MAGNITUDE SWITCHING TIME EFFECTS IN HANDWRITING AND MENTAL IMAGERY

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PREFACE

The experiments described in this dissertation involve many of the major components of traditional psychology: perception and imagery; response planning and control; feedback and knowledge of results; information processing about space and form. The focus of the research is upon response production. Thus the paper brings a number of traditional areas of psychology to bear on the question of how people form and execute responses, whether those responses are overt such as in motor movement or are covert such as in mental imagery.

I wish to express my appreciation to Dr. Robert Weber, who served as my Thesis and Dissertation Adviser, for his continual guidance, encouragement and help. Dr. Robert Stanners, Dr. Larry Hochhaus and Dr. John Gelder also served as committee members, and I should like to express appreciation and thanks to them for their valuable thoughts.

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INTRODUCTION

This dissertation has been formatted according to American Psychological Association specifications. The deviation from the Oklahoma State University format was used to facilitate publication in the Journal of Experimental Psychology. Permission to use this format was granted by the Graduate College.

Abstract

Four experiments were conducted to study a new phenomenon: the existence of a substantial switching time effect in response generation. Experiment 1 studied rapid alternation between small-, medium-, and large-sized handwriting. A derived switching time score was used to show that the time to switch between writing sizes is on the order of two-thirds the time for producing a character in its own right. In Experiment 2 the writing size switching effect was shown to be resistant to practice effects. Evidence was found for a central origin of size switching where a symbolic model of size representation describes the effect. Experiments 3 and 4 questioned possible size switching effects in mental imagery. Evidence was found for a switching effect in mental imagery that is adequately described with an analog model where size is represented by a moving pointer on an intensity continuum. It was concluded that response generation programs for motor systems are governed by a symbolic model of size representation whereas programs for mental image production are governed by an analog model of size representation.

Magnitude Switching Time Effects in

Handwriting and Mental Imagery

Traditionally, two lines of research on switching effects have been followed. The first investigated receptive attention alternating from one channel or category to another (Cherry, 1953; Broadbent, 1954; Treisman, 1969). The so-called 'shadowing' experiments are examples. The second analyzed attention demands while varying the number of signals to which attention is directed (Green & Swets, 1966; Shaw, 1980). Both lines of attention research focused upon attention in concurrent processing of received information.

An important example of concurrent or dual-task research (Posner & Keele, 1969) studied attentional demands within a single trial. In this study, subjects were to rapidly alternate attention from one channel or category to another. Subjects rotated a handle to move a pointer to a visible target. On some trials an auditory signal was presented. Subjects were to respond as quickly as possible to this signal with their other hand. Subjects in a control condition responded to the auditory signal but did not rotate the handle. Attention requirements were computed by subtracting the time to respond to auditory signals in the control condition from the time to respond in the experimental condition. Results showed that the greatest amounts of attention were required for movement initiation and termination phases of a trial. The least amounts were required during movement.

The present experiments employ a single task paradigm. This differs from studies on response generation which use the dual-task paradigm (Keele, 1973; Navon & Gopher, 1980; Wickens, 1980). Studies measuring attentional demands by using a secondary stimulus in the dual task paradigm have contributed significantly to knowledge of movement production. Unfortunately, this technique may prevent a pure measure of the demands of a primary task. Thus Klein (1976) argued that inferences about attention demands for dual-tasks may be unwittingly based upon structural interferences. For example, it is difficult to chew food and talk at the same time, not because attention capacity is exceeded, but because muscle movements interfere with each other. Klein believed that structural interference in specific perceptual, memory, or response systems may masquerade as attention limitations. The problem of structural interference can be avoided by requiring subjects to alternate response characteristics within a single task rather than responding simultaneously to dual tasks.

An example of using sequential alternation of response characteristics to study attention switching is found in the work of Weber, Blagowsky, and Mankin (in press). Four experiments investigated the existence of a very large switching time effect that occurs from rapidly alternating between overt and covert (mouthed) speech. This is referred to as an intensity switching effect. In Experiment 1 the generality of the switching time effect was determined by comparing intensity switching time with category switching time. Category switching involves alternating between categories of materials such as numbers and letters. For number conditions a sequence of ten characters "1, 2, 3, 4, 5, 1, 2, 3, 4, 5" was generated either by speaking it, or by mouthing it, or by alternating between speaking/mouthing. For the letter conditions the sequence of ten characters "a, b, c, d, e, a, b, c, d, e" was generated either by speaking, mouthing, or alternately speaking/mouthing. For the category switching conditions the sequence of ten characters "1, a, 2, b, 3, c, 4, d, 5, e" was generated by speaking, mouthing, or alternating between speaking/mouthing. The generation time for completion of the ten-item sequence was the dependent variable. To better understand the process of alternating between intensities or categories, an index of switching time was computed based upon formula 1.

$$\text{Mean Time/Switch} = (\text{Alternate} - ((\text{Speak} + \text{Mouth})/2)) * (1/9). \qquad (1)$$

The division by 2 gives the average time for generating the 10 item sequence under the two constant response intensities, speaking or mouthing. The factor 1/9 was used because there are only nine switches in a ten item sequence. For intensity switching data, the time it takes for each switch was nearly equal to the generation time for a single character. Results also showed that the mean time per switch for intensities takes much longer than mean time per switch for alternating between the categories of letters and numbers.

Weber et al. (in press) performed a second experiment to test whether the switching effect for intensities and for categories was a short-lived coding effect or a more intrinsic process that is resistant to practice. In this experiment a single highly practiced subject was tested over a ten day period using the procedure in Experiment 1. Results indicated that the intensity switching effect is very impervious to practice. In contrast, an additional five days of testing indicated that the category switching time was virtually nil after practice. It was concluded that category switching is a short-lived phenomenon because subjects just learn another string of characters that is ultimately no more arbitrary than either the letter names or digit names alone.

Experiments 3 and 4 expanded the investigation on the switching time effect. In these experiments vocal intensity was manipulated over three levels, mouth, speak, and yell, where 'mouth' had the same meaning as before, 'speak' was in a normal conversational volume, and 'yell' required actual shouting. Manipulating intensity in this manner distinguished between two models of how control processes work to change intensity: (1) a digital or symbolic model in which intensity is altered by passing different parameter values to an intensity function; and (2) an analogic model in which intensity is selected by the position of a pointer on an intensity continuum. Weber et al. thought that if a symbolic model holds, it should take no longer to switch between mouth and yell than between mouth and speak, or speak and yell. In contrast, if the analogic model holds, it should take longer to switch between mouth and yell than between mouth and speak, or speak and yell. Examination of the results showed that alternate conditions took almost twice as much time in the generation of a sequence as did constant conditions. The important switching time comparisons indicated a clear result; virtually identical times for each type of switch. This was interpreted as evidence supporting the symbolic model in which parameters are passed to an intensity function.

In conclusion, Weber et al. (in press) found that the switching time effect is a reliable and powerful phenomenon that is not due to nominal memory load. Nor is it due to a lack of encoding practice. The results were also contrary to a model in which intensity is represented as an analog quantity. Moreover, the results were contrary to a theory that would claim that the intensity switching effect is due to rapid activation and damping of peripheral components such as muscles, etc. Clearly, a central model is implied if the switching time is constant across a wide range of magnitude changes in peripheral muscle motions.

Appendix A presents a detailed historical discussion of the role of control processes in response generation. Appendix B assesses the value of applying models such as computer functions to human information processing of concurrent tasks.

