PRIMING EFFECTS IN SWITCHING ATTENTION BETWEEN WORKING MEMORY AND VISUAL PERCEPTION

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PRIMING EFFECTS IN SWITCHING ATTENTION BETWEEN

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PREFACE

The following series of experiments explored factors which influence the time required to shift attention between working memory and visual perception. I believe it is important for psychology to study switching time, as it gives one a unique empirical method for assessing the capabilities of human information processing. This study makes use of the switching time paradigm originated by Dr. Robert Weber. This paradigm is a promising means of studying attention switching and may have practical as well as scholarly value.

I wish to express my deepest appreciation to Dr. Weber for his wisdom, guidance, and encouragement. I would also like to thank the other members of my committee, Dr. Donald Fromme, Dr. Diana Byrd, and Dr. Micheal Folk for their advice and assistance. Also, special thanks go to Rick Gowdy and Kevin Polk for making the long hours spent preparing this document a little more bearable.

My wife, Della, through her love, encouragement, and steadfast support made this dream a reality. I would like to dedicate this dissertation to her, to my mother, who has always been there when I needed her, and finally, to my father.

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The time it takes to switch attention has been a topic of interest to cognitive psychologists in the last two decades because it represents a limitation on human information processing capabilities. By studying switching time and those variables which have an effect on the time required to switch attention, it is possible to gain valuable clues as to the functioning of the control processes which govern attention's focus. A number of methods have been used to study the time required to shift attention. These methods are reviewed in Appendix A. One recently developed method which holds a great deal of promise is the switching time paradigm (Weber, Blagowsky, & Mankin, 1982).

The switching time paradigm has been used to investigate switching attention between outputs of varying magnitude (Weber, Blagowsky, & Mankin, 1982; Mankin, 1983). These studies used both a method and a switching time formula which has proven to be a useful way of analyzing switching time data, and which is used in the current research. The switching time formula is as follows: Switching time = (alt - ((a+b)/2)/# of switches, where alt = time required to alternate between tasks, a = time required to do the first task only, and b = time required to do the second task only.

Analysis of switching time between inputs using the switching time paradigm has only recently been undertaken. Weber, Byrd, and Noll (1984) examined the time required to switch between working memory and visual perception. In the first experiment it took an average of about 290 msec to perform such a switch. This switching time effect was found to be impervious to practice. The second experiment varied the size of the letter lists held in working memory or processed perceptually. The results indicated that as list length increased (thus imposing a greater load on working memory), switching time also increased. In addition, longer list lengths produced a dramatic increase in errors. This suggests that switching attention in this situation may be effected by the working memory load, and that working memory and the switching process may share the same limited capacity.

Visual perception and working memory are often required in the processing of widely varying stimuli. The type of stimuli involved may affect the time it takes to execute a working memory-visual perception switch. The following experiments examined memory-perceprtion attention switching; specifically, these experiments explored how the relatedness among the stimuli held in memory and processed perceptually affects the time required to execute a memory-perceptual attention switch.

One type of relatedness that could affect a memory-perceptual attention switch is semantic relatedness. Semantic relatedness has been shown to have an affect on item recognition (Meyer & Schvaneveldt, 1973; Loftus, 1973). That is, the presentation of an item "primes" closely related items (items of the same category), making subsequent recognition of those items faster. The effect of the relatedness of stimuli in attention switching has not been determined.

Two classes of models concerning the effect of concept relatedness on processing in memory make differing predictions for attention switching. One class of models predicts a priming effect when attention is switched between closely related stimuli while the other predicts an interference effect for this same situation. One model included in the class predicting priming effects is the spatial model of semantic attention (Hutchinson & Lockhead, 1977; Lockhead, Gaylord, & Evans, 1977). This model states that attention travels through semantic space in an anolog fashion, somewhat like a spaceship traveling different distances in space; the farther separated the two concepts, the longer the travel time required. Figure 1 is a representation of the spatial model of semantic memory.

Insert Figure 1 About Here

There are other types of attention switches that have been found to operate in an analog fashion. Shulman, Remington, & McLean (1979), in an ingenious series of experiments, found support for the analog movement of attention across the visual field. Kosslyn, Ball, & Reiser (1978) found similar effects in the movement of attention across mental images. In addition, Axelrod & Powazek (1972) found evidence suggesting that the rate of switching between the ears depends on the angular separation between the sound sources, with larger angles corresponding to longer switching times.

The second model which belongs to the class of models predicting the existence of priming effects in attention switching is The spreading activation model (Collins & Loftus, 1975). According to this model, when one concept in memory is activated, this activation can spread along connections in the semantic network to other nearby concepts.

The second class of attention switching models predicting that related items may cause difficulty in switching attention includes lateral inhibition and interference explanations of memory processes. Lateral inhibition occurs most notably in vision (Naka & Witkovsky, 1972). Light enters the eye in rather diffuse patterns. The stimulation of certain cells in the retina tends to inhibit the activity of other nearby cells. This activity results in the sharp images we see in vision. Whether it occurs in processing sematic material has not been determined. Figure 2 is a representation of the lateral inhibition model.

Insert Figure 2 About Here

An interference view would maintain that related items may interfere with one another. Visually processing an item may cause confusion if a closely related item is held in working memory.

The purpose of this series of experiments was to determine the effect of the relatedness of stimuli involved in a working memory-visual perception attention switch on the time required to execute such an attention switch. In the following experiments, the relatedness of stimulus items involved in a working memory-visual perception switching situation was varied in two ways. First, the category membership of the items was varied; subjects were required to switch attention with items from a single category in both working memory and visual perception, and with items from two separate categories in memory and perception. Second, the semantically referenced size of items switched between was manipulated, such that at times the magnitude of the size difference between the items involved was either large or small.

In Experiment 1, subjects were required to perform two types of switching operations: a) within-category switching, which involves switching between items belonging to the same semantic category and b) between-category switching, which involves switching between items belonging to different semantic categories. Thus, the purpose of the first experiment was to determine which view of semantic attention switching best describes the operation of the working memory-visual perception switch. If switching within a single category is faster than switching between categories (such as switching between letters and numbers) it would be consistent with priming effects occuring in attention switching. However, if switching between categories is accomplished more rapidly than switching within a category, it would support a lateral inhibition or interference view of semantic attention switching.

This experiment employed two types of stimuli in an effort to determine which of the models most adequately accounts for switching between semantic categories in memory and perception. The stimuli vary in the nature of their semantic classes. They are: a) character stimuli, letters of the alphabet and digits and b) words. The word categories used were two of the six superordinate categories normed for typicality by Rosch and Mervis (1975). The categories selected (words, digits, and letters) were chosen to provide a broad range of categories and thereby to test the range of applicability of any switching time effects.

The pilot data suggested that the two classes of stimuli (letters/digits and words) would behave similarly in terms of switching time. If this were the result, it would support an argument for a substantial generality for switching effects between memory and perception.

However, it was possible that the two types of stimuli would bring about divergent results. If this were true, there would be a number of explanations, depending on exactly what differences presented themselves. For example, a facilitation effect might have been found in switching between similar lists when word stimuli were used, but not when character stimuli were involved. Such a result would have occured if character stimuli are organized differently in memory than word stimuli.

Experiment 1 A

Method

Subjects. Subjects were 20 undergraduate psychology students at Oklahoma State University who received extra credit for their participation. The age ranges were from 18 to 25 years, An equal number of male and female subjects were involved in the experiment.

Stimuli. Four lists of stimuli were used: two lists of character stimuli and two lists comprised of the ten most typical members of two common categories. The two character lists were as follows: 1) the first 10 nonconsecutive consonants of the alphabet (B,D,F,H,J,L,N,P,R, and T), and 2) the ten single digits (0,1,2,3,4,5,6,7,8, and 9). The two word categories were from those defined by Rosch & Mervis (1975) as explained above. The categories are clothing (pants, sweater, socks, shoes, vest, dress, coat, shirt, jacket, hat), and vehicles (car, boat, bus, trolley, train, tank, truck, raft, tractor, sled). The stimuli were presented to the subjects on a black and white video monitor by means of an Apple II computer.

Procedure. The experiment was a 2 X 2 X 4 within subjects design, with two major classes of stimuli used (characters and words), two categories of stimuli nested within each class (letters and numbers within the character class, and clothing and vehicles within the word class), and four types of trials (memory alone, perception alone, alternating within a category, and alternating between categories). There were 16 possible types of experimental trials which were randomly presented to subjects in a single block of trials. The 16 trial types are shown in Table 1. In order to calculate a switching time, three types of trials are necessary: 1) memory alone, 2) perception alone, and 3) alternating between perception and memory.

Insert Table 1 About Here

For the perception mode, the subject read perceptual information as rapidly as possible. First, the subject saw a series of three asterisks (or three groups of asterisks in the conditions using words) for a four second duration. Following this display, the screen was cleared, the computer's timer routine was started, and a second display of three stimuli (letters, numbers, vehicle names, or clothing names, depending on the condition) was presented four lines below the previous display. The subject's task was to read aloud the stimuli presented on the screen as quickly as possible, beginning with the presentation of the second display, and pressing the space bar when the task was completed. Pressing the space bar stopped the timer and recorded the time that particular trial has taken. After a three second interval, the next randomly determined trial began.

For the memory mode, the subject unloaded information from working memory as rapidly as possible. First, the subject saw a series of three stimuli for a duration of four seconds. The subject was to remember the list in order. Following this display, the screen was cleared, the timer started, and a series of asterisks were presented four lines below the previous display. As soon as the asterisk display was presented, the subject's task was to rapidly say aloud the items of the list he/she was asked to remember, pressing the space bar when finished. Again, the time it took the subject to complete the task was recorded.

In the alternating trials, the subject alternated between information in perception and in memory as rapidly as possible. First, the subject was presented a series of three stimuli for a four-second duration. The subject was instructed to remember the list in order. Following this display, the screen was cleared, the timer started, and another series of three stimuli was presented four lines below the first. The task was to alternate saying one stimulus item from the perceptual list (the second display, which remained on the screen) and then one item from the memory list (the first display) as quickly as possible until the subject had said aloud all six stimulus items for that trial. The subject was to press the space bar when the task was completed. Again, the time it took for task to be completed was recorded.

The following is an example of the alternating mode, character stimuli, within-category condition. If a subject were presented the letters L N P in the first list, followed by B D F in the second list, the correct response would be B-L-D-N-F-P. Subjects were instructed to always start with the first stimulus item of the second display. Stimulus items in the first display were never duplicated in the second display, and the character stimulus items were never mixed with the word stimulus items.

Each trial was scored for errors during its execution. A strict criterion was used. A trial was considered an error if a nonappearing stimulus item was added, if a stimulus item was omitted, or if any of the items were said out of sequence.

Subjects were required to sort the word stimuli into two categories to insure that the categories used were discernable to the subjects. All subjects were able to successfully sort the stimuli into the appropriate categories.

Results and Discussion.

Figure 3 displays the switching time results for character and word stimuli calculated using the switching time formula. The major result of the first experiment is that within- category switching takes less time to execute than between-category switching. An analysis of variance was performed on the data, involving 4 stimulus types (letters, numbers, clothing, and vehicles) X 2 switching conditions (within-category and between-category) X 2 stimulus classes (words and characters) X 2 sexes. Significant interactions were observed for stimulus class X switching condition, $F\ (1,18) = 11.39$, $p < .0034$, and stimulus type in memory X switching condition, $F\ (2,36) = 5.07$, $p < .0115$.

Insert Figure 3 About Here

Simple effects tests were also conducted. The two types of switching conditions were found to be significantly different for word stimuli, $F(1,36) = 40.14$, $p < .01$, but not for character stimuli, $F(1,36) = 3.49$, $p < .10$. A similar analysis for each stimulus type in memory found the switching conditions significantly different for clothing in memory, $F(1,54) = 40.14$, $p < .01$, and for vehicles in memory, $F(1,54) = 10.59$, $p < .01$, but not for letters in memory, $F(1,54) = 2.41$, $p < .25$, or for numbers in memory, $F(1,54) = 2.29$, $p < .25$. In other words, only when word stimuli were involved were the switching times for within category and between category switching significantly different. The analysis of variance is summarized in Table 2, and the simple effects tests in Table 3.

Insert Table 2 And

Table 3 About here

The switching time differences found for within-category switching and between-category switching provide support for those models which predict that switching between items belonging to the same category should be more rapid than switching between items from different categories. The spatial model of semantic memory makes such a prediction; if attention travels through semantic space in an analog fashion, travel time between more closely related items should be less than the travel time required between less related items.

Another view of memory processes which explains the results is the spreading activation model. According to this view, attention directed at one item in a category may raise the activation level of other nearby items, thus priming them for subsequent retrieval. Priming would be expected to occur to a greater extent in within-category switching than in between-category switching.

A major disadvantage of the current study is its inability to discriminate between these two models. This drawback is not unique to the current study. Meyer and Schvaneveldt (1971), for example, discuss the difficulty involved in experimentally distinguishing a location-shifting model of priming from a spreading activation model of priming. Both types of models account equally well for the body of research done on priming effects.

Insert Table 4 About Here

The results cannot be attributed to a speed-accuracy trade-off. Correlation coeficients were calculated between the number of errors committed in a condition and the mean performance time per item for that condition. The correlation coeficients are displayed in Table 4. No significant positive or negative correlations were observed, nor was any pattern discernable. If a negative correlation had been found, it might have indicated that subjects attempted to adjust their pace because of the possibility of making an error.

Differences for within-category and between-category switching were found for character stimuli as well. However, these diffferences were not significant. One possible explanation for this lack of a significant effect for character stimuli is that letters and numbers may be stored more closely together than words from different semantic categories. Thus, these two types of character stimuli may have behaved much as though they were members of the same category.

In Figure 3, when comparing the switching times for the numbers in memory and letters in memory for both within-category and between-category switching, it is evident that the letters in memory condition takes longer for each type of switching. Newmann-Kuel's Multiple Range Tests find the two stimuli in memory conditions significantly different for both types of switching, C.diff = 65.55, $p \leq .05$. This may be the result of a memory load effect. Letters have been found to take up more space in working memory than numbers (Cavanaugh, 1978). An increase in working memory load may bring about an increase in switching time, as found in Weber, Byrd, and Noll (1984).

For the word stimuli in the within- category alternating conditions, a Newmann-Kuel's test found the difference for switching between two lists of clothing and two lists of vehicles is not significant, C.diff = 65.55, $p > .05$. In the between-category alternating condition, however, when clothing is held in memory and vehicles processed perceptually, switching times are 70.92 msec slower than when the positions of the stimuli are reversed. A Newmann-Kuel's test found this difference to be significant, C.diff = 65.55, $p < .05$. It is doubtful that a memory load effect accounts for this difference, because one would expect such an effect to appear in the within category conditions as well. Some type of interference effect may be responsible, but its exact nature has not been determined.

No significant gender effects were found in the analysis of the switching time data.

