set memory loads. This reversal of effect for the conditions with larger character strings echoes the results of Krueger (1984) who found that "different" trials from "same-different" judgement tasks, which involve the comparison of simultaneously presented character strings, have a speed advantage over "same" trials. Krueger (1984) attributed this fast-"different" effect to a self-termination factor within a serial search process. Both the fast-"positive" response-type effect for union decisions and the fast-"negative" effect for the selected intersection decisions should be of intrinsic interest to those involved in human decision making research.

Positive Set Size x Type of Decision x Display Set Size. This interaction is illustrated in Figure 10. Both union trials and intersection trials employing a display set size of eight and union trials using a display set size of six produced significant linear trends across the four levels of positive set size. The most interesting facet of this three-way interaction is that for intersection decisions employing a display set size of six, positive set size had no significant effect on the dependent variable, RT. This lack of positive set-size effect may be a result of parallel processing of the members in the positive set.

Previous research has demonstrated that parallel processing of a positive set can occur in decision making situations (Neisser, 1963; Neisser, Novick and Lazar, 1963). A number of two-part theories of perceptual processing contain a parallel processing component in conjunction with a serial processing component (Atkinson & Juola, 1973; Hoffman, 1979; Neisser, 1967; Schneider & Shiffrin, 1977; Shiffrin & Geisler, 1973).

Fisher (1982) concluded that parallel processing is limited to situations which have a display set size no greater than six. Fisher's (1982) conclusion may help to explain why positive set size had no effect for intersection decisions employing a display set size of six but produced significant increases in RT for intersection decisions using a display set size of eight. In the former trial condition parallel processing is possible but in the latter situation the display set size exceeds the situational parameters in which parallel processing can occur (Fisher, 1982).

Another explanation for the absence of positive set size effect for intersection decisions using a display set of six members involves the negative set. If the subjects in this condition employed the negative set in the decision process when it was efficient to do so, as outlined by Haygood and Johnson (1983), the maximum number of items that would have to be located in any of the four positive set size levels would be three. A search for the positive set members would be the most efficient strategy with the small positive set sizes of two and three. It becomes more efficient to use the negative set with the larger two positive set sizes. Only two or three negative set members, as opposed to four positive set members, need to be located in order to determine the correct response in the intersection decision condition with a positive set size of four and a display set size of six. The utility of using the negative set may not be as obvious in this condition as in the condition in which both the positive set and the display set are equal in size. Searching for one negative set member that does not belong is more obviously efficient than searching for the six positive set members that do belong. During the short debriefing session following the experimental procedure, nine of the 24 subjects, who were in the positive set-size condition of six, reported using the negative set focus strategy while responding to trials which contained both a positive set and display set-size of six.

If subjects responding to intersection trials with a display set size of six used the negative set when it was efficient to do so, as outlined above, then no more than three characters would have to be located in order to determine the correct response. The difference in the dependent variable, RT, in response to searches for one, two, or three members may not have been significant and may help to explain the apparent lack of positive set size effect for intersection decisions using the smaller display set size.

In a serial search process, the addition of each member to the positive set results in an increase in RT. In a parallel processing situation, RT is independent of the number of members being searched for. In the present research, differences in RT in response to variations in the number of items being searched for would not have been significant in the event these items were being processed in a parallel fashion. Parallel processing could have been used to process the positive set exclusively and in this situation positive set size would not have significantly influenced RT.

A third interpretation of the flat RT effect for intersection decisions with a display set size of six combines the two previous explanations. Subjects may have used the negative set when it was efficient to do so, as outlined by Haygood and Johnson (1983) and used a parallel search strategy to process the one, two or three members that would need to be located in order to make a correct decision. Future research will be needed to test these hypotheses in order to understand better the lack of positive set-size effect for intersection decisions with the small positive set size.

Type of Trial x Type of Decision X Display Set Size.

This interaction is illustrated in Figure 11. An increase in display set size had an additive effect on RT for both intersection and union decisions and positive and negative trials. This finding of a positive relationship between display set size and RT supports previous research by (Fisher, 1982; Schneider & Shiffrin, 1977).

The fast-"positive" trial effect for union decisions occurs at both levels of display set size and supports previous research findings (Bamber, 1969; Nickerson, 1965; Sternberg, 1975). The fast-"negative" trial effect for intersection decisions is consistent at both levels of display set size.