The switching time paradigm seems to have great potential for studying control processes at work in the selection of characteristics on a response continuum. This paper reports four new experiments that were conducted on the switching time phenomenon. Experiment 1 focused on magnitude switching in handwriting. Experiment 2 studied resistance to practice for possible handwriting switching effects. Experiment 3 addressed the question of size switching in mental imagery using a procedure similar to that in Experiment 1. Experiment 4 further investigated switching time effects in mental imagery using a related task. Results from these experiments were merged with the previous switching effect results (Weber et al., in press) for convergence on two important questions: (1) How general is the switching time phenomenon in response generation?; and (2) What is the form of a model (analog or symbolic) that represents the action of control processes at work in switching response characteristics.

Experiment 1

This experiment expanded the notion of switching time for speech output to handwriting. If a substantial switching time effect exists in more than one mode of the response system, then the generality of the effect will be extended. Furthermore, by testing whether an analog or symbolic parameter substitution model describes a possible switching time effect for handwriting, constraints may be placed on any general description of this control process.

In this study, subjects were asked to perform a single motor task while rapidly changing the magnitude of movement. Thus the focus was upon the motor control parameter of size and how alternation time is affected by the degree of parameter change.

Method

Subjects. The subjects were 24 undergraduate volunteers, with an equal number of males and females, who received a small extra credit bonus for participation.

Procedure and Design. Subjects were randomly assigned to two modes with an equal number of males and females in each mode. Subjects in the Write mode wrote the letters of the alphabet from memory. Subjects in the Trace mode simply traced over their own writing of the letters. The Trace mode was designed to control for peripheral muscle movements which otherwise might be used to explain possible effects in the Write mode.

Subjects in the Write mode wrote the first 20 letters of the alphabet in lower-case cursive so that the entire string was written in one continuous motion. The letter 't' was not crossed and the letters 'i' and 'j' were not dotted. This manipulation prevented subjects from necessarily lifting their pencil from the paper. The first 20 letters of the alphabet were used because pilot subjects, tested with sub-strings of 10 letters (a...j), indicated that automatic writing programs could be quickly developed which acted to diminish initial switching effects.

The string of 20 letters was written in nine different sizes: (1) Small, where the short letters such as a, e, and i were 3 mm tall and the stems of the tall letters such as b, h and k were approximately 6 mm tall; (2) Medium, where the short letters were 6 mm and tall letters were 12 mm; (3) Large, where the short letters were 12 mm and tall letters were 24 mm; (4) Small/Medium, alternating the magnitude between successive letters, writing the first small, the second medium, etc.; (5) Small/Large, alternating between small and large; (6) Medium/Large, alternating between medium and large; (7) Medium/Small, to balance Small/Medium; (8) Large/Small, to balance Small/Large; and (9) Large/Medium, to balance Medium/Large. Thus for each size alternation a given letter in the string (a...t) received both values of response size. This manipulation was designed to inhibit automatic motor programming; and to control for unnatural or difficult letter shapes which might occur from alternating sizes in one direction only. Each of the nine ways of writing the letters was presented individually on an 8 1/2 x 14 inch piece of paper. The papers contained a set of lines which defined where subjects were to write the letters (see Figure 1 for examples). These lines defined correct response sizes for the "ball" or "body" of the letter.

Insert Figure 1 about here

Subjects in the Trace mode followed the same procedure as the Write mode; only instead of actually writing, the subjects simply traced over carefully written examples of their own handwriting.

The writing of the different letter sizes was first modeled by the experimenter. A block of practice trials followed. The experimenter initiated each trial by saying "go" and starting the clock. The experimenter visually monitored each trial and stopped the clock when subjects completed writing the twentieth letter, _t_. Subjects were instructed to write as accurately and as rapidly as possible. Accuracy meant getting the correct letter between the lines without either spillover or undershoot. Verbatim instructions are presented in Appendix C. If the experimenter noticed that accuracy was being sacrificed for speed, or speed for accuracy, he asked subjects to modify their response style to provide comparable emphasis on accuracy and speed. As will be shown subsequently, speed-accuracy trade-off problems are minimal in a list processing task such as this. If subjects reported that they were confused or if the experimenter witnessed a blocking during any trial, then that trial was terminated and repeated one trial later. Confusion, blocking, or completely skipping a letter or a switch in size resulted in an error. The correction procedure for errors probably leads to conservative differences, since errors or blocking were most likely to occur on difficult items--and such items would receive more practice with the correction procedure.

Each subject received six replications where each replication was randomly composed of all nine sizes. This manner of composing replications resulted in equal practice for all sizes. However, it resulted in more practice for alternate sizes than for constant sizes. Possible differences between constant and alternate sizes are therefore likely to be conservative, since the more difficult alternation conditions receive more practice. In summary, the design consisted of the following factors: 2 modes (Write, Trace) x 2 sexes x 6 replications x 9 size conditions. Mode and sex were between-subject variables, and replication and size were within-subject variables. The principal dependent variable was the time to write a 20 letter list--expressed as time per letter. Derived switching time scores were also employed. Secondary dependent variables were accuracy of responding and frequency of errors such as confusion, blocking, skipping a letter, or failing to switch sizes.

Accuracy was determined by measuring the height of one letter, 'h', against the height prescribed by a given size condition. The letter 'h' was chosen because preliminary work showed it to have a relatively large error, and measurements on the letter could be well defined. Measurements were obtained as described in Figure 2 where the length was recorded from the lower left stem of the 'h' to the top of the "hump". Three methods were used for describing accuracy. In the first method, accuracy was expressed as the signed deviation from the correct height. In the second method, accuracy was expressed as the absolute deviation from the correct height. In the third method, accuracy was expressed as the percent deviation from the required or expected height of the letter. The three accuracy measurements were calculated for each subject on all sizes in replications 1 and 6.

Insert Figure 2 about here

Results

Data were analyzed for four dependent variables: generation time, derived switching time, error rate, and accuracy of letter height. Sex was dropped as a between-subjects variable in this and all subsequent analyses because preliminary analyses indicated that it was an insignificant main and simple-main effect. In addition, the alternate sizes of similar order (e.g., Small/Medium and Medium/Small) were first averaged for each subject with the notation, SM:MS. (There were no significant differences between such similar pairs, where $p < .05$ is defined as significant.) This left six levels of size: Small, Medium, Large, SM:MS, ML:LM, and SL:LS.

Generation Time. Table 1 (in Appendix D) summarizes the analysis of variance for generation time. As a main effect, the Write mode generated characters significantly slower than the Trace mode with means of 1.015 sec and .826 sec, respectively, (F (1,22) = 6.52, $p < .02$). Replications showed a general trend towards faster generation times with the means for Replications 1 through 6, respectively: 1.082, .963, .917, .887, .857, and .817 sec, F (5,110) = 55.03, $p < .0001$. Additionally, the main effect for Size was significant. The sizes and their respective means, ranked from lowest to highest, were: Small = .656, Medium = .747, SM:MS = .966, Large = .974, SL:LS = 1.079, and ML:LM = 1.101 sec, with F (5,110) = 127.78, $p < .0001$.

The top of Table 2 presents the means and standard deviations for constant and alternate sizes in the Write and Trace modes. This interaction between mode and size was significant, with F (5,110) = 39.19, $p < .0001$. For constant sizes in both modes the order of times was Small < Medium < Large, where the Newmann-Keuls' critical differences between means that must be reached or exceeded for significance were C.diff.2 = .067, and C.diff.3 = .073, $p < .01$. Newmann-Keuls' multiple range tests were conducted to test all individual comparisons. This multiple comparison procedure was used because it is more conservative with respect to Type I error than are individual *t* - tests.

For alternate sizes, each alternate size in the Write mode was significantly slower than the respective alternate size in the Trace mode, with the mean time for alternate sizes in the Write mode = 1.232 sec and the mean time for alternate sizes in the Trace mode = .865 sec. For both modes, ML:LM and SL:LS were not different from one another. However, both of these alternations were slower than SM:MS, C.diff.2 = .067, C.diff.3 = .073, $p < .01$, so that the order of times was SM:MS < (ML:LM = SL:LS).