Insert Figure 4 About Here

Figure 4 displays the mean performance times per item for the memory alone, perception alone within-category alternating, and between-category alternating conditions. The mean performance times are the raw scores which are used to calculate switching times. A 4 X 4 X 2 X 2 analysis of variance, consisting of four stimulus types (letters, numbers, clothing, and vehicles), four modes of presentation (memory alone, perception alone, within-category alternating, and between-category alternating), two stimulus classes (words and characters), and two sexes, was performed on the mean performance times per item for all cells in the design. Table 5 summarizes the results of this analysis. Significant interactions were observed for stimulus class X mode of presentation, $F(3,54) = 5.07$, $p < .0038$, and for stimulus type X mode of presentation, $F(6,108) = 4.39$, $p < .0005$. No gender effects were observed in this analysis, and the observed effects accounted for .28 of the total variance.

Insert Table 5 About Here

Simple effects test were conducted to find the differences involved in the interactions. Mode of presentation was found to be significant for character stimuli, $F\ (3,108) = 52.08$, $p < .01$. Subsequent Newmann-Kuel's tests demonstrated that for character stimuli, only the within- category and between-category alternating conditions are not significantly different, C.diff = 38.9, $p > .05$. These conditions are shown in Figure 4. This is not surprising, in light of the fact that when switching times are calculated, the two conditions are not significantly different.

For word stimuli, the perception alone trials and the within-category alternation trials, shown in Figure 4, are the only modes of perception not significantly different from one another, C.diff = 38.9, $p > .05$. A number of factors combines to make these two conditions statistically equivalent. More processing time was added to the perception alone conditions as compared to the within-category alternating condition in that the perception alone condition required six items to be visually processed, in comparison to three for the within-category alternating condition. However, switching time from working memory to visual perception was added to the time required to complete the within-category alternating condition. Evidently, the effects of these factors balanced each other in such a way as to make the two conditions statistically equivalent.

Insert Table 6 About Here

Simple effects tests found word and character stimuli to be significantly different for all modes of presentation. These simple effects tests are included in Table 6. This effect can clearly be seen in Figure 4, when comparing the conditions using clothing and vehicle stimuli to those using letters and numbers. This makes intuitive sense, as word stimuli are more complex and have a much larger set of possible responses than character stimuli. In addition, a number of disyllabic words were included in the study, which made responses in the conditions using words take longer.

Figure 4 shows the difference between perception alone and memory alone trials is about 70-80 msec. per item. A Newmann-Kuel's test demonstrated that this differnce is significant, C.diff = 38.9, $p < .05$. This difference probably occurs because an extra processing step must be accomplished in the perception alone trials, namely item recognition. For the memory condition this step occur when the items are first exposed, before the asterisks cue retrieval and start the timer in the memory trials.

Experiment 1 B

One question of interest is what effect practice will have on the category switching effects found in the first experiment. Weber, Blagowsky, and Mankin (1982) found that speech intensity switching is remarkably impervious to practice. At issue is whether semantic categories, as employed in Experiment 1 A, are also impervious to practice, or whether the semantic system is more flexible or plastic in its organization. It may be that repeated switching between concepts may effect the storage of those concepts in such a way as to facilitate subsequent switching. This process might occur in one of two ways: a) memory structures may be altered such that the semantic distance between the concepts is lessened, or b) the links between concepts may be "strengthened" such that one can more easily move attention from one concept to the other. If either view is accurate, one would expect the category effects found using words in experiment 1 A to dissipate with practice. It may also be the case that memory structures are more permanent in regard to attention switching. In this case, the category switching effects may withstand repeated practice.

Experiement 1 B is designed to study the effect of practice on switching attention between working memory and visual perception.

Method

Subjects. Two subjects, graduate students from the psychology department at Oklahoma State University, were involved in the experiment.

Procedure. The procedure was the same as in Experiment 1 A, except that the subjects were involved in three experimental sessions held on three consecutive days, with each session consisting of 160 trials (10 trials per condition).

Results and Discussion.

Switching times were calculated for the alternating conditions. The switching time results are included in Figures 5 and 6, and mean performance time results are displayed in Figures 7 and 8.

Insert Figure 5 and

Figure 6 About Here

Because of the small number of subjects involved, no statistical tests of significance were calculated for the data.

The results of the experiment failed to completely replicate the effects found in the first experiment, even on the first day of testing. It is difficult to make definite conclusions based on two subjects, especially in light of the large amount of variability in this particular task, as evidenced in the large standard deviations found in Experiment 1 A. The examined effects accounted for only 28% of the total variance, and it may be this high amount of variability which accounts for the inability to demonstrate the category switching effects when only two subjects were involved.

Because of this inability to replicate the results of the first experiment, the current findings do not provide clear evidence as to the effect of practice on the category switching effect. An experiment using a larger number of subjects is necessary to answer this question.

When word stimuli were involved, three of the switching conditions show an increase in time per character on the second day of testing, as shown in Figure 5. A notable exception is the condition in which vehicles appear in both memory and perceptual lists. The behavior of this fourth switching condition differs from the pattern exhibited by the other three, for reasons which are not clear.

The increase in performance time per character on the second day, coupled with decreases in the times for the memory and perception alone conditions, causes a large jump in switching time for word stimuli on day 2, as seen in Figure 6. There are a number of possible explanations for the increases seen in mean performance time for the three switching conditions. It could be that subjects were less motivated on the second day of testing. The sessions involved 45 minutes of intense concentration. With such a task, a lull in concentration in the middle session would not be surprising. However, if this were the explanation, one might expect to see comparable increases in performance times for the alone conditions, which is not the case.

Another explanation is that subjects experimented with various strategies on the second day of testing, in an attempt to make the switching task more manageable. After becoming acquainted with the task on the first day, subjects may have attempted to find ways to decrease the cognitive load imposed by the switching task. For example, subjects may have attempted to use various mnemonics to remember the items presented in the memory lists. Regardless of the explanation, in general it seems to take longer for subjects to show improvement with practice in the switching conditions as compared to the memory or perception alone conditions.

Insert Figure 7 And

Figure 8 About Here

The results for the character stimuli resemble the results of Experiment 1 A even less than do the word stimuli results. The non-significant differences between the two types of category switching are not evident in this experiment, as seen in Figures 7 and 8. Figure 8 does show evidence of the memory load effect noted in the first experiment; switching conditions with letters held in memory take longer than those with numbers held in memory.

The character stimuli also show an increase in switching time on the second day of testing. This result is consistent with that discussed earlier for word stimuli.

EXPERIMENT 2

The stimulus materials used in Experiment 1 differed in their category membership: character classes vs. word classes. In Experiment 2, the stimulus materials differ on an analogic dimension, semantically referenced size. What effects on switching time, if any, occur when there is switching between words referencing similar or different sizes? There are a number of studies which suggest that physical properties such as size or length have an effect on processing rates. For example, Moyer (1973) asked subjects to judge the relative size of animals from memory. He found that such comparisons are of an analog nature; judgements involving animals which are more similar in size (such as a wolf and a lion) took longer than judgements involving animals which were less similar in size (such as a moose and a roach). Moyer found a size-distance effect in the sense that a fairly linear relationship exists between processing time and the logarithm of the estimated difference in animal size.

This linear relationship seems to hold for a wide variety of stimuli and situations. Paivio (1975) demonstrated the same effect for a variety of stimuli other than animals. Johnson (1939) found the same relationship between processing time and similarity in perceptual comparisons of line lengths. This relationship is even present in the comparison of abstract qualities (Banks and Flora, 1977).

One conclusion which can be drawn from these studies is that information concerning physical and abstract qualities of items held in memory is represented or modeled in the memory structures holding those items. The way in which items are held in memory effects the processing of the items. One explanation for this size-distance effect is that some form of lateral inhibition of processing is occuring when closely related items are processed. It may be that the activation of one item inhibits the processing of other nearby items.

An interesting question is whether the same sort of inhibitory effects are seen in switching attention between working memory and perception. The lateral inhibition and interference views of attention switching predict just such results: When switching between items which are similar and thus stored more closely, switching should take longer because of the inhibitory effect that the activation of one item has on nearby items.

The spatial model of semantic memory and the spreading activation models predict exactly the opposite effect. According to these models, switching attention between less similar items should take longer.

Experiment 2 examined the effect of the physical relatedness of items held in working memory and processed perceptually on the time required to switch attention between working memory and visual perception. Two lists of animals served as stimuli: a list of large animals and a list of small animals.

There are three meaningful outcomes possible for this experiment: 1) switching between animals of similar size may be faster than switching between animals of less similar size (a priming effect), 2) switching between animals of similar size could have taken longer than switching between animals of less similar size (a lateral inhibition or interference effect), or 3) the size manipulation may not have affected this type of attention switching because the information is available independently of the item's size.

If switches of attention between animals similar in size are executed faster than switches between animals less similar in size, it would suggest the existence of priming effects in within-category switching based on similarity in semantically referenced size. This result would be consistent with items being stored in memory based on their relative similarity, including size, to other items in memory.

If attention switches between less physically similar items are executed more quickly than those between more physically similar items, support would be found for the lateral inhibition or interference model of attention switching. In the lateral inhibition view, if physically similar items are stored more closely than physically dissimilar items, and if the activation of an item inhibits the processing of nearby items, then one would predict longer switching times for more physically similar items. In interference terms, physically similar items may cause interference in working memory storage.

Experiment 2 A

Method

Subjects. Subjects were 20 undergraduates from psychology classes at Oklahoma State University, who received extra credit for their participation. The age range was from 18 to 25, and an equal number of male and female subjects participated.

Stimuli. Two name lists of ten animals each were used in the experiment. The lists consisted of the ten largest and ten smallest mammals from a list of 176 items compiled by Paivio (1975), which were subject-rated for size. The two lists were as follows: 1) large animals (lion, horse, cow, camel, elk, bear, moose, giraffe, rhino, zebra), and 2) small animals (mouse, rat, squirrel, rabbit, skunk, cat, fox, beaver, raccoon, and monkey).

Procedure. The experiment was a 2 X 4 within subjects design, involving two animal sizes (large and small), and four conditions (memory alone, perception alone, alternating within one animal size, and alternating between two different animal sizes. The eight types of trials are represented in Table 7.

Insert Table 7 About Here

Memory alone, Perception alone, and alternating trials progressed in the same fashion as described in Experiment 1. Each trial was scored for errors as it was executed; the definition of an error remained the same as in the first experiment.

A sort task was undertaken to confirm that subjects could classify the animal stimuli as to size. Subjects were asked to arrange the animal names on cards from smallest to largest. All subjects placed the small animals in the first group of ten animals, and the large animals in the second group of ten animals.

Results and Discussion.

Figure 9 displays the switching time results for the within-size and between-size switching conditions. Figure 10 shows the mean performance times per item for all conditions. The results are clear-cut; the more disparate in size that items are, the longer it takes to execute a working memory-visual perception switch. A 2 X 2 X 2 analysis of variance, involving two switching conditions (within-size and between-size), two animal sizes in memory (large and small), and two sexes, was performed on the calculated switching times. The analysis of variance indicated that the between-size and within-size switching conditions are significantly different from one another, $F(1,18) = 14.84$, $p<.0012$. Table 8 summarizes the results of the switching time analysis. In addition, a 2 (animal sizes) X 2 (sexes) X 4 (modes of presentation) analysis of variance was performed on the mean performance times for all conditions. A significant effect was found for mode of presentation, $F(3,54) = 23.96$, $p<.0001$. A Newman-Kuel's test revealed all comparisons between modes of presentation to be significant, C.diff = 48.3. Table 9 displays the analysis of the mean performance times.

Insert Table 8, Table 9,

And Table 10 About Here

As in the first experiment, the existence of a speed-tradeoff was tested for by calculating a correlation coefficient between the number of errors committed in each condition and the mean performance time for that condition. No significant negative correlations were observed, the type of correlation which one would expect if a speed-accuracy tradeoff existed. One positive correlation was found, in the perception alone conditon for large animals, indicating that when errors were made in this condition, mean performance time increased. The correlation coeficients are shown in Table 10.

Insert Figure 9 And

Figure 10 About Here

The results shown in Figures 9 and 10 may be explained if size is a dimension which determines the location of items in memory storage. In this case, items more similar in size may be stored more closely together in semantic space. If attention travels through space in an analog fashion, as suggested by the spatial model of semantic attention, the travel time for attention would be less the more closely related in size the two items are. Thus, the results of this experiment are consistent with those of the first experiment.

A multi-dimensional scaling study by Rips, Shoben, and Smith (1973) using bird and mammal names as stimuli, seems to suggest that size may well be one of the dimensions by which items are organized in memory. The maps of conceptual space created by the procedure clearly show the items arranged by size on one axis, and by a ferocity dimension on the other axis.

As in the first experiment, a spreading activation model would also account for the results. If items similar in size are stored more closely together in memory, activation may spread from initially presented items to other related items, allowing subsequent items to be accessed more easily.

At first glance, the results of this experiment seem inconsistent with the results of mental size compasrison studies. These studies find a size disparity effect, such that the more similar in size two items are, the longer it takes for subjects to tell which is larger. However, the two situations are quite different. Kosslyn, Murphy, Bemesderfer, & Feinstien (1977) found that size comparisons of objects closely related in size often involve the generation of a mental image of the items in question. Such a step is time consuming, probably accounting for the size disparity effects found in mental size comparison studies, and is not necessary is switching attention between working memory and visual perception. Interestingly, Kosslyn et al. found that size comparisons of objects from different categories take longer than size comparisons of objects from the same category. This result is consistent with the findings of both Experiment 1 A and this experiment.

As in the first experiment, no significant gender effects were observed. The observed effects accounted for .28 of the total variance.

Experiment 2 B

As in the Experiment 1, the possibility exists that any switching effects found may be modified by practice. It is possible that the structure of memory may be changed by repeated attention switching between items such that subsequent attention switching between those items is accomplished more rapidly. In order to investigate this possibility, Experiment 2 B was conducted, involving repeated experimental sessions with two subjects. This experiment explores the effect of physical similarity on working memory-perceptual switching, when such a switch is well practiced.

Method

Subjects. Two subjects, graduate students from the psychology department at Oklahoma State University, were involved in the experiment.

Procedure. The procedure was the same as in Experiment 2 A, except that the subjects were involved in three experimental sessions held on consecutive days.

Results and Discussion.

As in Experiment 1 B, no statistical tests of significance were performed, because of the small number of subjects. The results of this experiment indicate that with practice, the differences between the various switching conditions become much smaller.

The switching time results are shown in Figure 11. On the first day of testing, the results are similar to those found in Experiment 2 A, with between-size switching taking longer than within-size switching. The results of the third day of testing show a difference of 58 msec between the fastest and slowest switching condition.

The mean performance time per item results displayed in Figure 12 show the same trend. On the first day of testing, large differences exist, especially when comparing the within-size alternating condition using large animal stimuli to the other three conditions. By the third day, all four switching conditions are within a 60 msec. range.

Insert Figure 11 And

Figure 12 About Here

The results shown in Figures 11 and 12 may indicate that as subjects become more practiced, they are able to rearrange memory structures in such a way as to make the size variable less of a factor. Requiring one to switch between the <u>same</u> twenty items may eventually cause the storage of those items to be modified such that these items are stored more closely in semantic space. Another possiblity is that the links between the various items are "strengthened" by repeated switching, such that subsequent switching between those concepts is accomplished more quickly.

Again, as in Experiment 1 B, one must be cautious about making conclusions based on two subjects. This is especially true in this case, as a great deal of variability seems to be involved in the task. This paradigm seems particularly vulnerable to the effects of "noise" in practice effects studies. Excessive variability in either of the switching conditions, the perception alone conditions, or the memory alone conditions can cause large changes in the switching times for a particular subject. As discussed earlier, the most sensible control for this problem is the use of more subjects in such studies.