Display Size x Block. This interaction, which can be seen in Figure 14, illustrates the effects of both display set size and practice on RT. The additive effect an increase in display set size had on RT supports the conclusions of Tiechner and Krebs (1974). Schneider and Shiffrin (1977) found that when display sizes are small the additive effect of display set size decreases with practice. Practice resulted in a significant decrease in RT for both display set sizes supporting Schneider and Shiffrin's (1977) finding and supporting previous research (Mowbray & Rhoades, 1959; Newell & Rosenbloom, 1981). The largest drop in RT occurred early in the trial sequence for both the six and eight display set size conditions which supports the findings of Mowbray and Rhoades (1959).

Position Effects. Figure 20 shows the mean RT for union-positive trials with a display set size of 8 or 6, at each position of the probe stimulus within the display set. The RT data produced a significant linear trend for trials using a display set size of six and for trials using a display set size of eight. The fact that a significant relationship was found between the position of the probe stimulus in the display set and RT challenges Sternberg's (1969b) conclusions about the exhaustive nature of the memory scanning process for union decisions. The discovery of the position effects does not support Sternberg's (1975) contention that positive set items are compared with every item in the display set regardless of whether the probe stimulus was matched before reaching the last item in the scan process. These results do, however, provide support for the self-terminating cognitive search model advocated by Shaw (1969); Shaw & LaBerge (1971); and Shaw (1977).

Percent Correct Data

Positive Set Size. Figure 21 illustrates this main effect. Although the error rate associated with the two and four positive set size conditions does not differ significantly, the general trend suggests that as positive set size increases, PC decreases.

Block. Figure 22 illustrates this main effect. The only significant difference found among the PC for the ten blocks was between the first block and the subsequent nine blocks. The error rate decreased significantly from the first to second block but did not change during the last nine blocks. Howell and Kreidler (1963) reported no significant trend in improvement of response accuracy for subjects completing 20 trials of a CRT task.

Although the CRT task used by Howell and Kreidler (1963) more closely resembles the CRT tasks employed in the current research, Bailey and Koch's (1976) conclusions regarding change in error rates over time more closely parallel the results of current research. Each of the ten blocks in the current study consisted of 48 trials. The first block in the current study contained more than twice the total number of trials used by Howell and Kreidler (1963). An analysis of the PC data for the first 20 trials of the current study might reveal response accuracy results that are more consistent with those of Howell and Kreidler (1963).

Bailey and Koch (1976) concluded that, once a basic skill is developed, the proportion of errors remains about the same. Assuming that subjects in the current study mastered the CRT task they were asked to perform within the first block of 48 trials, then Bailey and Koch's (1976) conclusion can be used to understand the lack of change in response accuracy during the last nine blocks of the experimental procedure.

Gender x Type of Trial. In this interaction, illustrated in Figure 23, it can be seen that for both male and female subjects negative trials produced a significantly higher response accuracy rate than positive trials. Males, however, responded more accurately than females on positive trials.

Type of Decision x Type of Trial. Figure 26 illustrates this interaction. The error rate for union-positive stimulus trials was significantly greater than the error rate for union-negative stimulus trials. This higher error rate for positive trials agrees with what would have been predicted using Krueger's (1983) internal-noise principle. Krueger (1983) proposes that internal noise often makes two identical letters appear different but rarely makes two different letters appear identical. Confidence in perceived differences consequently is reduced and perceived mismatches tend to be rechecked. Krueger (1978) found that the rechecking process is not always complete and that subjects, due to impatience and other moderating variables, allow a 4% risk of error. Misperceived matches result in a false-negative responses to positive trials and inflate the error rate for positive trials. Although Krueger's research was based on data collected from subjects performing "same-different" judgement tasks, the internal-noise theory can be used to understand the differential error rates found with subjects performing CRT tasks in the current research.