Insert Table 2 about here

The Mode x Replication interaction indicated that subjects in the Write mode were responding more rapidly over replications than subjects in the Trace mode, with the change from Replication 1 to Replication 6 for Write = .347 sec and the same change for Trace = .182 sec, with F (5,110) = 5.68, $p < .0001$. The Replication x Size interaction indicated that practice had more effect on the alternate sizes than the constant sizes with the change in times across replications for constant sizes = .215 sec and the change for alternate sizes = .312 sec, with F (25,550) = 3.07, $p < .0001$.

Switching Time. If the alternate conditions as a whole require more time than the constant conditions as a whole, then a signficant switching time exists in the data. If this comparison is not significant, then further tests comparing the derived switching time scores are not necessary. The following results are from a test where all constant sizes and all alternate sizes were pooled into two separate levels levels of a single treatment effect. The dependent variable in this analysis was generation time.

Figure 3 shows that for both modes the alternate sizes were slower than the constant sizes which indicates that switching sizes requires time for writing and tracing. The means for alternate and constant sizes for the Write mode were 1.232 sec and .797 sec, respectively. The means for alternate and constant sizes for the Trace mode were .865 sec and .787 sec, respectively. The F-test for this effect showed $F\ (1,20) = 151.22$, $p < .0001$. Newmann-Keul's critical differences for these means were C.diff.2 = .062, $p < .05$. The difference between alternate sizes and constant sizes is greater for the Write mode than the Trace mode, C.diff.2 = .062, $p < .05$, indicating that the switching effect is more pronounced for the Write mode, with $F\ (1,20) = 73.58$, $p < .0001$.

Insert Figure 3 about here

The important derived results for switching time are based on Weber, et al.'s equation (1) given in the text; except that here a separate switching time was computed for each pair of alternating sizes and the infla multiplication was by 1/19 because there are 19 switches in a 20 character string. As an example for the SL:LS switching time, the Switching Time equation in the present study becomes:

$$ST = (SL{:}LS - ((Small + Large)/2)) * (1/9) . \qquad (2)$$

The derived switching times for each mode are depicted at the bottom of Table 2. For the Write mode the mean time per switch for SM:MS is significantly slower than both SL:LS and ML:LM, so that the order of times is SM:MS > (ML:LM = SL:LS). ML:LM) C.diff.2 = .038, C.diff.3 = .045, $p < .05$. For the Trace mode the order of times showed that SM:MS = ML:LM, ML:LM = SL:LS, and SM:MS < SL:LS, C.diff.2 = .038, C.diff.3 = .045, $p < .05$.

Error Rate. Only 2.2% of all responses in the experiment resulted in errors. Virtually every error occurred in the Write mode. Errors of omission, where subjects forgot the letter string or omitted a letter, accounted for 6.9% of errors. The remainder (93.1%) were errors committed by failing to alternate letter size. For the different sizes, 3% of the errors occurred in constant sizes and 97% occurred in alternate sizes. For alternate sizes, 35%, 35%, and 27% occurred in SM:MS, ML:LM, and SL:LS, respectively. Therefore, the smallest number of errors occurred in the alternate size condition having the greatest size variation. Error rate correlated positively with generation time with $r = .95$, $p < .01$. This result is contrary to a speed-accuracy tradeoff which predicts a negative correlation between time and errors.

Accuracy. Overall, the trend was to write and trace letters slightly larger than prescribed, with a signed mean of +0.65 mm for the Write mode and +0.50 mm for the Trace mode. An analysis of variance, using the signed deviation as the dependent variable, resulted in no significant effects for mode, replication, size, or any interaction. The correlation between signed deviation and generation time was insignificant with $r = .05$, $p > .28$.

Results using absolute deviation as the dependent variable were as follows. For both modes, the range of means across sizes suggested that the larger the writing and tracing, the greater are the absolute deviations. The sizes ordered for length of the frame in which the characters were written, were: Small, Medium, SM:MS, SL:LS, ML:LM, and Large, and the mean absolute deviations were .729, .771, .948, 1.333, 1.380, and 1.656 mm, respectively. An analysis of variance showed this effect for size significant with $\underline{F}$ (5,110) = 5.48, $\underline{p} < .001$. There were no significant effects for mode, replication, or any interaction terms. The correlation between absolute deviation and generation time was significant with $\underline{r} = .11$, $\underline{p} < .05$. This result is contrary to speed-accuracy tradeoff which would predict a negative correlation between time and accuracy.

A third method for expressing accuracy is percent deviation from the required or expected height of the letter. This method equalizes the accuracy terms for different letter heights by dividing the subject's written height by the required height. The correlation between percent error and generation time was not significant with $\underline{r} = .01$, $\underline{p} > .8$.

Discussion

Executing muscle movements for writing letters from memory is more time consuming than merely tracing perceptually available letters. Here tracing may be conceptualized as a tracking task. Writing on the other hand must utilize processes such as forming and executing motor programs. Contrary to previous claims (Hollerbach, 1982), size of writing itself had an effect on the rate of generation. For the constant sizes, Large took longer than Medium which took longer than Small.

Apparently, increasing the size of writing while holding accuracy relatively constant increases travel distance without equally increasing velocity. This result agrees with Wing (1978) who found that time to write increases as a function of increased size.

Perhaps more important to the research questions are the results given in Figure 3. This figure indicates that the switching effect was not in the perceptual or response stage. For the alternate sizes, the difference between the Write mode and the Trace mode represents the amount of switching time that was due to central components. The slope of the line representing means for the Trace mode indicates the amount of switching time that might have been due to peripheral perceptual and response factors in the task. For both modes combined, when the size of writing was alternated, there was nearly a two-thirds increase in generation time over the time required for a constant size.

The most critical results for theory are the switching time values. The results here were somewhat ambiguous. Switching times for SM:MS were slower than SL:LS. This result contradicts predictions based upon an analog model of size representation where distance on the size continuum determines switching time positively. The alternative symbolic model was also unsupported because the symbolic model would predict approximately equal switch times for alternations involving different sizes. It is possible that the SM:MS switching time was slower than SL:LS because an artifactual discrimination problem slowed subjects' processing time. For the Medium-Small size condition, the particular sequence of tall and short letters becomes visually confusing. A somewhat different conclusion about the model which operates in handwriting size switching emerges when the ML:LM switching time is considered.

ML:LM involves adjacent sizes and produces a time approximately equal to SL:LS which has nonadjacent size values. Hence this comparison supports a symbolic model of intensity representation where the size value is read into a size parameter. In this case it takes no longer to input a small value than to input a large value. Thus the switching time results clearly rule out an analog model and provide marginal support for a symbolic model of size representation. It is also concluded that switching the magnitude of a handwriting response occurs centrally. A peripheral model would predict that rapid activation and damping of peripheral components (hand and arm muscles) would affect generation time in an analog fashion.

At this point it is necessary to consider the alternative interpretation that a speed-accuracy tradeoff is the basis of the switching time effect. The small error rate and the positive correlations between accuracy and generation time do not support this possibility.

In summary, by comparing the results from this experiment with those from Weber et al. some tentative conclusions may be drawn. For speech and for handwriting a substantial switching effect exists. In each case this effect is not explainable using speed/accuracy tradeoff. Finally, both sets of experiments were contrary to an analog model of magnitude representation in which magnitude is selected by moving a pointer along an internal continuum.

Experiment 2

This study addressed the following question. Is the magnitude switching phenomenon in handwriting a short-lived coding effect, as found in Weber et al.'s category switching study? Or is it a more intrinsic process that is resistant to practice? Weber et al. found that vocal intensity switching was not likely to dissipate with practice. They tested a single subject over a ten day period with four replications per day. The initial switching time was 0.24 sec per switch on Day 1. The switching time diminished to 0.19 sec per switch on Day 10. If the cognitive control processes underlying handwriting size switching operate similarly to the processes underlying vocal intensity switching then no substantial decrease in the effect should be found.