Interestingly, three of the four switching conditions increased in switching time on the second day of testing. Figure 12 reveals that, unlike the results for switching conditions in Experiment 1 B, the mean performance times did not increase, but remained virtually the same for these three conditions. The increase in switching time occurs because the mean performance times for the memory and perception alone conditions show improvement on the second day, and when entered into the switching time formula, yield larger switching times. As in Experiment 1 B, the switching conditions generally take more practice to show improvement than do the various alone conditions.

GENERAL DISCUSSION

Two experimental procedures were used to explore the effect of the relationship of stimuli involved in switching attention between working memory and visual perception. The major finding was that priming effects occur when word stimuli in working memory and visual perception are from the same semantic category. An important issue is the locus of the priming effect. Figure 13 represents the current task in the form of a hypothetical flow chart.

Insert Figure 13 About Here

One step in which priming is most likely to occur is the visual recognition process (step 3). Attention is concentrated on at least one of the memory items just prior to the execution of this step. If the memory items are from the same category as the items to be visually processed, the stage is set for some sort of priming. Of course, if the memory items are not from the same category, a priming effect would not be seen.

In fact, a priming effect occuring in the processing of visually presented stimuli has already been found in a number of studies. Loftus (1973) asked subjects to produce a member of a category and a short time later produce a different member of the same category. Loftus found a 300 msec. facilitation effect when responses were preceded by other members of the same category. Meyer and Schvaneveldt

(1973) have also shown that it is easier to retrieve information from memory if related concepts have been accessed a short time previously.

A second possible locus of priming effects is step 5, in which the subject finds the appropriate item held in working memory. This raises a question: Can an item already in working memory be primed, such that it is available more quickly for processing? It may be that once an item is at the threshold of activation which makes it available to working memory, additional activation only serves to maintain it at that threshold. However, it may also be the case that additional activation allows the concept to be more easily retrieved and processed in working memory.

The question of priming effects in working memory has implications for the structure of working memory. The existence of such effects would support the notion that working memory consists of concepts in long-term memory which have been raised in activation to a certain critical level. Views of working memory as a seperate buffer would not explain priming effects in working memory similar to those which occur in retrieving information from long-term memory. Further research involving attention switching may increase our understanding of the structure of working memory.

The two models of priming presented in this study differ in their views of how facilitation occurs. The spatial model of semantic memory has an active explanation of priming in that the facilitation of retrieval is due to the action of the retrieval mechanism. This view is somewhat similar to the retrieval of data stored on magnetic tape. The focus of retrieval can only be directed at a single location at any one time. It takes a finite amount of time to move that focus from one location to another, and the farther separated the items to be retrieved, the longer it takes to access the information.

On the other hand, the mechanism for priming in spreading activation is more passive; it does not lie in the actual movement of the attention's focus through semantic space. Rather, priming is based on the conduction of activation along the links in the conceptual network, which raises the resting activation level of concepts.

The two models are similar in that they both assume a network memory structure, such as that proposed by Anderson & Bower (1973). In such networks, concepts are represented as nodes which are linked together in various ways, depending on their relationship to one another.

It is interesting to speculate on the possible practical applications of switching ability. Kahneman has demonstrated that tests of the ability to selectively attend to stimuli can be predictive of a number of practical skills (Gopher and Kahneman, 1971; Kahneman, Ben-Ishari, and Lotan, 1973). Kahneman and his associates, using a dichotic listening task, were able to predict with a fair degree of accuracy the flight performance of cadets in the Israeli Air Force and the accident rate of bus drivers.

The test used in these studies was a dichotic listening task. The dependent variable obtained was errors committed. In contrast, the tasks used in the current study yields a direct estimate of the time required to switch attention. These task yield a measure which should be much more sensitive to individual differences. They may have promise as a measure of the efficiency of the human central processor and, as such, may have predictive ability for a wide range of activities.

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Table 1

Sixteen Trial Types Used in Experiment 1 A

Trial Type	Stimulus Class			
	Characters		Words	
Alone Trials				
Memory Mode	Letters*	Numbers	Clothing	Vehicles
	***	***	***	***
Perception Mode	***	***	***	***
	Letters	Numbers	Clothing	Vehicles
Alternating Trials				
Within-Catgeory	Letters	Numbers	Clothing	Vehicles
	Letters	Numbers	Clothing	Vehicles
Between-Catgeory	Letters	Numbers	Clothing	Vehicles
	Numbers	Letters	Vehicles	Clothing

* Top list - memory, Bottom list - percpetion

Table 2

Analysis of Variance Summary Table. Experiment 1 A.

Switching Time.

Source	df	MS	F	p F
Mode	1	265279.8	29.94	.0001
Mode X Sex	1	11562.5	1.31	.2683
Subj(Sex) X Mode	18	8859.4		
Class	1	5342.1	.65	.4297
Class X Sex	1	6635.3	.81	.3798
Subj(Sex) X Class	18	8183.3		
Stim(Class)	2	74542.9	7.09	.0025
Stim(Class) X Sex	2	13178.4	1.25	.2977
Subj(Sex) X Stim(Class)	36	10514.9		
Sex	1	97754.1	1.92	.1829
Subj(Sex)	18	50949.4		
Class X Mode	1	78623.8	11.39	.0034
Class X Mode X Sex	1	1413.8	.20	.6562
Subj(Sex) X Class X Mode	18	6902.2		
Stim(Class) X Mode	2	22094.8	5.07	.0115
Subj(Sex) X Stim(Class) X Mode	36	10514.9		

Table 3

Analysis of Variance Summary Table. Experiment 1 A.

Simple Effects Tests. Switching Time.

Source	df	MS	F	p F
Mode at Class				
Mode at Char	1	27531.2	3.49	.10
Mode at Word	1	316372.4	40.14	.01
Error	36	7880.8		
Mode at Stim				
Mode at Letter	1	14121.1	2.41	.25
Mode at Number	1	13414.7	2.29	.25
Mode at Clothing	1	298511.3	50.96	.01
Mode at Vehicles	1	62046.2	10.59	.01
Error	54	5858.2		
Class at Mode				
Class at Between	1	62477.3	8.28	.01
Class at Within	1	21488.6	2.85	.10
Error	36	7542.7		
Stim at Mode				
Stim at Between	2	119914.3	16.1	.01
Stim at Within	2	73361.1	9.87	.01
Error	72	7436.3		

Table 4

Experiment 1 A. Correlation Coefficients for Errors and Mean Performance Times.

	Stimulus Class			
Trial Type	Words		Characters	
	Clothing	Vehicles	Letters	Numbers
Memory Alone	-.10*	.31	-.29	.07
	.68	.17	.21	.78
Perception Alone	-.03	-.06	.06	.38
	.89	.80	.80	.09
Within-Catgeory	.09	.40	-.04	-.14
Alternating	.71	.08	.86	.55
Between-Category	.01	-.18	.01	-.13
Alternating	.96	.46	.97	.59

*Top number- Correlation Coefficient, Bottom number- Level of Significance.

Table 5

Analysis of Variance Summary Table. Experiment 1 A.

Mean Performance Times.

Source	df	MS	F	p F
Mode	3	12714062	30.87	.0001
Mode X Sex	3	541312	1.31	.278
Subj(Sex) X Mode	54	411807		
Class	1	25362627	94.92	.0001
Class X Sex	1	178085	.67	.4249
Subj(Sex) X Class	18	267191		
Stim(Class)	2	793161	7.97	.0014
Stim(Class) X Sex	2	54936	.55	.5805
Subj(Sex) X Stim(Class)	36	99506		
Sex	1	1137	0	.99
Subj(Sex)	18	7546871		
Class X Mode	3	712663	5.07	.0038
Class X Mode X Sex	3	44535	.32	.8149
Subj(Sex) X Class X Mode	108	140563		
Stim(Class) X Mode	6	613811	4.39	.0005
Stim(Class) X Mode X Sex	6	123875	.89	.5072
Subj(Sex) X Stim(Class) X Mode	108	139673		

Table 6

Analysis of Variance Summary Table. Simple Effects Tests. Experiment 1 A. Mean Performance Time.

Source	df	MS	F	p F
Mode at Class				
Mode at Char	3	14384104	52.08	.01
Mode at Word	3	25896071	93.76	.01
Error	108	276185		
Mode at Stim				
Mode at Letters	3	12372258	53.7	.01
Mode at Numbers	3	3586357	15.57	.01
Mode at Clothing	3	18661247	81	.01
Mode at Vehicles	3	9343182	40.55	.01
Error	162	230384		
Class at Mode				
Class at Memory	1	4661542	27.07	.01
Class at Perception	1	6857379	39.82	.01
Class at Within	1	2742039	15.92	.01
Class at Between	1	13239654	76.88	.01
Error	72	172219		
Stim at Mode				
Stim at Memory	2	173243	1.34	.5
Stim at Perception	2	186428	1.43	.25
Stim at Within	2	1829748	14.12	.01
Stim at Between	2	3079770	23.76	.01
Error	144	129631		

Table 7

Eight Trial Types Used in Experiment 2 A

Trial Type	Animal Size	
Memory Mode	Large*	Small
	***	***
Perception Mode	***	***
	Large	Small
Within-Size	Large	Small
Alternating	Large	Small
Between-Size	Large	Small
Alternating	Small	Large

*Top list - memory, Bottom list - perception

Table 8

Analysis of Variance Summary Table. Experiment 2 A. Switching Time.

Source	df	MS	F	p F
Mode	1	128304.7	15.12	.0011
Mode X Sex	1	4059.2	.48	.4980
Subj(Sex) X Mode	18	8484.6		
Stim	1	92.6	.01	.9275
Stim X Sex	1	3562	.33	.5741
Subj(Sex) X Stim	18	10866.9		
Sex	1	193560.8	3.08	.0964
Subj(Sex)	18	62898.7		
Mode X Stim	1	1328.3	.21	.6542
Mode X Stim X Sex	1	20003.1	3.12	.0941
Subj(Sex) X Mode X Stim	18	6404		

Table 9

Analysis of Variance Summary Table. Experiment 2 A.

Mean Performance Time.

Source	df	MS	F	p F
Mode	3	9853014	23.96	.0001
Mode X Sex	3	876548	2.13	.1055
Subj(Sex) X Mode	54	411270		
Sex	1	1795481	.57	.4619
Subj(Sex)	18	3177051		
Stim	1	128451	.85	.3683
Stim X Sex	1	167043	1.11	.3066
Subj(Sex) X Stim	18	150853		
Mode X Stim	3	9646	.08	.9656
Mode X Stim X Sex	3	103348	.85	.4743
Subj(Sex) X Mode X Stim	54	121392		

Table 10

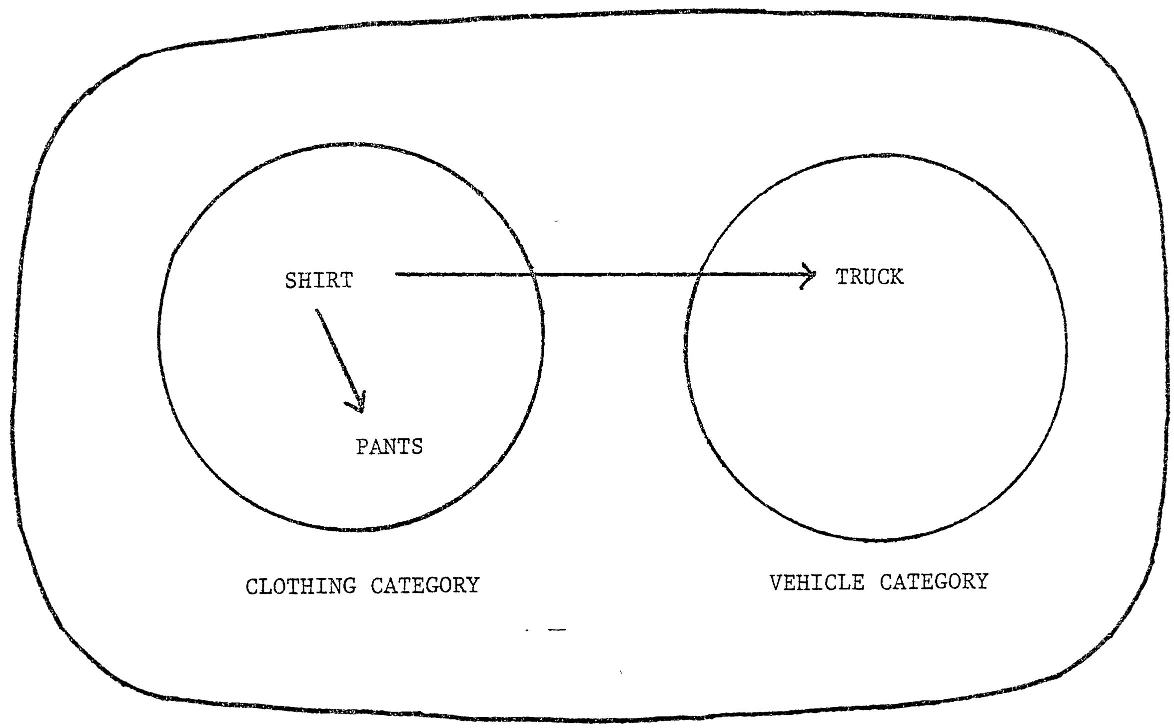
Experiment 2 A. Correlation Coefficients for Errors and Mean Performance Times.

Trial Type	Animal Size: Small	Large
Memory Mode	-.18*	.27
	.44	.25
Perception Mode	.07	.53
	.77	.01
Within-Size	.21	.20
Alternating	.38	.39
Between-Size	.02	-.08
Alternating	.93	.74

*Top number - Correlation Coefficient, Bottom Number - Level of Significance.

Figure Caption

Figure 1. The spatial model of semantic memory as it relates to switching within category and between categories. Attention has more distance to travel when switching between categories.



MEMORY

Figure Caption

Figure 2. The lateral inhibition model in regard to within-category and between-category switching. Activation of a concept inhibits processing of nearby concepts, slowing within-category switching.