The inflated error rate for negative trials may have been influenced by internal noise, as Krueger (1983) proposed, in conjunction with a characteristic unique to the union decision-making process. As stated above, the presence or absence of a probe stimulus in the display set differentiated positive and negative stimulus trials in the present research. A positive relationship exists between the size of the positive set and the number of individual paired comparisons, assuming a serial-type processing of the positive set, that must be made in a union decision-making situation in order to make an accurate response. In a union-negative trial, all paired comparisons between members of the positive and display sets would result in a "different" judgement, assuming error-free performance. In a union-positive trial, all but <u>one</u> of the paired comparisons would result in a "different" judgement. Thus, "different" judgements are disproportionately represented within the union decision process. As positive set size in the union decision process increases from two to six the ratio of "different" to "same" paired-comparison judgements increases. An increase in display set size would also increase the number of paired comparisons that would need to be made in order to make an accurate decision and this increase would consequently affect, in a similar manner, the ratio mentioned above.

The number of positive and negative union trials were counterbalanced and equal in number within each of the ten blocks of trials. Using a serial search model, the paired comparisons between positive set and display set members contained a disproportionate number of "different" judgments. Due to the disproportionate number of "different" judgements inherent in both positive and negative union trials, subjects may have been conditioned to expect and process mismatches between positive set and display set items. This comparison-type conditioning may increase the probability of responding inaccurately to the one comparison in a positive trial between the probe stimulus and positive set twin that should receive a "same" response. Krueger's (1983) internal-noise principle can be used in conjunction with the multiple paired-comparison model to explain the inflated error rates for union-positive decisions. As stated above, the principle contends that internal noise can make two identical letters appear different but rarely makes two different letters appear identical. Internal noise increases the probability that a union-positive trial or, to be exact, the one comparison between the probe stimulus and its positive set twin, is responded to inaccurately. The comparison-type conditioning within union trials in conjunction with Krueger's internal-noise principle offers one explanation for the inflated error rate found in union-positive trials.

Krueger (1983) also predicted faster correct judgements for same or positive trials since positive trials, according to the internal-noise principle, do not require the frequent rechecking that is often part of the decision process for negative trials. The type of decision x type of trial interaction for the RT data, outlined above, showed that union decisions positive trials were, on average, significantly faster than negative trials. Krueger's (1983) internal-noise principle offers one explanation for the increased error rate and faster response time found with positive trials in the current research.

CONCLUSIONS

The present research provided support for three of the five predictions outlined in the introduction. The fast-"positive" effect that characterized union decisions was not found for intersection decisions. A reversal of the fast-"positive" effect was found for intersection trials with positive set sizes larger than three.

CRT appears to be a linear function of positive set size for intersection-positive decisions. The increase in positive set size from two to six members did not produce a curvilinear trend for intersection-negative trials. CRT appears to be independent of positive set size for intersection-negative decisions. A positive relationship exists between display set size and RT, which confirms previous research findings. The increase in positive set size from six to eight characters resulted in significant increases in RT. The cognitive search process for union-positive trials is well described by a serial self-terminating model. The significant linear trend found for union-positive trials across the positive set-size levels suggests that a serial search occurred. The significant position effects found at both display set size levels suggest that a self-terminating search strategy was employed. The present research helped to clarify certain aspects of human decision-making processes and illuminate other areas which will require more research.

Future research may focus on the reversal of the fast-"positive" effect for intersection decisions. The fast-"negative" effect for intersection decisions should be of intrinsic interest in the realm of CRT research and communications theory. More generally speaking, the difference in processing styles, which appear to affect both RT and error rates, of positive and negative trials needs further research. More research is needed in order to define and understand the conditions in which parallel processing can occur. The inflated error rates found for intersection-positive trials should be of concern to researchers as well as system designers interested in reducing the probability of error in human decision making. The author recorded 17 complaints from subjects regarding the discriminability of the display set stimuli displayed on the computer monitor. The complaints centered on difficulties discriminating letters, such as "E" and "F", in the display sets. Future replications of this research, or other research investigating human decision making processes, may wish to investigate the effects of changes in character size and font on both RT and response accuracy.