Method

Subjects. The subjects were one male and one female who participated in Experiment 1. These subjects were selected because of their availability for testing over an extended period.

Procedure and Design. The procedure was the same as in Experiment 1 except that the subjects were run over a five day period. One session, composed of four complete randomized replications, was given each day. The first replication was considered warm-up and practice, and the results for it are not considered. Experiment 1 included two modes (Write and Trace) whereas this experiment included only the Write Mode.

Accuracy of responding was determined by the method used in Experiment 1. In the present experiment, accuracy was measured for all replications on Days 1 and 5.

Results

Results are given for the same dependent variables in Experiment 1. The analyses of variance used 5 days x 3 replications x 6 sizes as the within-subject variables. Alternate sizes were averaged as in Experiment 1 using the same notation.

Generation Time. Table 3 (in Appendix D) summarizes the analysis of variance for generation time. As a main effect, generation time gradually decreased over days with the means for Days 1 through 5 = .737, .683, .640, .606, and .576 sec, respectively, F (4,4) = 15.64, $p < .01$.

The top of Table 4 presents the means and standard deviations for constant and alternate sizes summed over days. For constant sizes generation time increased where the order of times was Small < Medium < Large, C.diff.2 = .282, C.diff.3 = .036, $p < .05$.

For alternate sizes, the order of times showed that ML:LM took longer than both SM:MS and SL:LS, which did not differ, so that the order of times was (SM:MS = SL:LS) < ML:LM. Newman-Keul's values for these comparisons were C.diff.2 = .282, C.diff.3 = .036, $p < .05$.

Insert Table 4 about here

The Day x Size interaction, depicted in Figure 4, was significant. For this figure, the three alternate sizes and the three constant sizes were pooled. Here, alternate sizes improved more rapidly over days than constant sizes, with F (20,20) = 2.52, $p < .02$.

Switching Time. The bottom portion of Table 4 gives the means for the switching times. In Figure 4 these means are plotted as a function of days, where the derived switching times for Days 1 through 5 were .283, .279, .234, .217, and .194, respectively. This gradual decrease in switching times was significant, with F (4,4) = 84.35, $p < .001$. For Figure 4, the three types of switches (SM:MS, ML:LM, SL:LS) were averaged because an analysis of variance indicated that the switching times for each size alternation were not different, F (2,2) = 1.35, $p > .4$. As an indication of the relative magnitude of the switching time, the average time per switch remained on the order of one half to one third the time to generate a single character in its own right.

Insert Figure 4 about here

Error Rate. Of the 270 responses in the experiment, 5.2% resulted in errors. Constant sizes accounted for 7.1% of the errors while alternate sizes accounted for 92.9% of the errors. Virtually all of the errors in the alternate sizes occurred because subjects failed to alternate letter sizes correctly. The correlation between error rate and generation time when compared over days was not significant, $r = .77$, $p > .1$. Likewise, the correlation between error rate and generation time when compared for sizes was not significant, $r = .76$, $p > .05$. Clearly, the positive correlations are contrary to a speed-accuracy tradeoff.

Accuracy. Overall, the trend was to write letters slightly larger than prescribed, with a signed mean of +1.018 mm for Day 1 and +1.074 mm for Day 5. The difference between days was not significant, with F (1,1) = .001, $p > .9$. The correlation between absolute deviation and generation time was also not significant, with $r = .15$, $p > .5$. The correlation between percent error and generation time was not significant, with $r = .20$, $p > .4$. Again, these correlations are contrary to a speed-accuracy tradeoff.

Discussion

As in Experiment 1, the size of writing had an effect on generation time. For the constant sizes, Small < Medium < Large. This again supports the hypothesis that if accuracy is held relatively constant, larger size writing results in greater travel distance but not in an equally greater velocity. When the size of writing is alternated there is roughly a two-thirds increase in generation time over the time required for a constant size.

The switching time results showed a more consistent pattern than in Experiment 1. With extended practice, the switching times for the three size alternations were not different. Thus for the present experiment, support is found for a symbolic model of size representation where the value of the size parameter is inserted in to the output function without regard for the absolute magnitude of that value.

Experiment 3

This experiment was conducted to test possible switching effects in mental imagery. By extending the investigation beyond motor response systems (speaking and writing) to mental imagery three important issues may be addressed: (1) the generality of the switching function will be extended to other than motor response systems; (2) a model of size representation (analog versus symbolic parameter substitution) may be tested for other than explicit behavioral systems; and (3) if switching effects are different for implicit versus explicit behavior then important knowledge of the switching phenomenon will have been obtained.

How might image size be expected to affect image generation time? Kosslyn (1980) reported an experiment by Kosslyn, Reiser, Farah, and

Fliegel (Note 1) which addressed this question. This experiment tested the hypothesis that images of greater size and complexity take more time to generate than smaller less complex images. Subjects were asked to image relatively large and small versions of detailed and undetailed drawings of an animal. Detailed drawings required more time to image, but this effect was the same for both sizes. There was no effect of size on image formation times. Kosslyn (1980) argued that size effects occur as a consequence of how easily one can see where parts belong. Thus, size itself should not be a limiting parameter. However, what Kosslyn referred to as "zooming" and "panning" of images does require time. Zooming and panning are two procedures which Kosslyn claimed are used to transform images. For example, if a person is asked whether a frog has a short tail, Kosslyn reports that people will frequently image the animal, then "zoom in" (expand a portion of the image) to see whether there is a short tail. These transformation procedures apparently operate according to an analog model where the image passes through intermediate stages or along a continuum as it is being zoomed and panned.

Zooming and panning transformations were implicitly discussed by Bundesen, Larsen, and Farrell (1981) who studied mental transformations of image size and orientation. In this experiment, subjects were shown pairs of asymmetrical characters such as the letters, _J_, _P_, and _R_. The first member of the pair was presented for 500 msec and then was allowed to decay for 1100 msec. The second member of the pair was then exposed in the same location as the first stimulus. Subjects were to decide as quickly as possible if the two stimuli were the same except for changes in size and orientation. Results showed that reaction time was a linear positive function of the difference in size between the first and the second stimulus. Apparently, subjects were transforming their images of the first stimulus in order to match it with the second stimulus. Bundesen, et al. concluded that differences in size were visually resolved as differences in depth so that images were transformed along the depth plane to alter their apparent size. This explanation for the size-time relationship is strikingly similar to Kosslyn's "zoom" and "pan" operations.

The present experiment differs from studies which require subjects to zoom and pan images. In those studies, subjects first formed an image and then performed a transformation on the image. In the present experiment, subjects will be asked to generate a series of discrete images, one at a time, of different sizes and in different locations. The procedure is designed to inhibit the formation of a single image which may then be "zoomed" or "panned" to some prescribed size. If zooming and panning can be inhibited, then a realtively pure measure of the time to change a size parameter for image generation may be obtained.

In this experiment, images will be of simple block letters. According to Kosslyn's argument dealing with pure generation time as opposed to transformation time, generating a series of images that are a constant large size should take no more time than generating a series of images that are a constant small size. Three hypotheses address possible switching effects for alternating sizes. (1) If time is needed for people to reset the size parameter for image generation, then switching effects for imagery should be found. (2) If the switching phenomenon is particular to motor programs (as opposed to non-motor programs) no switching effects should be found in imagery. (3) Even if switching effects occur for both writing and imagery, the switching phenomenon might be described by two qualitatively different models of magnitude representation.

Method

Subjects. The subjects were 24 naive volunteers from undergraduate psychology courses who received extra credit for participation. One additional subject was not used in the analyses because of an inability to form mental images as required in the procedure.