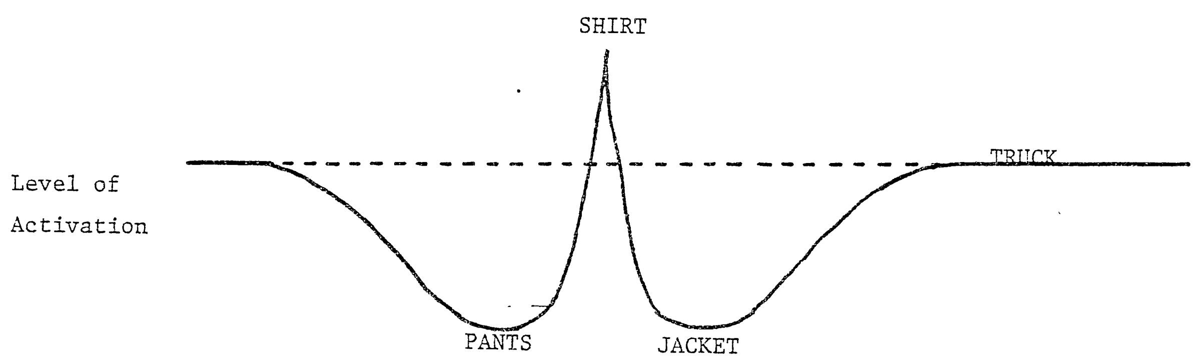
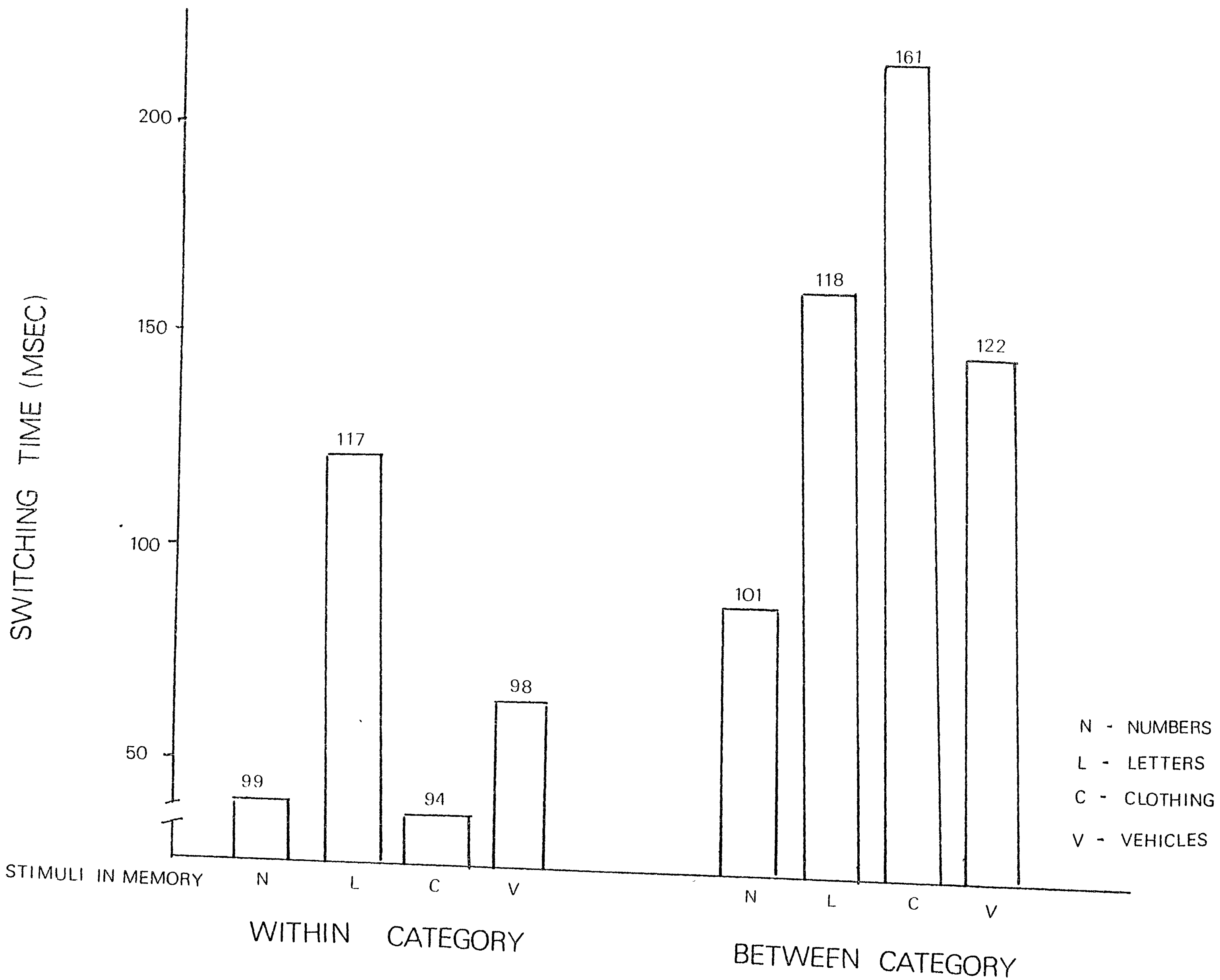

SHIRT
TRUCK
Level of
Activation
PANTS
JACKET

Figure Caption

Figure 3. Experiment 1 A. Switching times for within-category and between-category switching conditions.



SWITCHING TIME (MSEC)
200
150
100
50
99
117
94
98
101
118
161
122
STIMULI IN MEMORY
N
L
C
V
N
L
C
V
WITHIN CATEGORY
BETWEEN CATEGORY
N - NUMBERS
L - LETTERS
C - CLOTHING
V - VEHICLES

Figure Caption

Figure 4. Experiment 1 A. Mean performance times per item for memory, perception, within-category alternating, and between-category alternating conditions.

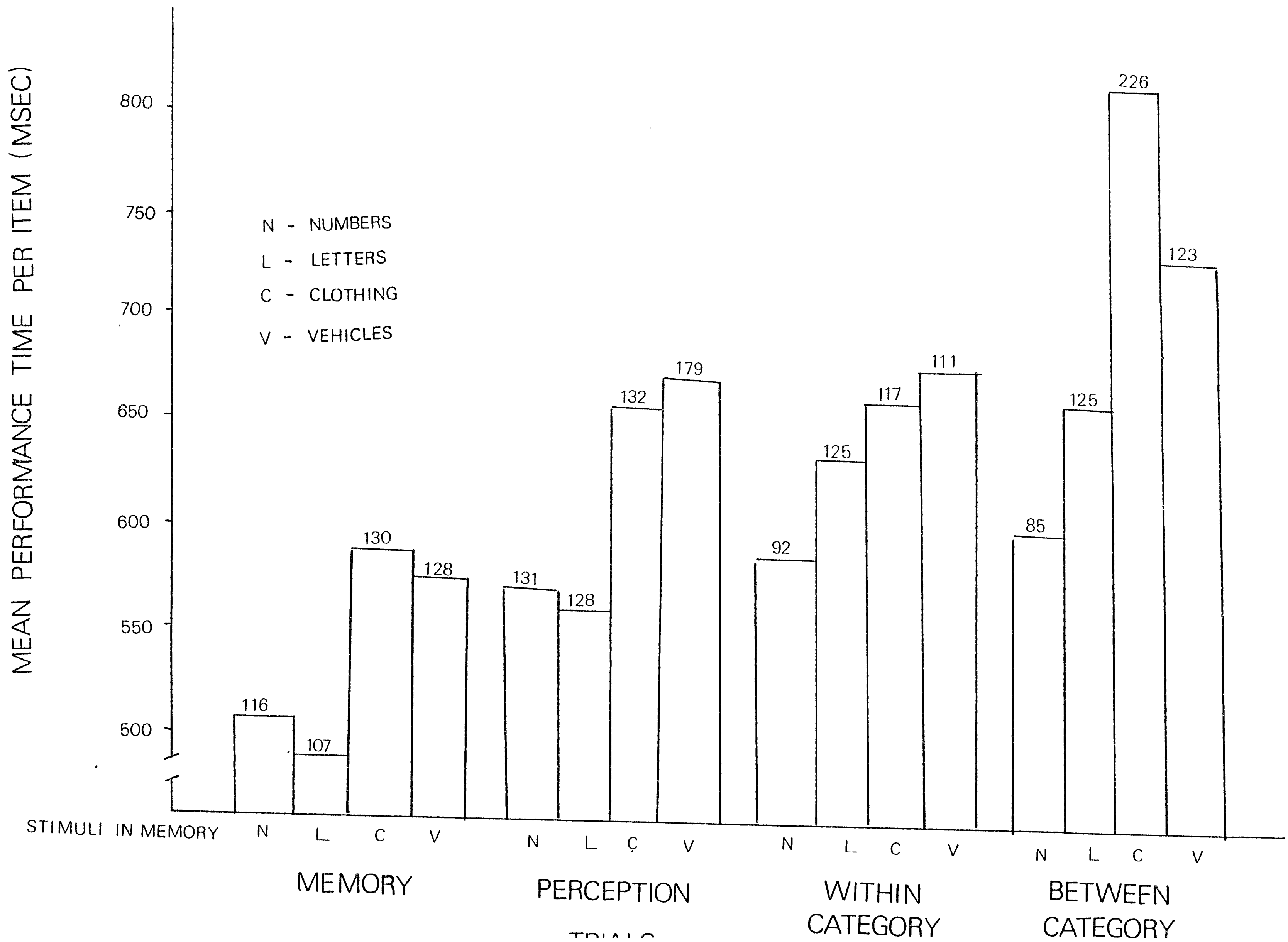
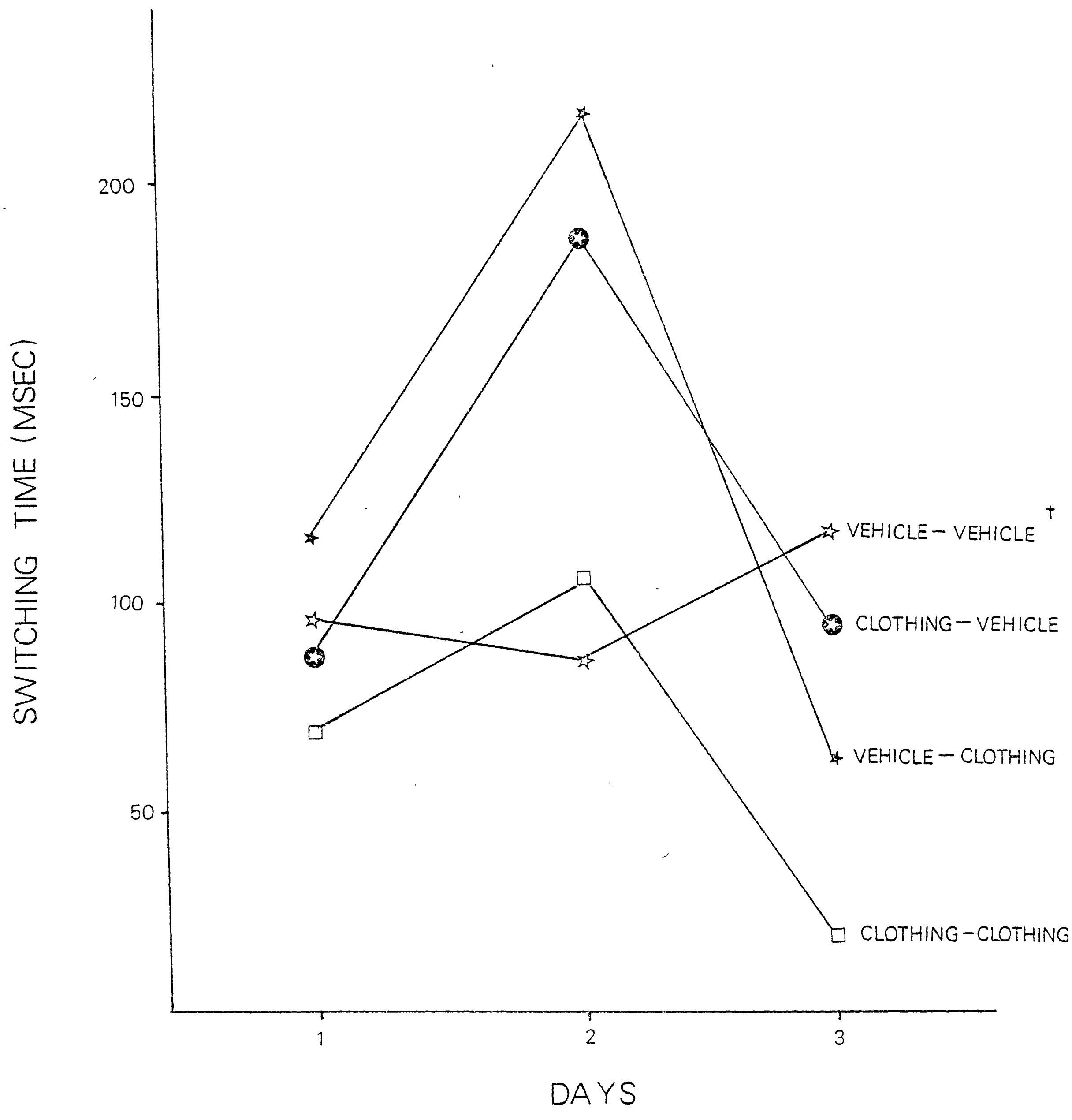

MEAN PERFORMANCE TIME PER ITEM (MSEC)
800
750
700
650
600
550
500
N - NUMBERS
L - LETTERS
C - CLOTHING
V - VEHICLES
116
107
130
128
131
128
132
179
92
125
117
111
85
125
226
123
STIMULI IN MEMORY
N L C V
N L C V
N L C V
N L C V
MEMORY
PERCEPTION
WITHIN CATEGORY
BETWEEN CATEGORY

Figure Caption

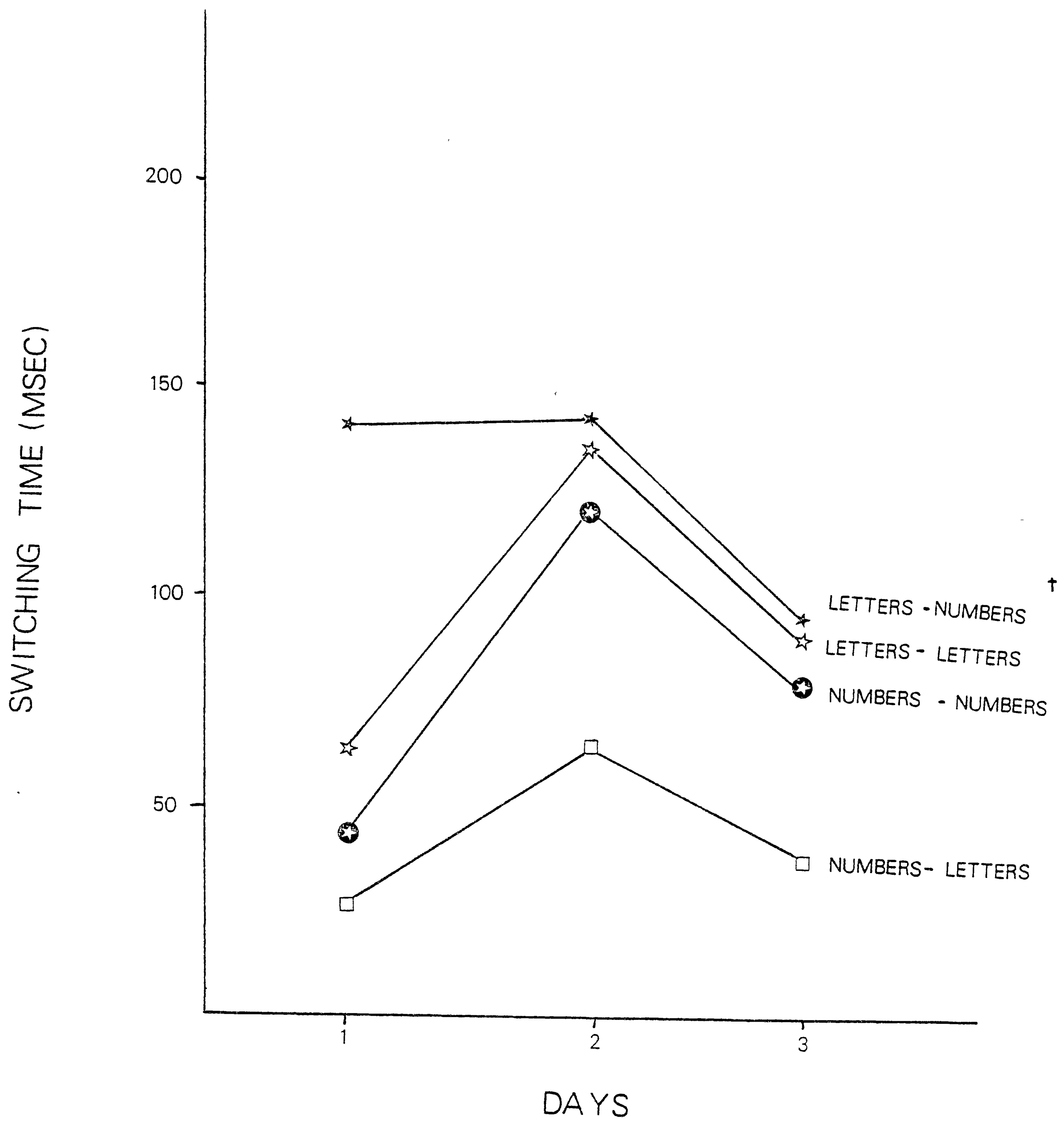
Figure 5. Experiment 1 B. Switching times for within and between category switching conditions using word stimuli, measured across three sessions.