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Table 1

SUMMARY OF ANALYSIS OF VARIANCE (Beckman and Coates, 1992) - RT

Source	df	SS	MS	F	eta^2
N	2	40.818469	20.4092345	5.71**	0.0169
UI	1	24.058308	24.0583080	6.73**	0.0200
N*UI	2	2.513372	1.2566862	0.35	......
PN	1	22.377054	22.3770538	24.34**	0.0722
N*PN	2	6.206728	3.103364	3.38*	0.0100
UI*PN	1	55.399554	55.399554	60.26**	0.1787
N*UI*PN	2	11.740403	5.870201	6.39**	0.0190
BLOCK	9	7.043973	0.782664	11.68**	0.0346
N*BLOCK	18	1.606366	0.089243	1.33	......
UI*BLOCK	9	0.844320	0.093813	1.40	......
N*UI*BLOCK	18	0.486617	0.027034	0.40	......
PN*BLOCK	9	0.283333	0.031481	0.88	......
N*PN*BLOCK	18	0.365629	0.020313	0.57	......
UI*PN*BLOCK	9	0.313764	0.034863	0.98	......
N*UI*PN*BLOCK	18	0.530710	0.029484	0.83	......
SUBJ(N*UI)	30	107.261454	3.575382	n.t.	......
SUBJ*PN(N*UI)	30	27.579472	0.919316	n.t.	......
SUBJ*BLOCK(N*UI)	270	18.099708	0.067036	n.t.	......
SUBJ*PN*BLOCK(N*UI)	270	9.645565	0.035724	n.t.	......

* $p < .05$
** $p < .01$

Table 2

SUMMARY OF ANALYSIS OF VARIANCE - REACTION TIME

Source	df	SS	MS	F	eta^2
PSET	3	874.5979	291.5326	23.60**	0.1927
PN	1	78.3141	78.3141	34.70**	0.0173
IU	1	83.4440	83.4440	6.75*	0.0184
DSIZE	1	252.3340	252.3340	125.69**	0.0556
GENDER	1	15.7723	15.7723	1.28	......
BLOCK	9	28.9470	3.2163	18.71**	0.0064
PSET*PN	3	4.0744	1.3581	0.60	......
PSET*IU	3	106.7990	35.5997	2.88*	0.0235
PSET*DSIZE	3	104.3782	34.7927	17.33**	0.0230
PSET*GENDER	3	75.7712	25.2571	2.04	......
PSET*BLOCK	27	26.8139	0.9931	5.78**	0.0059
PN*IU	1	588.6320	588.6320	260.84**	0.1297
PN*DSIZE	1	1.0355	1.0355	2.85	......
PN*GENDER	1	3.2875	3.2875	1.46	......
PN*BLOCK	9	3.3109	0.3679	3.75**	0.0007
IU*DSIZE	1	10.5367	10.5367	5.25*	0.0023
IU*GENDER	1	0.0409	0.0409	0.00	......
IU*BLOCK	9	0.6550	0.0728	0.42	......
DSIZE*GENDER	1	2.7168	2.7168	1.35	......
DSIZE*BLOCK	9	7.0071	0.7786	5.15**	0.0015
GENDER*BLOCK	9	1.9706	0.2190	1.27	......
PSET*PN*IU	3	290.8143	96.9381	42.96**	0.0641
PSET*PN*DSIZE	3	7.1855	2.3952	6.59**	0.0016
PSET*PN*GENDER	3	2.5723	0.8574	0.38	......
PSET*PN*BLOCK	27	7.4206	0.2748	2.80**	0.0016
PSET*IU*DSIZE	3	31.7072	10.5691	5.26**	0.0070
PSET*IU*GENDER	3	26.1750	8.7250	0.71	......
PSET*IU*BLOCK	27	3.7269	0.1380	0.80	......
PSET*DSIZE*GENDER	3	11.8688	3.9563	1.97	......
PSET*DSIZE*BLOCK	27	6.4452	0.2387	1.58*	0.0014
PSET*GENDER*BLOCK	27	5.5643	0.2061	1.20	......
PN*IU*DSIZE	1	16.2733	16.2733	44.79**	0.0036
PN*IU*GENDER	1	8.2304	8.2304	3.65	......
PN*IU*BLOCK	9	1.1613	0.1290	1.31	......
PN*DSIZE*GENDER	1	0.0916	0.0916	0.25	......
PN*DSIZE*BLOCK	9	1.2356	0.1373	1.33	......
PN*GENDER*BLOCK	9	1.6497	0.1833	1.87	......
IU*DSIZE*GENDER	1	7.3389	7.3389	3.66	......
IU*DSIZE*BLOCK	9	0.4231	0.0470	0.31	......
IU*GENDER*BLOCK	9	0.6752	0.0750	0.44	......