Procedure and Design. Subjects were randomly assigned to one of two modes (Image and Perception), with an equal number of males and females in each mode. Subjects in the Image mode imagined a string of 10 upper case block letters (A...J) within a string of ten blank squares. Subjects in the Perception mode perceived the same string of letters which were actually drawn in the string of ten squares. The Perception mode was designed to control for memory loads that may exist in the task and also to assess the possibility that the hand movements made during responses contribute to a switching effect.

The string of squares was arranged in nine different sizes (see Figure 5 for examples): (1) Small, where the squares were 1.13 cm on a side and area = 1.28 square cm; (2) Medium, where the squares were 2.25 cm on a side and area = 5.06 square cm; (3) Large, where the squares were 4.5 cm on a side and area = 20.25 square cm; (4) Small/Medium, alternating the size of the squares between Small and Medium, where the first is small, the second is medium, etc.; (5) Small/Large, alternating between small and large size squares; (6) Medium/Large, alternating between medium and large; (7) Medium/Small, to counterbalance Small/ Medium; (8) Large/Small, to counterbalance Small/Large; and (9) Large/ Medium, to counterbalance Medium/Large. Each of the nine arrangements of squares was presented on an 8 1/2 x 14 inch sheet of white paper.

Insert Figure 5 about here

The nine arrangements of squares, individually presented in random order, constituted one replication. Each subject received 6 replications. In summary, the experimental design consisted of 2 modes (Image, Perception) x 2 sexes x 6 replications x 9 sizes. Modes and sexes were the between-subject variables while replications and sizes were the within-subject variables.

Instructions to subjects are given verbatim in Appendix C. The instructions began with an explanation of mental imagery by asking subjects to imagine the front of their house or apartment on a sheet of white paper. Next subjects were shown a string of squares like those used in the experiment except here the upper case block letters, A...J, were drawn in the squares. Subjects were shown that some of the letters contained a long horizontal line (A,E.F.G,H,J) while others did not (B,C,D,I). The letter 'I' was drawn so that it was a single vertical line without the two horizontal lines on the top and bottom. Subjects were then told that they should imagine (or perceive) the letters one at a time in successive squares. They should tap the top of the imagined letter (or percept) with a pen if the letter contained a horizontal line. They should tap the bottom of the letter if it did not contain a horizontal line. The experimenter then modeled the procedure. A block of practice trials followed. The experimenter pressed a switch to start a msec clock for each trial and simultaneously told subjects, "go". The experimenter pressed another switch when the subjects completed the series of taps. Finally, subjects were instructed to perform as rapidly as possible but without in any way responding so rapidly that they did not first generate a clear image (or clearly perceive) each letter.

At the conclusion of the experiment a post-experiment questionnaire was administered to each subject. Four questions were asked in order to determine (1) which string of squares was most difficult, (2) if the images were clear, (3) if images were the correct size, and (4) whether subjects formed images as instructed or used some alternative strategy to perform the task.

Results

The following analyses pertain to this experiment alone. A subsequent analysis will treat Experiments 3 and 4 combined. In this analysis there were four dependent variables; generation time, switching time, error rate, and post-experiment questions. Sex was dropped as a variable because preliminary tests showed it to be insignificant. Alternate conditions of similar size were combined as in Experiment 1 with the same notation (there were no differences between similar pairs of alternate sizes).

Generation Time. Table 5 (in Appendix D) summarizes the analysis of variance for generation time. As a main effect, the Image mode generated characters significantly slower than the Perception mode, with means of 1.352 sec and .488 sec, respectively, F (1,22) = 45.76, $p < .0001$. Replications were generally faster with the mean time for

Replications 1 through 6 = 1.037, .944, .902, .893, .876, and .867 sec, respectively, F (5,110) = 5.84, $p < .0001$. Additionally, the main effect for size was significant. The sizes and their respective means, ranked from lowest to highest, were Small = .854, Medium = .898, SM:MS = .904, Large = .932, ML:LM = .956, and SL:LS = .978 sec, with F (5,110) = 21.22, $p < .0001$.

The top of Table 6 presents the means and standard deviations for constant and alternate sizes in the Image and Perception modes. For constant sizes in the Image mode the order of times was Small < (Medium = Large) C.diff.2 = .039, C.diff.3 = .046, C.diff.4 = .051, $p < .05$. For constant sizes in the Perception mode the times were not different, with Small = Medium = Large, C.diff.2 = .039, C.diff.3 = .046, C.diff.4 = .051, $p < .05$.

For alternate sizes in the Image mode the order of times was SM:MS < (ML:LM = SL:LS), C.diff.2 = .039, C.diff.4 = .051, C.diff.5 = .054, $p < .05$. For alternate sizes in the Perception mode there was again no difference between sizes, with SM:MS = ML:LM = SL:LS, c.diff.2 = .039, C.diff.3 = .046, C.diff.4 = .051, $p < .05$.

Insert Table 6 about here

The Replication x Size interaction indicated that practice had more effect on the alternate sizes than the constant sizes, with the change in times for alternate = .187 sec and the change for constant = .152 sec, F (25,550) = 1.77, $p < .01$.

Switching Time. An important analysis preceeds the description of the derived switching time results. This test determined whether a significant switching time exists in the data, where all constant sizes and all alternate sizes were pooled into two separate levels of a single treatment effect. The dependent variable in this test was generation time.

Results from this analysis are depicted in Figure 6 which shows, for the Image mode, that the alternate sizes took longer than the constant sizes (mean for alternate = 1.391 and for constant = 1.313 sec), C.diff.2 = .046, $p < .01$. For the Perception mode, generation time for alternate sizes was not different from constant sizes (mean for alternate = .500 and for constant = .477 sec), C.diff.2 = .033, $p < .05$ not reached or exceeded for significance. Thus, the switching effect was not significant for the Perception mode even though the alternate sizes had slightly higher generation times than the constant sizes.

The Replication x Size interaction was not significant with $F(5,110) = 1.59$, $p > .16$. This indicated that the switching effect for the Image mode was stable across the six replications.

Insert Figure 6 about here

The important derived switching time scores are depicted at the bottom of Table 6. A comparison of the means for the Image mode indicated that (SM:MS = ML:LM) < SL:LS, C.diff.2 = .042, C.diff.3 = .48, $p < .01$. Thus the largest switch between sizes (SL:LS) resulted in the longest switching time, a finding consistent with an analog pointer representation.

A second analysis on switching times was conducted to test whether the sum of the two smaller switching times (SM:MS and ML:LM) equaled the switching time for SL:LS. This analysis tested whether switching times were additive, as would be expected for an analog model. A nonsignificant difference for (SM:MS + ML:LM) versus SL:LS would be consistent with additivity. In fact, results indicated that this comparison was <u>not</u> significant where the mean for SL:LS = .150 sec and the mean for SM:MS + ML:LM = .111 sec, F (1,22) = .98, $p > .33$. The switching effect for visual image size scaling is therefore consistent with an additive analog model.

<u>Error Rate</u>. Only 2.7% of the 1296 responses in the experiment resulted in errors. Virtually all errors occurred as a result of subjects incorrectly tapping the top or bottom of the image or percept frame. Surprisingly, the image mode accounted for 31% of the errors while the Perception mode accounted for 69%. For each mode, error rate did not correlate significantly with generation time. For the Image mode r = - .37, $p > .4$. For the Perception mode $r = .15$, $p > .7$.