†CONDITIONS LISTED AS FOLLOWS: MEMORY LIST–PERCEPTION LIST

Figure Caption

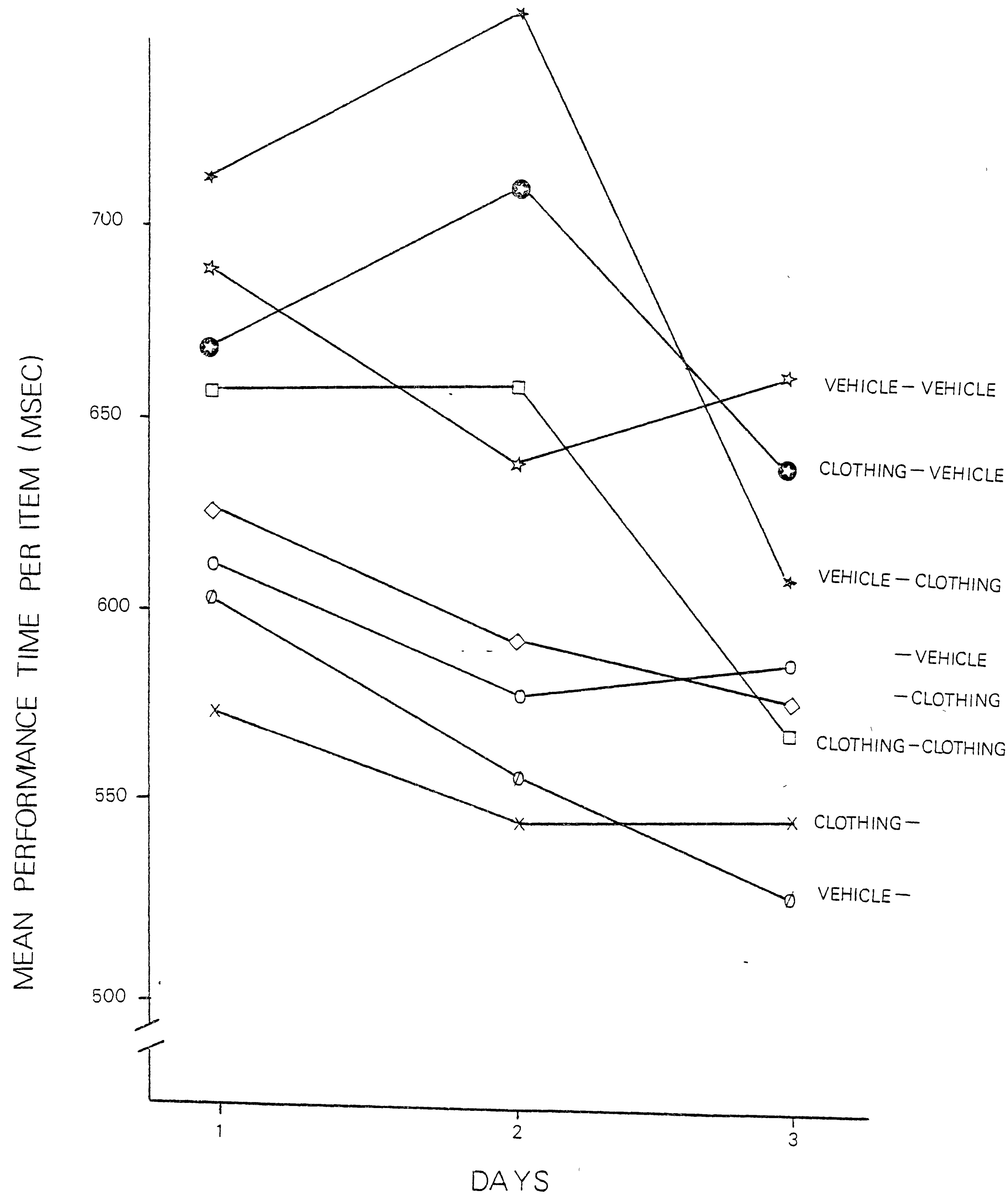
Figure 6. Experiment 1 B. Switching times for within category and between category switching conditions using character stimuli, measured across three sessions.



† CONDITIONS LISTED AS FOLLOWS: MEMORY LIST–PERCEPTION LIST

Figure Caption

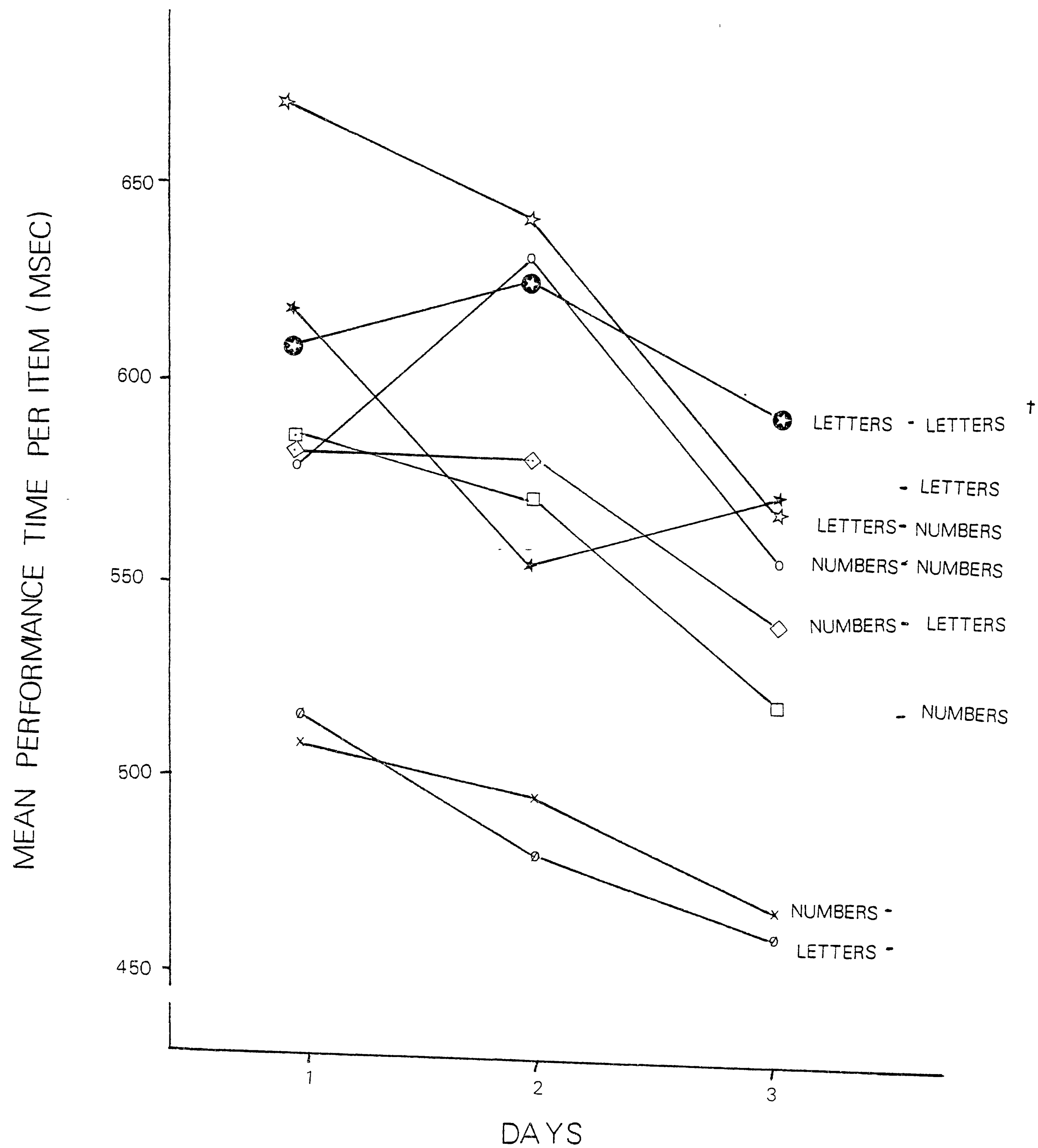
Figure 7. Experiment 1 B. Mean performance times per item for conditions using word stimuli, measured across three sessions.



†CONDITIONS LISTED AS FOLLOWS: MEMORY LIST—PERCEPTION LIST

Figure Caption

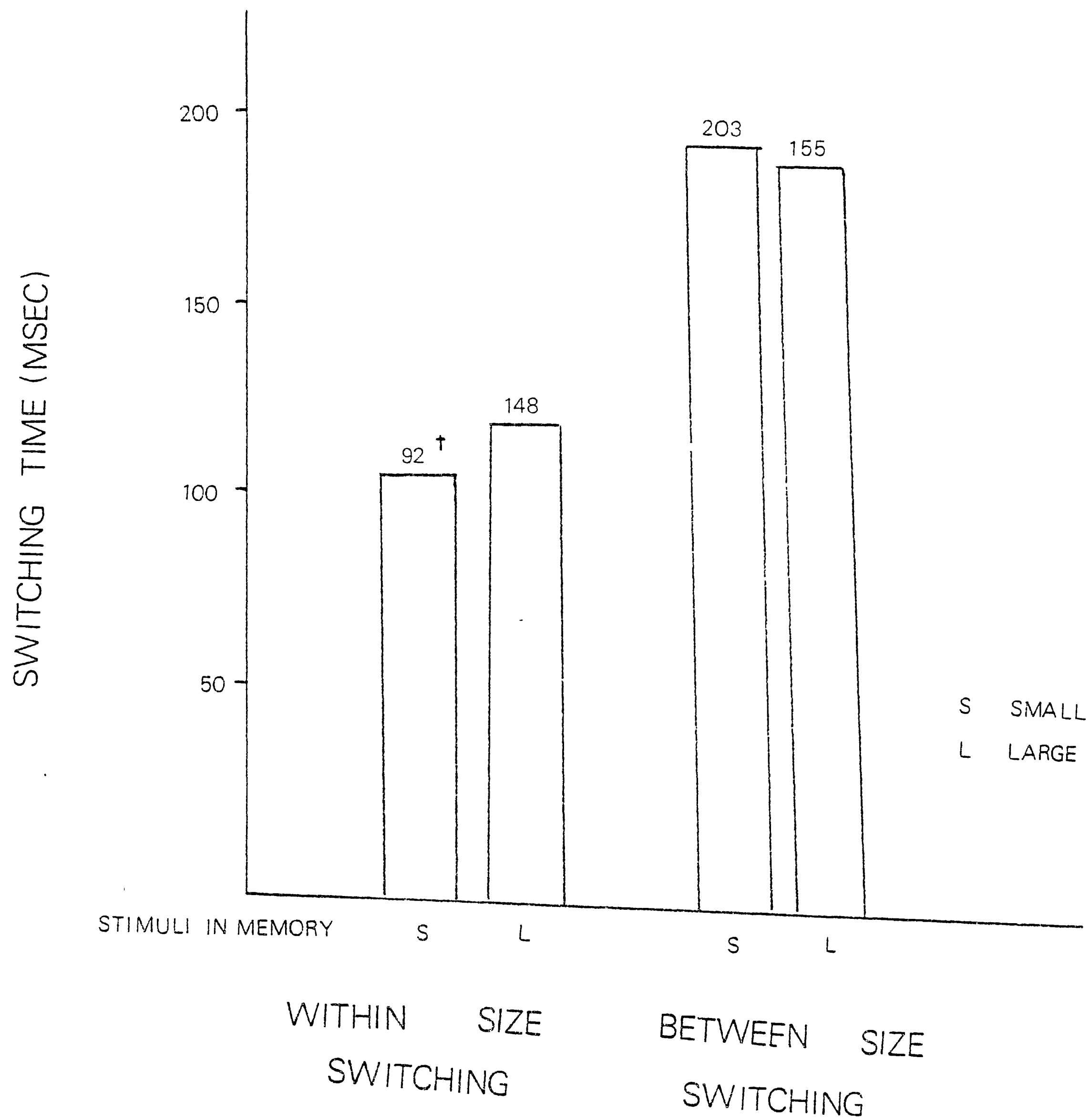
Figure 8. Experiment 1 B. Mean performance times per item for conditions using character stimuli, measured across three sessions.



†CONDITIONS LISTED AS FOLLOWS: MEMORY LIST–PERCEPTION LIST

Figure Caption

Figure 9. Experiment 2 A. Switching times for within size and between size switching conditions.



†STANDARD DEVIATION

Figure Caption

Figure 10. Experiment 2 A. Mean performance times per item for memory mode, perception mode, and alternating modes.