Table 2 (Cont.)

DSIZE*GENDER*BLOCK	9	1.2984	0.1443	0.95	......
PSET*PN*IU*DSIZE	3	22.0391	7.3464	20.22**	0.0049
PSET*PN*IU*GENDER	3	4.8349	1.6116	0.71	......
PSET*PN*IU*BLOCK	27	2.8256	0.1047	1.07	......
PSET*PN*DSIZE*GENDER	3	2.3669	0.7890	2.17	......
PSET*PN*DSIZE*BLOCK	27	5.1619	0.1912	1.85**	0.0011
PSET*PN*GENDER*BLOCK	27	3.7165	0.1376	1.40	......
PSET*IU*DSIZE*GENDER	3	26.8584	8.9528	4.46**	0.0059
PSET*IU*DSIZE*BLOCK	27	3.1465	0.1165	0.77	......
PSET*IU*GENDER*BLOCK	27	4.6819	0.1734	1.01	......
PSET*DSIZ*GEND*BLOCK	27	3.4876	0.1292	0.85	......
PN*IU*DSIZE*GENDER	1	0.3179	0.3179	0.88	......
PN*IU*DSIZE*BLOCK	9	0.2456	0.0273	0.26	......
PN*IU*GENDER*BLOCK	9	0.8467	0.0941	0.96	......
PN*DSIZE*GENDE*BLOCK	9	0.8120	0.0902	0.87	......
IU*DSIZE*GENDE*BLOCK	9	1.7361	0.1929	1.28	......
PSE*PN*DSI*GEND*BLOC	27	3.8377	0.1421	1.38	......
PSET*PN*IU*DSIZ*GEND	3	1.7337	0.5779	1.59	......
PSET*PN*IU*DSIZ*BLOC	27	1.6799	0.0622	0.60	......
PSET*PN*IU*GEND*BLOC	27	2.0315	0.0752	0.77	......
PSE*IU*DSI*GEND*BLOC	27	4.2613	0.1578	1.04	......
PN*IU*DSIZ*GEND*BLOC	9	0.8644	0.0960	0.93	......
DS*PSE*IU*GEN*PN*BLO	27	2.2976	0.0851	0.82	......
S(PSET*IU*GENDER)	80	988.4128	12.3552	n.t.	......
S*PN(PSET*IU*GENDER)	80	180.5364	2.2567	n.t.	......
S*DSIZ(PSET*IU*GEND)	80	160.6065	2.0076	n.t.	......
S*BLOC(PSET*IU*GEND)	720	123.7682	0.1719	n.t.	......
S*PN*DSI(PSE*IU*GEN)	80	29.0638	0.3633	n.t.	......
S*PN*BLO(PSE*IU*GEN)	720	70.6847	0.0982	n.t.	......
S*DS*BLO(PSE*IU*GEN)	720	108.7785	0.1511	n.t.	......
S*PN*DS*BL(PS*IU*GE)	720	74.4046	0.1033	n.t.	......