<u>Post-Experiment Questions</u>. Results from the post-experiment questionnaire were as follows. Question One asked which size was most difficult. For the Image mode, 64% stated the SL:LS alternation, 18% the Small size, 9% the Large size, and 9% stated that no one size was most difficult. For the Perception mode, only 4 of the 12 subjects stated that one size was more difficult than the others. Of these 4 subjects, 2 selected the SL:LS alternation, 1 the ML:LM alternation, and 1 stated that alternate sizes in general were more difficult than constant sizes. Question Two asked subjects in the Image mode to rate the clarity of their images where 1 = very clear and 5 = not clear at all. The mean rating was 2.2 with SD = .62. Question Three asked subjects in the Image mode what percent of the time their images filled the entire square on the response sheets. The mean response was 94% of the time the squares were completely filled, with SD = 11%. Question Four asked

subjects in the Image mode what percent of the time they used imagery in the experiment as opposed to some other strategy such as memory of tapping sequences. The mean response to this question was that 97% of the time subjects were using imagery, with SD = 4.5%. If the results of the questionnaire are accepted, it would seem that subjects were doing what they were supposed to do.

A more comprehensive statistical analysis is given after Experiment 4. This comprehensive analysis pools Experiments 3 and 4 by treating each experiment as a related task under a single between-subjects factor. By increasing degrees of freedom and homogenizing error variance, the comprehensive analysis provides more power than this preliminary analysis and therefore decreases the liklihood of Type II errors.

Discussion

For a sequence of letters, forming images, extracting information from these images, and then generating the next letter is much more time consuming than registering, extracting information, and sequencing among perceptually available letters. Size itself had an effect on image generation time with Large equaling Medium and both taking longer than Small. This result is contrary to Kosslyn's (1980) claim that size does not affect image generation time.

The results most critical to theory are the switching time values. Because of the obtained switching time relation (SM:MS = ML:LM) < SL:LS, it is argued that a clear analog model of size representation exists in imagery. Switching from a small size to a large size would require moving a pointer along a size scale until the correct size is located, and then triggering the response plan. Furthermore, the equation defining this model is additive in form because the two adjacent size switches (SM:MS and ML:LM) when summed are not statistically different than the switching time for nonadjacent sizes (SL:LS).

While the switching time results seem to support an analog model, it is also necessary to consider some competing hypotheses or procedural problems. If these can be dismissed, the analog model would be supported even more strongly. For example, is it possible that the results are simply due to a speed-accuracy tradeoff? A speed-accuracy tradeoff requires a negative correlation between response time and error rate. Neither the Image nor the Perception modes had a significant correlation.

The procedure may be criticized because there exists no objective measure which insures that subjects are in fact generating images of the correct size. Thus whatever the size of squares, subjects might produce the same size of image. Several rebuttals to this argument exist. First, if subjects' images were formed in ideosyncratic sizes, no consistently clear size-related results would have been found. Second, if each subject was forming images of the same size without regard to the squares on the response forms, then an analog model would not be supported. Third, instructions to the subjects emphasized the necessity to generate images that filled the response squares and to alternate image size when the squares alternated sizes. Fourth, post-experiment questions indicated that virtually all of the subjects believed that they were forming images of the correct size.

In summary, the results for visual image size scaling are different than the results from Weber et al.'s study of vocal intensity scaling (in press) and the handwriting results of Experiments 1 and 2 in the present study. Both vocal and handwriting responses involve overt muscle control. Image production is a central rather than a muscular control system. The fact that an analog model was indicated for imagery and was contraindicated for voice and handwriting suggests a tentative generalization: the magnitude representation for motor response generation is, somewhat surprisingly, discrete and symbolic, while the magnitude representation for non-motor responses is analogic.

Experiment 4

Because research on mental imagery is often criticized for being subjective a second imagery task was studied. The procedure used in this experiment was borrowed in part from Brooks (1968). Brooks asked subjects to imagine a block drawing of a letter and then to classify successive corners of the letter as either top or bottom corners. Subjects responded in one of three ways: (1) by saying "yes" it is a top or bottom corner, or "no" it is not a top or bottom corner; (2) by pointing to a staggered series of characters ('Y' or 'N') when responding 'yes' or 'no'; and (3) tapping one hand for 'yes' and the other for 'no'. Brooks thought that imagery and like-modality perception (vision) share common processing resources that are not shared by speech. Results consistent with this view were found. Brooks' simple yet powerful method has clear potential for investigating switching effects in mental imagery.

Method

Subjects. The subjects were 24 naive undergraduate volunteers, with an equal number of males and females, who received a small extra credit bonus for participation. One additional subject was not included in the analyses because of an inability to form mental images as required in the procedure.

Procedure and Design. Twelve subjects with an equal number of males and females were randomly assigned to each of two modes (Image and Perception). The perception mode was designed to control for memory loads that may exist in the Image mode and also to assess the possibility that the hand movements made during responses contribute to a switching effect. Subjects in the Perception mode perceived a single block letter that was copied in each of ten squares. The letters were exactly as in Figure 7 only without the asterisks. Subjects in the Image mode generated images of a single block letter ten times. The ten images were "placed" individually in each of ten squares that were arranged in a staggered string. Figure 7 shows that each image fully occupied only one of the squares. The task for the Image mode was exactly the same as for the Perception mode only that the letter was imagined rather than perceived.

Insert Figure 7 about here

Three sizes of squares were used: small (sides of 1.13 cm), medium (sides of 2.25 cm), and large (sides of 4.5 cm). Areas thus increased logrithmically, with respective areas being 1.28, 5.06 and 20.25 square cm. For each mode, the string of squares was arranged 18 different ways, with six being of constant size and 12 being of alternating size.

All strings of squares were drawn so that every other square in the sequence was raised vertically on the paper (see Figure 8 for examples of sizes).

Insert Figure 8 about here

The staggered layout of squares was designed for three reasons: (1) to disrupt automatic motor programming of response sequences, (2) to approximate equal hand movements for constant and alternate sizes, and (3) to encourage the regeneration of an image when moving from square to square. In fact, pilot work had shown that without the staggering, subjects were likely to plan their responses several squares ahead.

The staggered layout was counterbalanced so that for each of the three constant sizes (Small, Medium, Large) the first square occurred in both a lower and higher position than the second square. Thus, for each of the three constant sizes, two layouts were necessary. For the alternate sizes, the 12 strings of squares were arranged as follows. Each of the three alternations between sizes (Small/Medium, Small/ Large, and Medium/Large) were counterbalanced for order as in the previous experiments. This produced six possible orders for the alternate size variable. Since each string of squares occurred in two possible layouts (first square raised and first square lowered) each of the six alternate sizes occurred twice to counterbalance for the two layouts. Thus, the 12 alternate sizes were: 3 size alternations x 2 orders x 2 layouts.

Stimulus items were borrowed from Brooks (1968). Four block letters (see Figure 9), *N*,*G*,*F*,*Z*, were used individually so that each of the three letters (*N*,*G*,*F*) was the only stimulus item for one complete replication of trials and the letter *Z* was used in practice trials.

Insert Figure 9 about here

The letters each have ten corners which subjects pointed to with a pen. Using the pointer insured that subjects in the Image mode formed spatial images the correct size. The sequence of responses for a single trial is shown in Figure 7. For the first square in the sequence subjects pointed to the first corner of the letter (indicated with the double asterisk in the first square of the string in Figure 7 - subjects did not see any asterisks; they are used here only for expository purposes). Next subjects moved to the second square where they pointed to the second corner of the letter (asterisk in the second square in Figure 7). Finally, when subjects arrived at the tenth square they pointed to the tenth corner and the clock was stopped. Corners were always sequenced in a clockwise direction around each letter.

In summary, the experimental design consisted of 2 modes (Image and Perception) x 2 sexes as between-subjects variables. Within-subjects variables were 3 replications (using the three letters, N,G,F, in counterbalanced order) x 18 sizes (6 constant + 12 alternate). The 18 sizes were individually randomized for each replication.