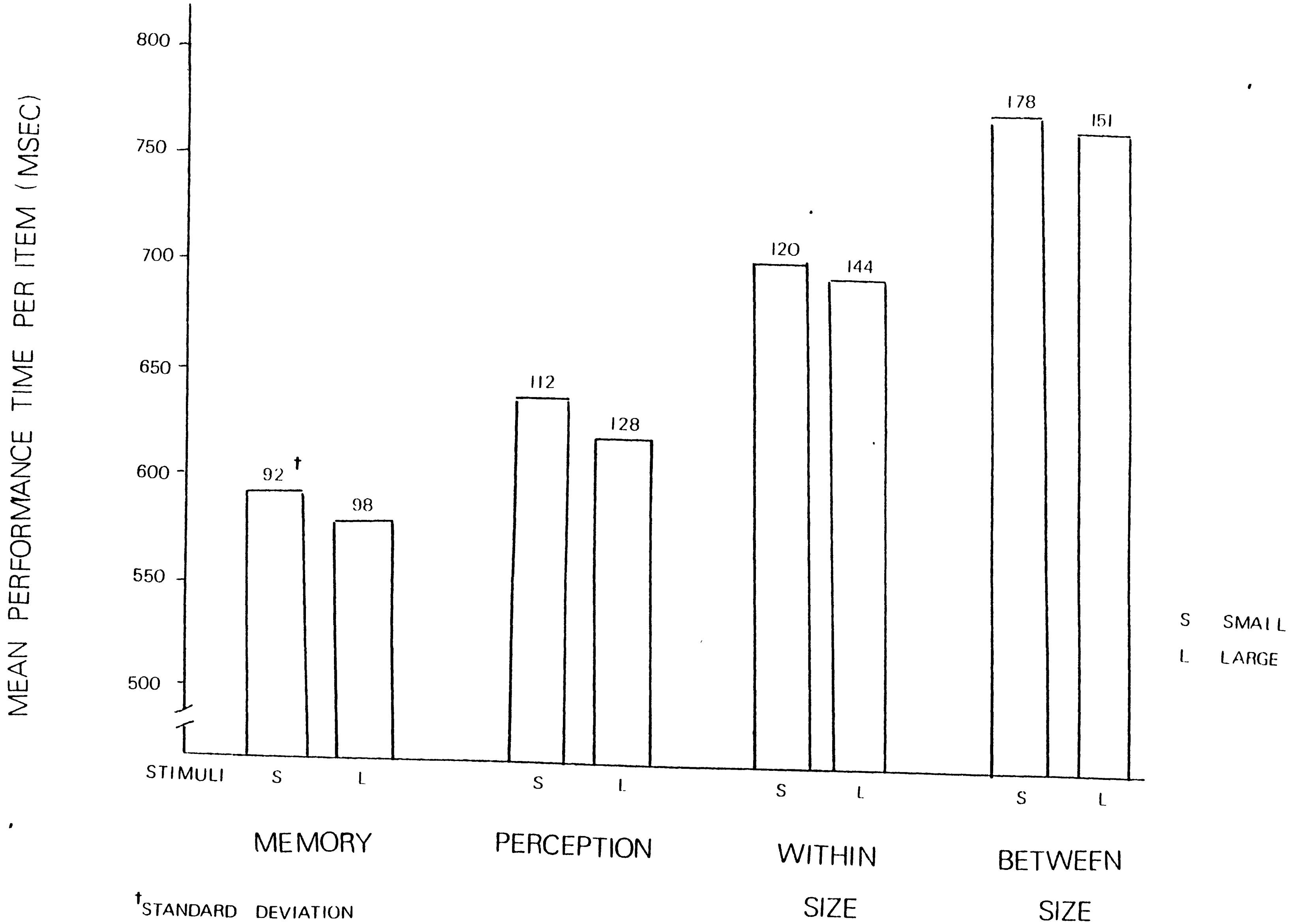

MEAN PERFORMANCE TIME PER ITEM (MSEC)
800
750
700
650
600
550
500
92 †
98
112
128
120
144
178
151
STIMULI
S
L
S
L
S
L
S
L
MEMORY
PERCEPTION
WITHIN SIZE
BETWEEN SIZE
S SMALL
L LARGE
†STANDARD DEVIATION

Figure Caption

Figure 11. Experiment 2 B. Switching times for within size and between size switching conditions, measured across three sessions.

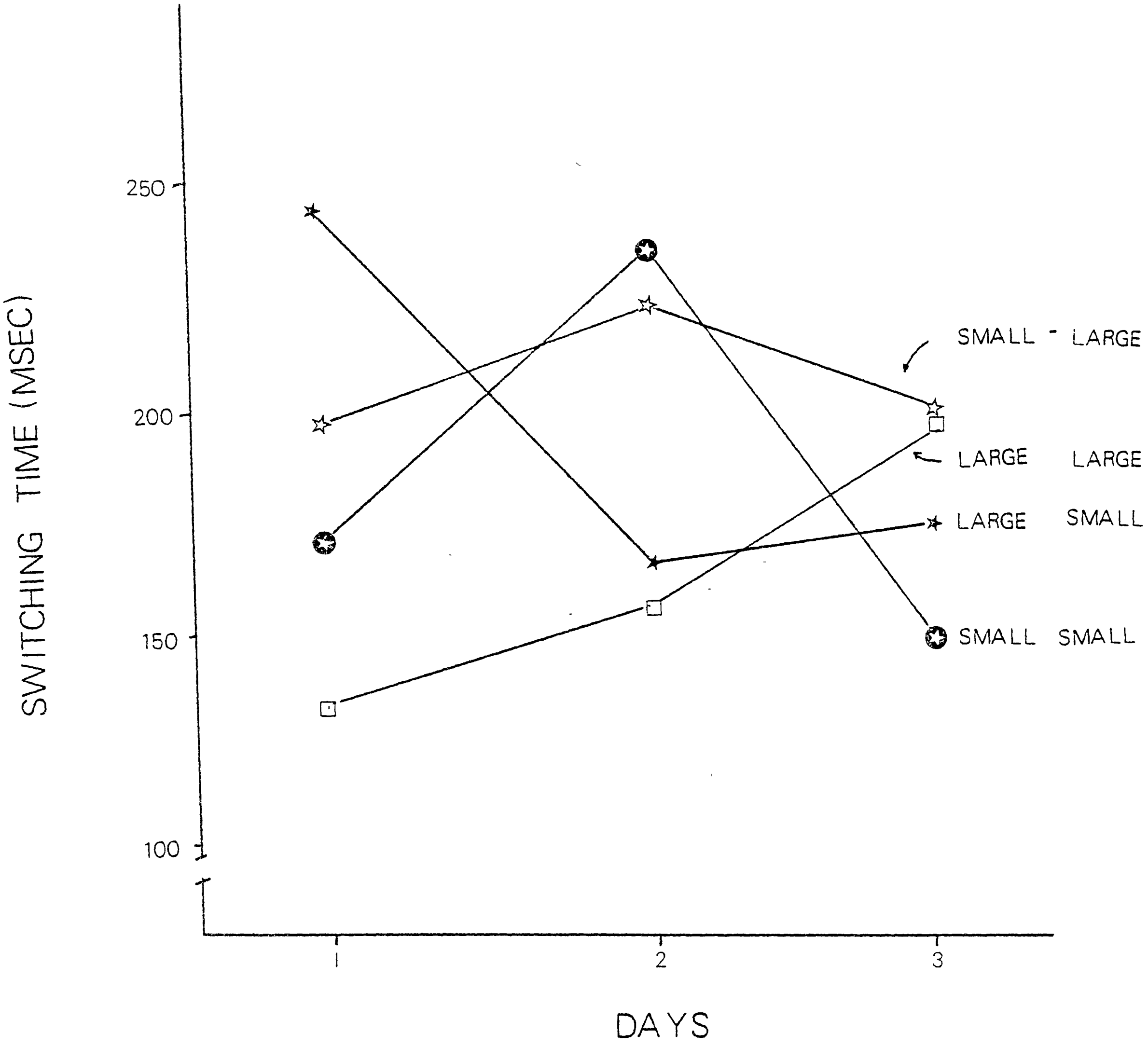
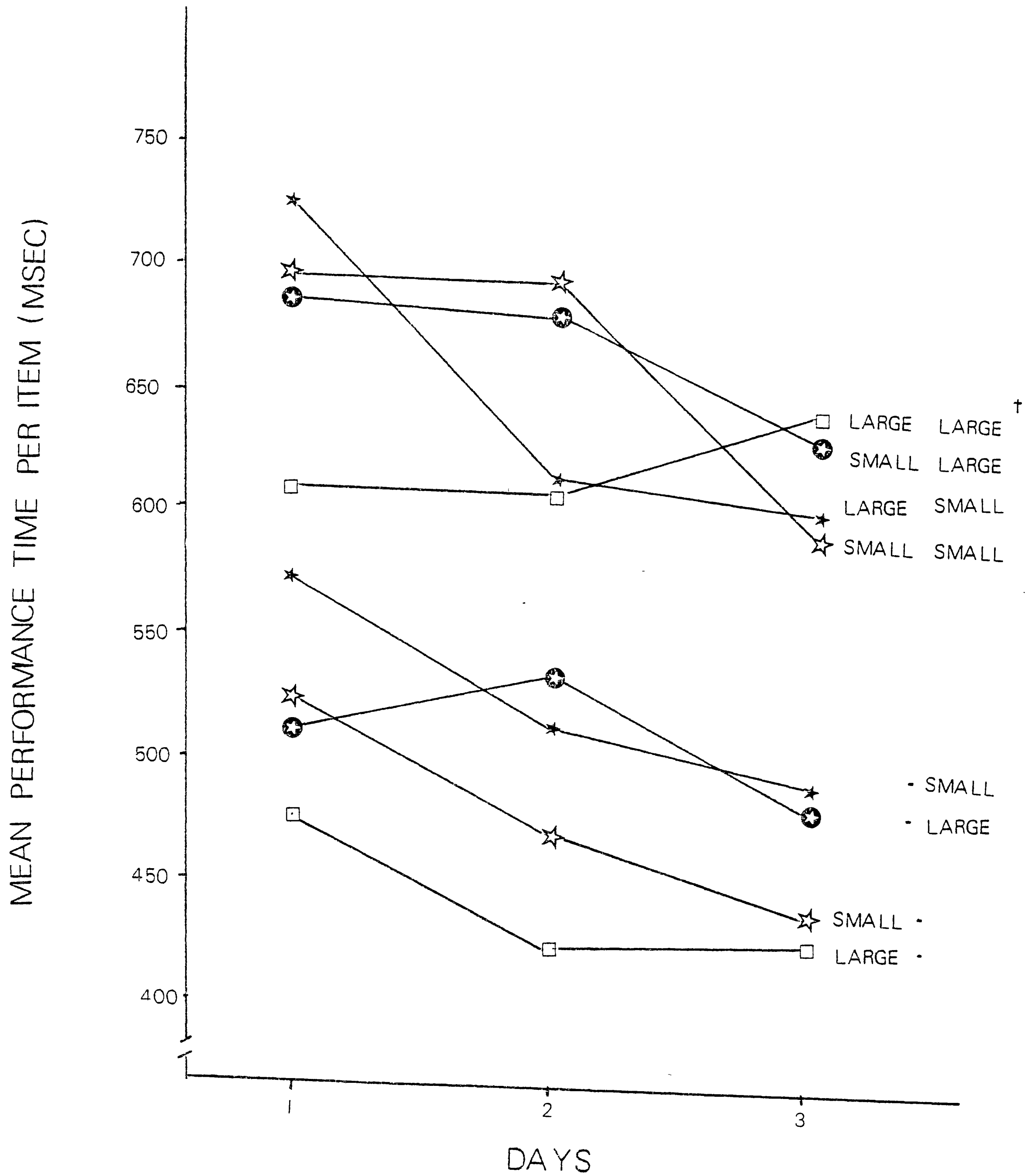

SWITCHING TIME (MSEC)
250
200
150
100
SMALL - LARGE
LARGE LARGE
LARGE SMALL
SMALL SMALL
1
2
3
DAYS

Figure Caption

Figure 12. Experiment 2 B. Mean performance times per character for memory mode, perception mode, and alternating modes, measured across three sessions.



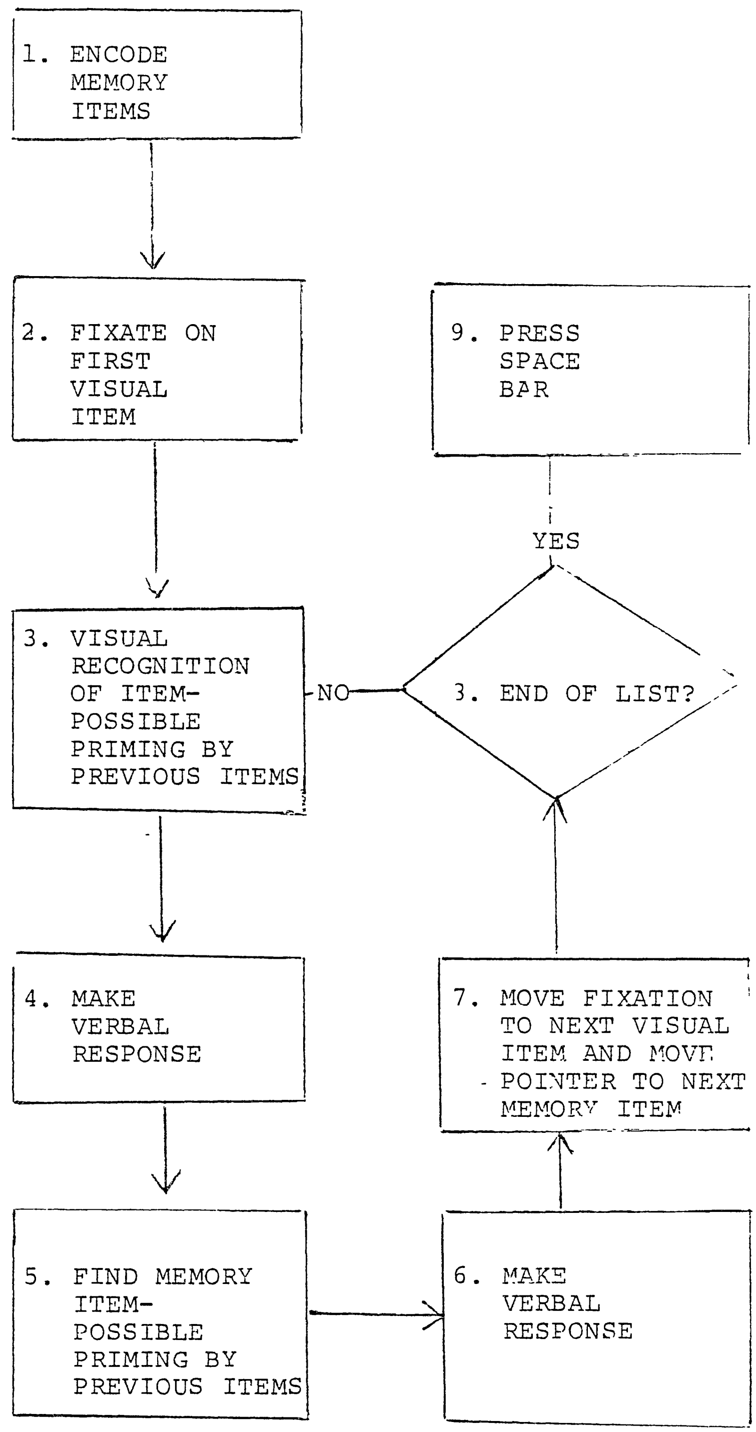
†CONDITIONS LISTED AS FOLLOWS: MEMORY LIST–PERCEPTION LIST

Figure Caption

Figure 13. Hypothetical flow chart of the steps involved in the working memory-visual perception switching task.

PRESENTATION OF MEMORY ITEMS

PRESENTATION OF VISUAL ITEMS



APPENDIX A

LITERATURE REVIEW

Historical Overview of Attention Theory

The purpose of this section is to provide a brief historical overview of attentional theory, and in particular, to refer to the developments of attention theory which relate to attention switching. This is to provide a background for the discussion of various experimental paradigms used to study the time it takes to switch attention.

Posner (1982) states that attentional theory has shown a cumulative development over the last 100 years. This cumulative development is evident in that many of the basic assumptions used in the study of attention switching come from the empirical findings of past researchers.