* $p < .05$
** $p < .01$

Table 3

SUMMARY OF ANALYSIS OF VARIANCE -- PERCENT CORRECT

Source	df	SS	MS	F	eta²
PSET	3	1.3614	0.4538	9.13**	0.0368
PN	1	5.1188	5.1188	151.92**	0.1384
IU	1	1.1993	1.1993	24.12**	0.0324
DSIZE	1	0.0295	0.0295	2.15	......
GENDER	1	0.2656	0.2656	5.34*	0.0072
BLOCK	9	0.2489	0.0277	6.42**	0.0067
PSET*PN	3	0.9541	0.3180	9.44**	0.0258
PSET*IU	3	0.4573	0.1524	3.07*	0.0124
PSET*DSIZE	3	0.0253	0.0084	0.62	......
PSET*GENDER	3	0.2696	0.0899	1.81	......
PSET*BLOCK	27	0.0935	0.0035	0.80	......
PN*IU	1	2.2356	2.2356	66.35**	0.0604
PN*DSIZE	1	0.0136	0.0136	1.05	......
PN*GENDER	1	0.1994	0.1994	5.92*	0.0054
PN*BLOCK	9	0.1433	0.0159	3.71**	0.0039
IU*DSIZE	1	0.0203	0.0203	1.49	......
IU*GENDER	1	0.0957	0.0957	1.92	......
IU*BLOCK	9	0.1444	0.0160	3.72**	0.0039
DSIZE*GENDER	1	0.0124	0.0124	0.91	......
DSIZE*BLOCK	9	0.0173	0.0019	0.52	......
GENDER*BLOCK	9	0.0332	0.0037	0.86	......
PSET*PN*IU	3	0.4454	0.1485	4.41**	0.0120
PSET*PN*DSIZE	3	0.0041	0.0014	0.11	......
PSET*PN*GENDER	3	0.2339	0.0780	2.31	......
PSET*PN*BLOCK	27	0.1105	0.0041	0.95	......
PSET*IU*DSIZE	3	0.0670	0.0223	1.63	......
PSET*IU*GENDER	3	0.3515	0.1172	2.36	......
PSET*IU*BLOCK	27	0.1754	0.0065	1.51*	0.0047
PSET*DSIZE*GENDER	3	0.0349	0.0116	0.85	......
PSET*DSIZE*BLOCK	27	0.0866	0.0032	0.87	......
PSET*GENDER*BLOCK	27	0.0973	0.0036	0.84	......
PN*IU*DSIZE	1	0.0074	0.0074	0.57	......
PN*IU*GENDER	1	0.1727	0.1727	5.12*	0.0047
PN*IU*BLOCK	9	0.0895	0.0099	2.32*	0.0024
PN*DSIZE*GENDER	1	0.0057	0.0057	0.44	......
PN*DSIZE*BLOCK	9	0.0280	0.0031	0.85	......
PN*GENDER*BLOCK	9	0.0405	0.0045	1.05	......
IU*DSIZE*GENDER	1	0.0202	0.0202	1.48	......
IU*DSIZE*BLOCK	9	0.0857	0.0095	2.58**	0.0023
IU*GENDER*BLOCK	9	0.0335	0.0037	0.86	......

Table 3 (Cont.)

DSIZE*GENDER*BLOCK	9	0.0285	0.0032	0.86	......
PSET*PN*IU*DSIZE	3	0.0192	0.0064	0.49	......
PSET*PN*IU*GENDER	3	0.1593	0.0531	1.58	......
PSET*PN*IU*BLOCK	27	0.1254	0.0046	1.08	......
PSET*PN*DSIZE*GENDER	3	0.0398	0.0133	1.03	......
PSET*PN*DSIZE*BLOCK	27	0.1701	0.0063	1.72*	0.0046
PSET*PN*GENDER*BLOCK	27	0.1744	0.0065	1.50*	0.0047
PSET*IU*DSIZE*GENDER	3	0.0537	0.0179	1.31	......
PSET*IU*DSIZE*BLOCK	27	0.0839	0.0031	0.84	......
PSET*IU*GENDER*BLOCK	27	0.0890	0.0033	0.77	......
PSET*DSIZ*GEND*BLOCK	27	0.1075	0.0040	1.08	......
PN*IU*DSIZE*GENDER	1	0.0101	0.0101	0.78	......
PN*IU*DSIZE*BLOCK	9	0.0631	0.0070	1.92*	0.0017
PN*IU*GENDER*BLOCK	9	0.0262	0.0029	0.68	......
PN*DSIZE*GENDE*BLOCK	9	0.0122	0.0014	0.37	......
IU*DSIZE*GENDE*BLOCK	9	0.0363	0.0040	1.09	......
PSE*PN*DSI*GEND*BLOC	27	0.0942	0.0035	0.95	......
PSET*PN*IU*DSIZ*GEND	3	0.0106	0.0035	0.27	......
PSET*PN*IU*DSIZ*BLOC	27	0.0884	0.0033	0.89	......
PSET*PN*IU*GEND*BLOC	27	0.0861	0.0032	0.74	......
PSE*IU*DSI*GEND*BLOC	27	0.1018	0.0038	1.02	......
PN*IU*DSIZ*GEND*BLOC	9	0.0358	0.0040	1.09	......
DS*PSE*IU*GEN*PN*BLO	27	0.0583	0.0022	0.59	......
S(PSET*IU*GENDER)	80	3.9783	0.0497	n.t.	......
S*PN(PSET*IU*GENDER)	80	2.6956	0.0337	n.t.	......
S*DSIZ(PSET*IU*GEND)	80	1.0948	0.0137	n.t.	......
S*BLOC(PSET*IU*GEND)	720	3.1008	0.0043	n.t.	......
S*PN*DSI(PSE*IU*GEN)	80	1.0353	0.0129	n.t.	......
S*PN*BLO(PSE*IU*GEN)	720	3.0908	0.0043	n.t.	......
S*DS*BLO(PSE*IU*GEN)	720	2.6570	0.0037	n.t.	......
S*PN*DS*BL(PS*IU*GE)	720	2.6349	0.0037	n.t.	......