Verbatim instructions are given in Appendix C. Before each letter was used in the experiment, subjects studied a drawing of the shape then drew it on paper from memory. Next, the ten corners were defined. A block of practice trials was given to each subject using the letter Z. The experimenter initiated each trial by saying "go" and started the clock. Performance was visually monitored by the experimenter who stopped the clock when subjects pointed to the tenth corner of the letter in the tenth square. If subjects reported that they were confused or if the experimenter witnessed an error during any trial, then that trial was terminated and repeated one trial later. A correction procedure such as this will introduce a conservative bias in the results by providing more practice on the more difficult conditions.

At the conclusion of the experiment subjects were given a post-experiment questionnaire. Three questions were asked in order to determine (1) which string of squares was most difficult, (2) if the images were clear, and (3) whether subjects were imagining the letters as instructed or if they were using an alternative strategy.

Results

The following analyses are again preliminary as they pertain to this experiment alone. Analyses were conducted for dependent variables identical to those in Experiment 3. Sex was dropped as a variable because previous analyses indicated that it was not significant. Previous analysis also indicated that the stimulus letters, F, N, and G, were not significantly different. Thus the following discussion will label the within-subjects variable, letter, as replication. As a final general note, the alternate sizes of similar size were combined with the same notation used previously.

Generation Time. Table 7 (in Appendix D) summarizes the analysis of variance for generation time. As a main effect, the Image mode responded slower than the Perception mode with means of 1.182 sec and .938 sec, respectively. This effect was significant, with F (1,22) = 6.04, $p < .02$. Replications showed a general trend towards faster generation times with means for Replications 1 through 3, = 1.185, 1.050, and .946 sec, respectively. This trend was significant, with

F (2,44) = 49.67, *p* < .0001.

The top of Table 8 presents the means and standard deviations for constant and alternate sizes in the Image and Perception modes. For constant sizes, the Image mode was slower than the Perception mode. However, for both modes the order of times was (Small = Medium) < Large, C.diff.2 = .048, C.diff.3 = .055, and C.diff.4 = .059, *p* < .01.

For alternate sizes, again the Image mode was slower than the Perception mode. The order of times for both modes was SM:MS < ML:LM < SL:LS, C.diff.2 = .048, C.diff.3 = .055, and C.diff.4 = .059, *p* < .01.

Insert Table 8 about here

The Replication x Size interaction indicated that practice had more effect on the alternate sizes than the constant sizes where the change in times for alternate = .254 sec and the change for constant = .240 sec., with *F* (10,220) = 2.18, *p* < .02.

Three results regarding the physical layout of the response squares should be mentioned before presenting the switching time results. First, the sizes where the first square in the sequence was lower resulted in faster generation times than those sizes where the first square was higher, with the mean for lower initial square layouts = 1.043 sec and the mean for higher initial square layouts = 1.100 sec. This difference was significant, with *F* (1,22) = 14.57, *p* < .001. Second, the Small/Medium size resulted in faster generation times than the Medium/Small size with means of 1.021 and 1.180 sec, respectively, C.diff.7 = .069, *p* < .01. Third, the Large/Medium size resulted in faster generation times than the Medium/Large size with means of 1.075 and 1.152 sec, respectively, C.diff.3 = .058, *p* < .01. These three results were the same for both modes. Therefore, it is argued that some mechanical feature of the treatment design is responsible for the effects. The present experiment is not designed to analyze or interpret these differences further, and so they will not be considered at this time.

Switching Time. An important analysis preceeds the description of the derived switching time results. This test determined whether a significant switching time exists in the data, where all constant sizes and all alternate sizes were pooled into two separate levels of a single treatment effect. The dependent variable in this analysis was generation time.

Results from this test, depicted in Figure 10, show that across both modes the mean time for alternate sizes was slower than for constant sizes with means of 1.086 sec and .999 sec respectively. This result was significant with $F\ (1,20) = 19.37$, $p < .001$. The Mode x Size interaction was not significant which indicates that an overall switching effect of similar magnitude occurred for both modes. The Replication x Size interaction was also not significant which indicated that the switching effect was constant across replications.

Insert Figure 10 about here

The derived switching times are depicted at the bottom of Table 8. For both modes, (SM:MS = ML:LM) < SL:LS, C.diff.2 = .052, C.diff.3 = .060, $p < .01$, with $F\ (2,44) = 20.84$, $p < .0001$. These results clearly support the analog model since the longest alternation between sizes (SL:LS) required the greatest amount of time, $p < .01$.

A second analysis of variance was conducted which determined the form of the analog model. The equation, SL:LS = (SM:MS + ML:LM), was tested across modes with the dependent variable being the derived switching times. The mean time for SL:LS was .146 sec and the mean time for (SM:MS + ML:LM) was .077 sec. These times were significantly different with $\underline{F}$ (1,22) = 4.48, $\underline{p}$ < .05. The results from this test suggest that a non-additive analog model can be used to describe the swtiching phenomenon. The reason for the nonadditivity is unclear. Finally, because the Mode x Switch interaction was not significant, this model holds equally for both modes.

Error Rate. From the total 1296 responses in the experiment, 79 were errors. Of this 6.1% error rate, 51% were from the Image mode while 49% were from the Perception mode. Approximately 95% of the errors occurred as a result of subjects either skipping a corner or repeating a corner of the letter. The remaining 5% occurred as a result of subjects skipping an entire square in the string. For both modes, error rate did not correlate significantly with generation time. For the Image mode, $\underline{r}$ = .36, $\underline{p}$ > .4, and for the Perception mode, $\underline{r}$ = .77, $\underline{p}$ > .07.

Post-Experiment Questions. Question One asked subjects to indicate which sequence of squares and sizes was most difficult. For the Image mode 70% indicated the Small/Large size combinations, 20% indicated that no size was most difficult, 5% stated Medium/Small and 5% considered Large the most difficult. For the Perception mode, 100% of the subjects believed that the Small/Large size combinations were most difficult. Question Two asked subjects in the Image mode to rate the clarity of their images where 1 = very clear and 5 = not clear at all. The mean response was 2.2 with SD = 1.5. Question Three asked subjects in the Image mode to estimate the percentage of times that they used imagery in the task as opposed to some other strategy such as memory of tap locations. The mean response was 95% of the time subjects used imagery, SD = 7.6%.

Discussion

As in Experiment 3, forming images, extracting information from these images, and then generating the next image was more time consuming than registering, extracting, and sequencing among perceptually available letters. However, the difference between modes was much less in this experiment than in Experiment 3. Size itself affected both imagery and perception with Large taking longer than Medium or Small, which did not differ. However, because this effect was similar for both modes, it is not possible to verify whether size affects image generation time or whether there exists some element common to both modes which is responsible for the size effect.

The important switching time results were inconclusive with respect to the difference between the Image mode and Perception mode. Both modes showed the same effect: the switch with nonadjacent sizes (SL:LS) was slower than the switches with adjacent sizes (SM:MS and ML:LM). These results suggest that an analog model may be used to describe the effect in both modes. Finally, for both modes, the equation describing the analog model is non-additive in form because SL:LS > ML:LM + SM:MS.

It is possible that the patterns of errors may explain why the two modes cannot be distinguished. Overall error rate was higher than for Experiment 3. This suggests that the present task was more difficult. Also, in this experiment error rate was essentially equal for both modes. Thus, inherent difficulties in the task may be creating results that mask the differences between imaging and perceiving.

Results from the post-experiment questions strengthen the argument that subjects in the Image mode were forming images and that these images were approximately the same quality as those reported by subjects in Experiment 3.

In summary, it is unclear whether the analog switching effect found for imagery is a function of the image production system or is a function of processes that are common to both imaging and perceiving.