For example, Helmholtz (1852) discovered that mental operations are slow enough to allow study, when he demonstrated that the rate of nerve conduction is only around 100 meters per second. Wundt (1912) found that two mental events occuring closely in time are handled in a successive manner. Wundt's findings provide a basis for study of attention switching in two respects: They suggest that attentional capacity is of a limited nature, and that when two operations are undertaken which overload this capacity, these operations are often performed successively. Welch (1898) added the idea that the interference produced on one task by another concurrent task could be used to study the common capacity required by the two tasks. This idea has been used in the study of attention shifts, especially in dichotic listening tasks.

Donders (1869) devised a scheme for studying the time it takes various stages of mental processes to be performed. Donders assumed that mental processes are organized into a series of stages. he attempted to measure the length of a processing stage by his subtractive technique. Donders constructed tasks which differed in that one of the tasks contained an extra stage of processing. By subtracting the processing time of the task without the extra stage of processing from the task containg that stage, Donders believed that the time required to complete that stage of processing could be measured. Although the subtractive method had several flaws, such as the assumption of strict serial processing, and the fact that inserting a processing stage may alter the entire structure of the task (Woodworth, 1938), Donders' attempt to study the time taken by various mental acts was an important step in the development of attentional theory.

Although the groundwork for the study of attention switching had been laid prior to 1920, attention theory was essentially dormant until the 1950's. During this period, behaviorism dominated psychology, and the emphasis on stimulus-response laws and the prohibition against studying unobservable components of behavior did not allow for the exploration of internal cognitve processes. According to Chase (1978), part of the reason for the decline of behaviorism was its inability to account for findings concerning the limits of human performance. New ideas were required to explain selective attention, limited attentional capacity, and attention switching.

Posner (1982) states that another important event in the development of attentional theory was the generation of a language by which the ideas of early researchers could be brought together into a systematic analysis of attention. This general language has been called information processing, and it developed from advances in telephone engineering and computers. According to Posner, the language of information processing provides a vehicle for the discussion of computational operations at every level of the system, from processing a series of letters into a meaning to the processes occuring at individual synapses.

In the 1950's, with the decline of behaviorism and the development of information processing concepts, the stage was set for the development of attention theories. Broadbent (1958) proposed one the first models of attention, based largely on an information-processing analysis of dichotic listening tasks. Dichotic listening involves the simultaneous presentation of different stimuli to the two ears (a discussion of the dichotic listening paradigm in relation to attention switching is presented in the next section). The experiments conducted by Broadbent and others (Cherry, 1953; Cherry & Taylor, 1954) showed that individuals are limited in their ability to process information. To account for these limitations, Broadbent proposed a filter model. Broadbent theorized that humans have a limited capacity perceptual channel, and can accept input from only one source at a time. The input channels leading into the single perceptual channel were selected between by means of a switch. This switch is located at the "bottleneck" formed by the junction of sensory input channels, and thus theories of this type have been referred to as bottleneck theories.

In terms of attention switching, Broadbent's filter model was quite limited. According to this model, attention switching occurred only at the junction of sensory input channels. Thus, attention could only be switched between those various input channels.

Broadbent's filter model could not explain some of the experimental effects being found in dichotic listening research. For example, Moray (1959) found that subjects would often hear their own names on the channel they were not attending to. In addition, Triesman (1960) found that if a meaningful message alternated back and forth between the ears, subjects often followed the meaningful message rather than attending to a single ear as they had been instructed. To account for the new data, Triesman proposed an attentuation model (Triesman, 1960). This model was also a bottleneck theory, but with the bottleneck placed at the pattern recognition stage, rather than the sensory input stage. Triesman proposed a filter which did not block out competing stimuli, but merely attentuated it, making it less likely to be heard. Messages from unattended channels did get through, and would be recognized if the recognition threshold for the particular message was exceeded. Each concept was assumed to have a different threshold, depending on its permanent threshold level (one's own name would be assumed to have a permanently low threshold), and temporary lowering of a threshold based on the listener's expectations.

The model proposed by Deutsch & Deutsch (1963), and elaborated by Norman (1968) places the bottleneck a later stage of processing, after perception has already occurred. Most stimuli are perceived, but many are quickly forgotten. Selection is based on the strength and the importance of the processed stimuli.

In terms of attention switching, Trieman's attentuation model and the Deustch-Norman model provided somewhat more flexibility to the switching mechanism than did Broadbent's filter model. Although switches of attention were still assumed to be solely between input channels, the basis for the attention selection process was expanded in these theories. Attention could be switched based on the semantic properties of the stimuli, instead of basing the attention switch simply on what channel was to be attended to.

A new conceptualization of the attention process was provided by Moray (1967). Moray likened the attention mechanism to a limited capacity processor of information. Earlier viewpoints, such as those of Broadbent, Triesman, and Norman, had pictured attention as a limited capacity channel. The distinction between these two views had a great effect on the type of attention theories proposed. The limited capacity channel view is the underlying conceptualization in bottleneck theories; at some point, the information processing system narrows, so that only a small amount of information can be processed at any one time.

One difficulty with this view of attention was discovering the location of the bottleneck. Some data seemed to suggest that the bottleneck occurred during perception (Broadbent, 1958; Triesman, 1971), while other data seemed to suggest that it occurred after perception (Lewis, 1970; MacKay, 1973; Corteen & Wood, 1972).

In contrast, attention as viewed as a limited capacity processor inplies that the capacity of attention can be allocated in a number of different ways, depending on the demands of the task. The individual can flexibly alter his or her internal self-programming to handle tasks in a variety of ways. Thus, the question of where the bottleneck occurs is no longer relevent; the individual may have the ability to place the bottleneck caused by limited capacity at whatever stage of processing is most compatible to the task at hand. Theories of attention which emphasize the allocation of the limited capacity of the central processor are referred to as capacity theories.

Johnston & Heinz (1978) proposed a variation on bottleneck theories which also contained the flexibility of capacity theories. They theorize that the individual has control over where the bottleneck in attention will occur. The later in processing selection of input to be attended to occurs, the more the capacity required.

Kahneman (1973) proposed a capacity model of attention. which assumed that the individual has a great deal of control over how the limited capacity of attention is allocated. Which activities are given capacity depends on the goals of the individual and whether or not the activity is one which involutarily demands attention. An interesting assumption of this theory is that processing capacity changes with the level of arousal. Capacity follows the inverted "u" shaped curve defined by the Yerkes-Dodson law; moderate levels of arousal yield the largest attentional capacity.

Capacity theories of attention assume a much more flexible role for the attention switching process. Since capacity can be flexibly altered to suit the demands of the situation, switching may take more or less capacity. It may be that concurrent tasks or other types of memory load have some effect on attention switching, if the switching process is subsequently allocated less capacity. The speed at which attention is switched may depend on the capacity demands of the situation.

Paradigms Used To Study Attention Switching

The following section describes the various types of experimental paradigms used to study the time it takes to switch attention. Results of studies using the various paradigms will be described, and advantages and disadvantages of each paradigm will be discussed.

The Dichotic Listening Paradigm- One of the earliest and most used schemes for studying selective attention in general, and switching processes in particular, was the dichotic listening, or shadowing paradigm. These familiar studies involved subjects listening to two distinct channels of information presented to the ears at various rates and in various sequences. Sometimes, the subjects were instructed to "shadow", or subvocally repeat, the items presented on one channel. Typically, however, in experiments studying switching time, the subjects were instructed to try to retain as much information from the two channels as possible. Since the subjects were attempting to monitor two channels of information at once, it was assumed that subjects would have to switch back and forth between the channels. The dependent variable typically used in such switching experiments was the percentage of items correctly recalled. The use of this dependent measure makes it difficult, but not impossible, to make inferences about the attention switching process; it is hard to draw conclusions about switching time from this paradigm, since no measure of that time is directly assessable through the task.

It was dichotic listening tasks that first started speculation that switching attention may take a finite ammount of time. Two series of experiments conducted in the early 1950's suggested the existence of switching time. Broadbent, a pioneer in attention theory, explored factors which influence item recall of simultaneous presentations to the two ears (Broadbent, 1954, 1956c, 1957a). Broadbent (1954) found that recall is a more natural (and effective) process in a dichotic situation when subjects recalled items which were presented to one ear, then recalled items presented to the other ear. This single ear strategy was much easier, even though it meant recalling some items out of temporal sequence. It was as though items were stored according to which ear they entered, and that switching attention between these two stores took more effort than simply recalling the all the items presented to one ear, then recalling all the items presented to the other. Broadbent postulated that two factors may account for this type of result: 1) subjects are unable to perceive the dichotically presented items simultaneously, and 2) subjects have difficulty rapidly switching attention back and forth between the ears.

The second early study which suggested the existence of switching time was conducted by Cherry & Taylor (1954). They alternated a single speech message between the ears at varying rates using an electronic switch. They found that intelligibility of the speech message dropped sharply at about 2.5 hz switching rate. One possible explanation was that this rate represented the point at which the attention switching mechanism could no longer keep up with the switches of the message.

A number of studies extended the findings of the early dichotic listening experiments beyond audition. Broadbent (1954c) found similar effects in switching between the eyes and ears. In addition, Sampson (1964) found that switching attention between the eyes (a very unnatural situation) seemed to involve some cost in terms of items recalled. It was concluded that attention switching could be responsible for such a loss of information.

Later experiments cast doubt on these early results, and questioned whether attention switching accounted for the drop in intelligibility when one was forced to rapidly switch attentional channels to follow a message (Moray, 1960; Savin, 1967). Savin, for example, found that subjects still prefer to group successive classes of items rather than simultaneously presented items of different classes, even when such items were presented to the same ear. It may be, however, that attention switching of a different sort, between classes of items, may have accounted for these results. If subjects were required to listen to two seperate classes of inputs, it may take time to switch attention between the two classes, making successive recall of each class a less effortful and more natural operation.

Broadbent continued his explorations of phenomena suggesting the existence of a finite switching time. Broadbent & Gregory (1961) found that having subjects switch sensory modalities in an alternation task makes that task more difficult. In alternating recall of items between vision and hearing, subjects recalled items more poorly than when recalling them grouped by vision or hearing. This deficit occurred even when item presentation was not simultaneous, suggesting that the cross-modality switching process may be more time consuming than switching within the same modality.

Triesman (1971) performed a series of experiments which strongly suggested the existence of a finite switching time in attention. She found that the recall of digits presented alternately to the ears was more difficult than successive presentation to one ear and then the other. The difficulty in recall increased as the item presentation rate became more rapid, which is exactly what would be expected if attention switching were causing the drop in items recalled. Triesman concluded that since presentation rate effected the recall of items, the difficulties in recalling items were located in the selection of input items to be attended to. She framed her results in terms of an attentuation model, stating that input from one channel (or even one type of attribute) may be attentuated or inhibited while the other occupies the capacity of the processor. This selective attentuator must be reset, which takes time, hence, brings about switching time.

Meanwhile, other investigators using the dichotic listening paradigm were expanding our understanding of attentional processes. Attention was beginning to be seen as a more complex process than had earlier been invisioned. Studies examining different types or classes of inputs brought about an understanding that attention switching involved more than the simple selection of an input channel. The characteristics of inputs could be selectively attended to and switched between.

Several dichotic listening experiments found effects when subjects were required to attend to different classes of stimuli. Gray & Wedderburn (1966) found that simulus class effects the ease with which items are recalled. Broadbent & Gregory (1964) found that a reduction in presentation rate from that used in Gray & Wedderburn produced a much greater improvement in performance when the items were of two alternated classes. It was suggested that the slowed presentation rate provided the subjects with time to switch attention between item type.

These studies suggested that the attention process has a great deal of flexibility in terms of what is to be attended to or switched between. Attention can be allocated to a number of sensory channels (between the ears, for example), but it can also be allocated to any number of attributes of a stimulus. Individuals can attend to the color, shape, texture, or other qualities of stimuli, and are seemingly oblivious to most other non-attended qualities (Rock & Gutman, 1981). The experiments in dichotic listening seemed to suggest the central processor is flexibly self-programmed to adapt to the situation at hand (Moray, 1967).

Some novel innovations have been introduced to study attention switching using the dichotic listening paradigm. One such innovation is the use of alternating clicks (rather than meaningful stimuli), with the subject's task being to estimate the number of clicks presented (Axelrod & Guzy, 1972; Axelrod & Powazek, 1972; Hoopen & Voos, 1981). The click estimates provided a more exact measure of the information being lost during attention switches. Axelrod & Guzy (1968) found that when the clicks are alternated from ear to ear, the subjects significantly underestimated the number of clicks presented. Hoopen & Voos (1981) argued that this early study was flawed in that the number of clicks to be counted and the number of switches performed were both systematically varied at once. After altering the paradigm to allow independence of these factors, Hoopen & Voos concluded that attention switching is time-consuming and performance-limiting.

Dichotic listening tasks have also been used to search for developmental differences in the attention switching process. For example, Hiscock & Kinsbourne (1980) have found a developmental increase in switching efficiency. They also noted a significant right ear advantage in dichotic listening tasks, when seperately analyzing the data presented to each ear.

Although dichotic listening experiments were the first to study switching effects, and easily account for the majority of attention switching experiments conducted, the paradigm presents some serious drawbacks to those wishing to study attention switching.

First of all, dichotic listening is a task involving two distinct input channels: the two ears. This has advantages in that it is easy to provide seperate inputs to each channel. However, the results of such experiments lack generalizability to all switching situations. It is a very rare occurence in the real world for an individual to receive two distinct, seperate inputs to the ears. The task is modeled after the notion of attention switching as a process of selecting from predefined input channels. However, attention has been found to be far more flexible than this; attention switches can be made on the basis of stimulus characteristics within the same input channel. Dichotic listening, which is inherently a two-channel task, is not well-suited to study the complex attention switching situations which the limited capacity processor is capable of.

For example, one question of interest is the time required to switch between differing outputs. This occurs in speaking or singing, when one switches the pitch or volume of one's voice. The dichotic listening paradigm is not equipped to study such a situation. The limited range of switching activities which can be studied using this paradigm is a serious drawback to its use in studying attention switching.

Dichotic listening tasks use error rates as the primary dependent variable. Thus, no direct measure of the time it takes to switch attention is available through the use of this paradigm. Switching time is inferred based on the stimulus presentation rate that begins to elicit a large number of errors. Criteria for what constitutes an adequate number of errors to infer that the rate of the stimuli shifting between the ears has overtaken the speed of the attention switching mechanism is strictly arbitrary. The lack of a direct empirical estimate of switching time is probably the most serious disadvantage to using the dichotic listening paradigm to study attention switching.

In addition, dichotic listening tasks do not provide subject self-pacing of attention switching. In the real world, it is the individual who determines the rate of attention switching. In dichotic listening, the experimenter must specify stimulus presentation rates, then infer switching time based on the errors which occur at each presentation rate. It would be advantageous if the subject could determine the rate of switching. Subject self-pacing provides an estimate of the switching time which is comfortable and efficient for the individual, and which is more congruent with the type of attention switches which occur in everyday life.