* $p < .05$
** $p < .01$

Appendix A

Instructions (Union Condition):

In the lower left-hand corner of the computer screen are (2, 3, 4, 6) characters. These (2, 3, 4, 6) are your "positive set". The positive set will remain visible in this corner of the screen throughout the testing procedure. (6, 8) characters will be presented to you in the middle of the computer's screen. These characters are the "display set". If you see **any** of the characters in the positive set represented in a display set, please respond by pressing the "1" key on the numeric key pad on the computer key board. If you do **not** see **any** character from the positive set represented in a display set, please respond by pressing a "2" key on the numeric key pad. If **one or more** of the members in the positive set are represented in a display set the correct answer would be a "1". Following each response the display set will disappear which will be followed by a warning "beep" indicating that a new display set is on the way.

At this time I would like to guide you through 12 practice trials to make sure that you understand the procedure.

You will be presented with a total of 480 display sets. After the first 240 trials you will be given a 60 second break during which time you may stretch and relax your concentration. During the first 240 trials your positive set will contain (6, 8) characters and during the last 240 trials your positive set will contain (6, 8) characters.

When asked to, please depress the "enter" key and the first display set will appear. Again, you will be responding with either a "1" for yes, one or more of the characters in the positive set are represented in the display set, or a "2" for no, none of the positive set members are represented in the display set. Please respond to each of the 480 display sets as quickly as possible with no more than 5% errors.

There will be a "white-noise" maker turned on during the procedure to block out any extraneous sounds. This will sound like a television set tuned into an empty or "snowy" channel.

I will not be in the room during the procedure. When the computer no longer presents you with a display set this means the procedure is finished. At this point please find me in the next room.

Are there any questions regarding the procedure?

I am now going to leave the room and turn on the white-noise maker. When you hear the white noise please depress the enter key to initiate the procedure.

Appendix B

Instructions (Intersection Condition)

In the lower left-hand corner of the computer screen are (2, 3, 4, 6) characters. These (2, 3, 4, 6) are your "positive set". The positive set will remain visible in this corner of the screen throughout the testing procedure. (6, 8) characters will be presented to you in the middle of the computer's screen. These characters are the "display set". If you see **all** of the characters in the positive set represented in a display set, please respond by pressing the "1" key on the numeric key pad on the computer key board. If you do **not** see **all of the** characters from the positive set represented in a display set, please respond by pressing a "2" key on the numeric key pad. If less than all of the members in the positive set are represented in a display set then the correct answer would be a "2". Following each response the display set will disappear which will be followed by a warning "beep" indicating that a new display set is on the way.

At this time I would like to guide you through 12 practice trials to make sure that you understand the procedure.

You will be presented with a total of 480 display sets. After the first 240 trials you will be given a 60 second break during which time you may stretch and relax your concentration. During the first 240 trials your positive set will contain (6, 8) characters and during the last 240 trials your positive set will contain (6, 8) characters.

When asked to, please depress the "enter" key and the first display set will appear. Again, you will be responding with either a "1" for yes, all of the characters in the positive set are represented in the display set, or a "2" for no, none or less than all of the positive set members are represented in the display set. Please respond to each of the 480 display sets as quickly as possible with no more than 5% errors.

There will be a "white-noise" maker turned on during the procedure to block out any extraneous sounds. This will sound like a television set tuned into an empty or "snowy" channel.

I will not be in the room during the procedure. When the computer no longer presents you with a display set this means the procedure is finished. At this point please find me in the next room.

Are there any questions regarding the procedure?

I am now going to leave the room and turn on the white-noise maker. When you hear the white noise please depress the enter key to initiate the procedure.