Expectancy or Response Set Paradigm- The second type of paradigm used to study the time required to switch attention is the expectancy or response set paradigm. This type of experiment has often been used to study switching attention from one sensory modality to another, although it is an approach capable of studying many attention switching situations. This approach involves having subjects expect to attend to a certain type of stimulus attribute, then require a response to be made to a differing stimulus attribute. The stimulus attributes may involve the sensory modality attended to, the type of stimulus attended to, or the particular aspect of a stimulus attended to. The time required to execute a response to an unanticipated stimulus attribute is typically longer than when the subject is responding to an expected stimulus attribute. Subtracting the mean reaction time to an expected attribute from the mean reaction time to an unexpected attribute yields an index of the time required to switch attention from one attribute to another.

The subject's expectancy that a certain attribute or modality will be attended to is typically created in one of three ways. First, cues may be provided to the subject before each trial instructing the subject to attend to a particular stimulus aspect or sensory modality. Second, numerous trials involving attention to an attribute or modality may proceed a switching trial, so that the subject believes the liklihood is great that the insuing trial will require attention to that attribute or modality. Third, some studies assume that a single trial primes the subject to attend to the type of stimulus presented in that trial. This assumption may not hold in many switching situations, and this particular method is not commonly used.

Wundt (1893) was interested in the effect of expectancy on the ability of subjects to attend to various stimuli. He states the following:

> Slighter but still very noticeable is the retardation (in quickness of response) if one arranges the experiment to have the observer in ignorance as to whether light, sound, or touch impression will be forthcoming, so that the attention cannot be turned to a particular sense organ. Immediately one notes a peculiar unrest because the strain of attention continously vacilates among the several senses.

Wundt seems far ahead of his time in his observations of the limited capacity of attention.

Kristofferson (1965,1967) was one of the first researchers to use the expectancy approach to study attention switching. Kristofferson (1965) was interested in what he referred to as minimum dwell time. This was the minimum amount of time that one must attend to a particular stimulus after directing attention to it and before attention can be switched to a different stimulus. Kristofferson presented subjects with two stimuli simultaneously, a tone and a light. The subjects' task is to indicate when one of the stimuli ceased. At times, subjects were cued as to which stimulus to attend to, and at times no cue was provided. Kristofferson found a minimum dwell time of about 60 msec. However, his method does not adequately divide minimum dwell time from the time required to switch attention. Kristofferson assumed that the actual switching time was minimal, an assumption Moray called "perhaps the biggest conceptual weakness of his scheme" (Moray,1969).

Kristofferson attempted to tie the conception of a "psychophysical time quantum" to attention switching, using his expectancy studies as the basis of his theorizing (Kristofferson, 1967). He suggested that the data processing operations of the nervous system were governed by a "clock" similar to those found in computers. The clock would generate a succesion of equally spaced points in time. These points in time would occur at a rate of about one every 50 msec. Kristofferson believed that these points determined when it was possible (but not necessary) to switch attention from one stimuli to another, and determined when information may be passed from one processing stage to another. Kristofferson's views are fascinating, but are based on his research involving minimum dwell time, research which seems to confound minimum dwell time and switching time.

One of the best examples of experiments using the expectancy approach to study switching time is that of LaBerge (1973). LaBerge had subjects perform detection or discrimination tasks using two different stimuli in two sensory modalities, vision and hearing. Using two types of tasks was assumed to be a "depth of processing" manipulation, as deeper processing was to occur in a discrimination between two stimuli than in the detection of a single stimuli. LaBerge used trials involving either discrimination or detection to set the subjects' expectancy as to which sensory modality to attend to. He found that the depth of processing involved effected both the time required to switch from the modality attended to and the time required to switch into the next modality. LaBerge's results suggested the existence of at least two factors involved in switching time: 1) the time required to exit a particular attentional state, and 2) the time required to enter a different attentional state.

Proctor & Fiscaro (1977) provide an example of the use of blocks of trials to create an expectancy for subjects to attend to a particular type of stimulus characteristic. They had subjects classify stimuli as being the same or different on one of three perceptual attributes (color, size, or form). In one condition, the subjects saw blocks in which the discrimination always involved attending to one attribute. In another condition, the stimulus attributes that the subjects were to attended to varied from trial to trial. Raection times were longer in the varied attribute condition. Proctor & Fiscaro concluded that time and central processing capacity are required to select between perceptual attributes.

Boulter (1977) has also found lengthened reaction times with visual, auditory, and tactile stimuli when the modality of the presented signal was uncertain. Similar uncertainty effects have even been found involving attending to differing spatial frequencies (Davis, 1981).

This particular class of experiments has proven to be very flexible in the studying of various aspects of attention switching. For example, Klein (1977) has used expectancy created by cueing to demonstrate a bias to attend to visual stimuli. Shulman, Remington, & McLean (1978), in an ingenious application of this paradigm, used cues to have subjects shift attention in the visual field while the eyes remained fixated on a central point. They discovered that attention can be moved in an analog fashion across the visual field independent of eye movements.

Cross-modality switching has been studied in psychiatric patients suffering from schizophrenia by using an expectancy approach. Mettler (1955) suggested that schizophrenics may have difficulties switching attention across sensory modalities. A number of studies have been performed comparing the switching efficiency of normals and schizophrenics (Sutton, Hakerem, Zubin, & Portnoy, 1961; Kristofferson, 1967; Davies-Osterkamp, Rist, & Bangert, 1977). The results of these studies all suggest that schizophrenics have much more difficulty switching attention between the senses than normals.

The expectancy paradigm has a number of advantages. First, it is quite flexible; a wide variety of attention switching situations can be studied using this method. This type of experimentation has certainly proven to be capable of studying many attention switching situations which could not be examined using a dichotic listening paradigm.

A second major advantage is that the primary dependent variable obtained using this paradigm is reaction time. It is possible, by comparing the performance of subjects in conditions requiring attention switching to subjects in conditions not requiring switches of attention, to estimate switching time. In comparison to dichotic listening tasks, the expectancy approach yields a more exact estimate of the time required to switch attention.

The expectancy paradigm also has a number of disadvantages. The paradigm typically requires subjects to perform some sort of discrimination task in addition to making switches of attention. This added task must take up some of the capacity of the central processor. The addition of another task may bring about an increase in switching time. Weber, Byrd, & Noll (1984) have found that increasing memory load greatly lengthens the time required to switch attention between working memory and visual perception. Because of the additional task required in expectancy experiments, the estimate of switching time obtained through use of this paradigm may be somewhat inflated.

In addition, the paradigm does not measure the time it takes to alternate between tasks requiring different attentional states. The expectancy approach simply misdirects the subjects' expectations, and measures the additional reaction time brought about by the misdirection. It may be that anticipating a response to a particular stimulus attribute does not require the same depth of processing as actually having to make such a response. LaBerge (1977) has demonstrated a depth of processing effect for attention switching; the more deeply processing occurs, the more time consuming a subsequent attention switch is. Thus, this paradigm may not yield as accurate an estimate of switching time as might be desired.

<u>The Attention Switching Time Paradigm</u>- The switching time paradigm involves measuring the time required to alternate between two tasks which involve attending to different stimulus attributes, input channels, output parameters, or output modalities. The times required to do each task seperately is also measured. The mean times required to do each task seperately, and the mean time required to alternate between tasks is placed into a switching time formula. The formula is as follows:

SWITCHING TIME = (ALT - (A + B))/ # OF SWITCHES where ALT = the time required to alternate between tasks, A = the time required to complete the first task alone, and B = the time required to do the second task alone. This formula yields an estimate of the average time required to execute a single attention switch.

A study conducted by Jersild (1927) seemed to anticipate this paradigm. Jersild did not use a switching time formula, but did compare the times required to execute a task involving a "shift of mental set" to the times required to do comparable tasks which did not require this shift.

Jersild measured the time required to alternately subtract three from a two digit number and give a common opposite of a word in a mixed list of words and numbers. He compared this time to the time required to perform each operation seperately on pure lists of numbers and words. He found surprisingly that it takes less time to accomplish the alternation task.

Spector & Biederman (1976) replicated Jersild's results. They explained that this effect seemed to occur because the class of stimuli provided the subjects with a cue as to the type of operation required. When Spector & Biederman constructed a task in which the type of operation required was not unambiguously cued by the type of stimuli used, a large shift loss (increase in switching time) was found.

Weber and his collegues have begun an extensive research program using the switching time paradigm. This research is designed to study various operations performed by the human operating system. The human operating system is analogous to the basic input/output systems found in computers; it is the underlying mechanism which allows us to select between various types of inputs and outputs, just as the computer operating system selects between inputs and ouputs. Although such an operating system seems logically necessary, it has been only marginally studied. In fact, artificial intelligence theories, which attempt to create computer simulations of human information processing, do not generally discuss control systems (Barr & Feigenbaum, 1981, 1982).

Much of the research already completed deals with switching between various output parameters. Weber, Blagowsky, & Mankin (1982) examined the switching time involved in alternating between various vocal output intensities. Two models of response intensity representation were suggested: 1) an analog model, in which the response intensity is represented by a pointer moving along an internal intensity continuum, and 2) a symbolic model, in which various parameters are substituted into the "formula" which determines response intensity. The results supported the symbolic model of response representation. It took no longer to switch from a low intensity vocalization to a yell than from a medium intensity vocalization to a yell.

Mankin (1983) studied magnitude switching effects in handwriting and in mental image generation. He found results suggesting that handwriting size may be represented in a symbolic manner, while image size seems to involve an analogic representation, with it taking longer to switch greater distances on an image-size continuum.

There are a number of other studies currently underway examining switching between various types of outputs. Weber & Brown (1984) are examining alternating between playing music and singing. Weber & Gowdy (1984) are looking at the time require to switch between vocal pitches. Preliminary results suggest that alternating between playing music and singing involves a considerable switching time, but that switching time between various vocal pitch outputs is very small, and in one case a negative switching time has been found. A negative switching time indicates that the time required to complete an alternating task is faster on the average than the times required to do the alone or non-alternating conditions. Such a result could occur either because of random variation (the alone and alternating conditions are assessed on different trials) or because of a refractory period for some of the processes in the alone conditions.

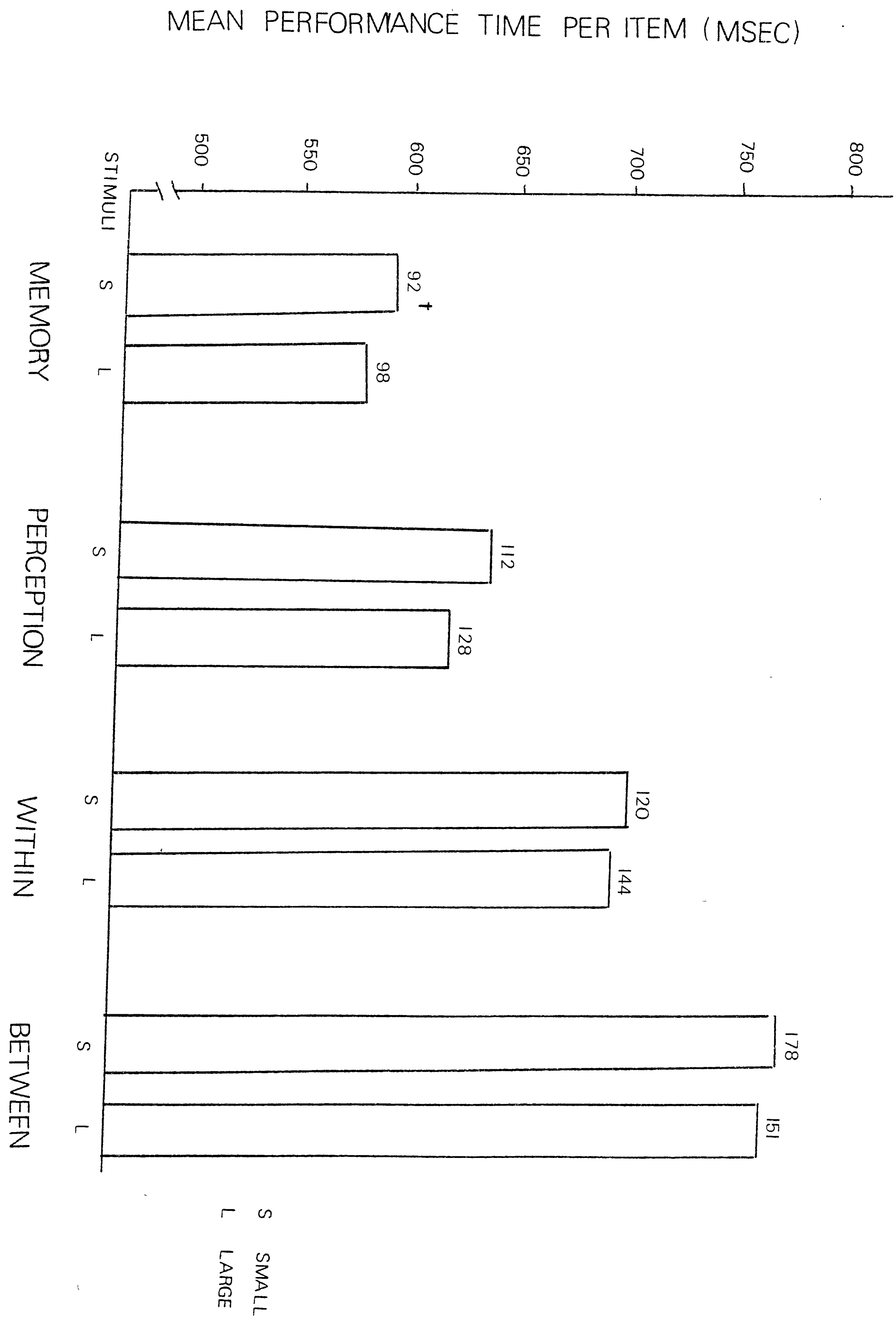
Studies have also been done examining switching between inputs. Weber, Noll, & Byrd (1984) are currently examining the time required to switch between working memory and visual perception. In the first experiment, a switching time of about 293 msec was found for such an attention switch, using letters as stimuli. In the second experiment, it was found that as working memory load increases, the time required to make a working memory-visual perception switch also increases.

The switching time paradigm has a number of advantages in comparison to other approaches. The dependent variable is a direct measure of the time required to switch attention. In addition, concurrent tasks, such as the discrimination tasks used in expectancy studies, are not necessary using this approach.

The paradigm is widely applicable to a variety of switching situations. Studies of output switching and input switching are equally feasible using this approach. In addition, the switching tasks are completely subject self-paced. This is similar to the type of attention switching found in everyday life, and tends to increase the generalizabilty of the findings.

The paradigm also has some disadvantages. Some information is lost in the averaging involved in the switching time formula. For example, in a memory-perceptual switching situation, the attention switch is executed in two directions: 1) from memory to perception, and 2) from perception to memory. There is no reason to assume that these two switches will take the same amount of time. The switching time formula does not provide separate switching times for these two switches, yielding instead the average of the two.

In addition, the tasks used in switching time studies are often highly simplified, and thus may lack some ecological validity. This criticism is not peculiar to the switching time paradigm, and has been leveled at attention and memory studies in general (Neisser, 1978). The simplified situations are often necessary to accurately isolate the switching effects form confounding variables.


MEAN PERFORMANCE TIME PER ITEM (MSEC)
500
550
600
650
700
750
800
STIMULI
MEMORY
PERCEPTION
WITHIN
BETWEEN
S
L
92 †
98
112
128
120
144
178
151
S SMALL
L LARGE

VITA

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Doctor of Philosophy

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