Experiments 3 and 4 Combined

The two image experiments are related tasks designed to converge on the question of possible switching effects in non-motor response systems. As mentioned in the results section of Experiment 3, it is plausible that combining the experiments will produce statistical tests that are more conservative with respect to Type II errors. Combining the experiments as two related tasks is justifiable in that the methods are similar. The subject populations are probably very similar; both were selected from similar undergraduate classes in the same semester. However, subjects were run in Experiment 3 before subjects were assigned to modes in Experiment 4.

The task in Experiment 3 required subjects to image or perceive a series of different letters. This task will be labeled the Multi-letter task. The task in Experiment 4 required subjects to image or perceive a single letter repeatedly. This task will therefore be labeled the Single-letter task.

Results

For each task, generation times were collapsed across replications. This manipulation created a balanced design with 2 tasks (Multi-letter and Single-letter) x 2 modes (Image and Perception) as the between-subject variables. The within-subject variable was size, where each task included the nine sizes described in Experiment 3. Sex was dropped as a between-subjects variable because it was not a significant effect. In these analyses, alternate sizes of similar size were combined. (Such pairs of sizes were not statistically different overall.)

Generation Time. Table 9 (in Appendix D) summarizes the analysis of variance for generation time. As a main effect, the Multi-letter and Single-letter tasks did not differ. The Image modes as a whole had longer generation times than the Perception modes (with means of 1.267 sec and .713 sec respectively), F (1,44) = 46.91, $p < .0001$. Additionally, the main effect for size was significant. The sizes and their respective means, ranked from lowest to highest, were Small = .928, Medium = .955, SM:MS = .969, Large = 1.000, ML:LM = 1.019, and SL:LS = 1.072 sec, with F (5,220) = 41.19, $p < .0001$.

The top of Table 10 presents the means and standard deviations for constant and alternate sizes in the Image and Perception modes. Generation times for constant sizes in both modes are depicted in Figure 11. The Image mode showed a clear effect with generation time a positive function of image size, so that the order of times was Small < Medium < Large, C.diff.2 = .031, C.diff.3 = .037, C.diff.4 = .041, $p < .05$. Constant sizes in the Perception modes did not differ from each other (Small = Medium = Large), C.diff.2 = .031, C.diff.3 = .037, C.diff.4 = .041, $p < .05$.

Insert Figure 11 about here

For alternate sizes in the Image modes the order of times was SM:MS < ML:LM < SL:LS, C.diff.2 = .031, C.diff.3 = .037, C.diff.4 = .041, $p < .05$. Alternate sizes in the Perception modes followed an order of times where (SM:MS = ML:LM) < SL:LS, C.diff.2 = .031, C.diff.3 = .037, C.diff.4 = .041, $p < .05$.

Insert Table 10 about here

The Task x Mode interaction revealed that the difference between the Image mode and the Perception mode was more pronounced for the Multi-letter task than the Single-letter task, with the differences between Image and Perception modes for tasks = .862 and .242 sec, respectively, F (1,44) = 14.69, $p < .001$. The Task x Size interaction indicated that the difference between SL:LS and the two other alternations is greater for the Single-letter task than the Multi-letter task, where the differences = .109 and .031 sec, respectively, C.diff.2 = .03, C.diff.3 = .037, C.diff.4 = .04, $p < .05$. Finally, the three-way interaction of Task x Mode x Size was not significant. This indicated that for each task, the Image and Perception mode showed similar response patterns.

Switching Time. An analysis preceeds the description of the derived switching time results. This test determined the extent of the switching effect, where all constant sizes and all alternate sizes were pooled into two separate levels of a single treatment effect. The dependent variable here was generation time.

The results for this test, depicted in Figure 12, show that for both modes, the alternate sizes were slower than the constant sizes,

F (1,44) = 33.44, $p < .0001$. The Mode x Size interaction for this analysis was not significant which indicated that the positive functions plotted in Figure 12 are significant for both modes.

Insert Figure 12 about here

The derived switching time results are given at the bottom of Table 10. For each mode the means for the three types of switch are plotted in Figure 13. The Image mode results showed an order of times of SM:MS < ML:LM < SL:LS, C.diff.2 = .031, C.diff.3 = .038, $p < .05$. For the Perception mode, the order of times was (SM:MS = ML:LM) < SL:LS, C.diff.2 = .031, C.diff.3 = .038, $p < .05$.

Insert Figure 13 about here

A second analysis was conducted on switching times to determine the form of the model which describes the switching effect. For both modes, the largest switching time (SL:LS) was compared with the sum of the two smaller switching times (SM:MS + ML:LM). Results showed for the Image mode that the larger switching time exceeds the sum of the two smaller times where the mean for SL:LS = .015 sec and the mean for SM:MS + ML:LM = .010 sec, F (1,44) = 4.92, $p < .05$. Results were similar for the Perception mode where the mean for SL:LS = .088 sec and the mean for ML:LM + SM:MS = .058 sec. The results from this test support a non-additive analog model.

Another test for the form of the analog model would be to test for increases in switching time against increases in the area covered by images. Here, an additive analog model would predict that the switching time for SL:LS should be twice the sum of ML:LM and SM:MS because the change in area from Small to Large is twice the sum of the changes in area for Small to Medium and Medium to Large. An analysis of variance for both modes revealed no difference between the switching time for SL:LS and the switching time for 2(SM:MS + ML:LM). From these results it is argued that the switching effect in imagery and perception can be described by an additive analog model where time is a function of change in area.

Post-Experiment Questions. Results from Question One which asked subjects which size was the hardest will be presented for the Image mode. Of the 24 subjects, 67% stated SL:LS, 14.5% stated that none of the sizes was hardest, 9% stated Small, 7% stated Large, and 2.5% stated Medium/Small. Results from Question Two which asked subjects to rate the clarity of their images where 1 = very clear and 5 = not clear at all, showed a mean response of 2.2 with SD = 1.1. Question Three asked subjects what percent of the time they used images in the task as opposed to some other strategy. Results were that subjects used images 96% of the time with an estimated SD = 6%.

Discussion

First, consider the ligitimacy and advantages for combining Experiments 3 and 4. The two related tasks did not differ with respect to overall generation time. This results, coupled with the procedural similarities between tasks, supports the claim that the tasks were highly related variations of one methodology. Another result which supports combining the experiments is that the three-way interaction, Tasks x Mode x Size, for both generation time and switching time were not significant. This indicates that the mental processes for perception and imagery in each task do not affect processing time differently. In Experiment 3 alone, there were clear differences between the Image and Perception modes. In Experiment 4 these differences were not apparent. After combining the experiments, the differences between modes were more consistent. That is, both generation time and switching time results showed differences between perception and imagery. Thus the claim is substantiated that combininig Experiemtn 3 and 4 will increase statistical power and therefore reduce the probability of Type II errors.

Second, the generation time results for modes revealed that perception processes and imagery processes differed. Overall results showed that imagining letters took longer than perceiving letters. Also, for the Image mode, subjects required more time to imagine larger letters. Contrast this second result with the Perception mode where subjects processed different size letters with equal speed. These results suggest that the image generation system behaves differently than the visual processing system.

These results relating character size with processing time conflict with previous findings. For example, Kosslyn (1980) argued that image complexity, not image size, affects generation time. The present results show that this is not always the case. Kosslyn might account for the present results by arguing that subjects were transforming images with "zoom" and "pan" procedures. These image transformation procedures do affect processing time according to an analog-like function such as that found by Bundesen et al. (1981). It is improbable, though, that subjects were zooming and panning images in the present tasks. The Multiletter task (Experiment 3) asked subjects to generate images of <u>different</u> characters--which required qualitatively different images. Thus it is unlikely that subjects were simply transforming previously generated images. The Single-letter task (Experiment 4) asked subjects to generate images on different areas of the response sheets (the response squares were horizontally arranged and were staggered). This procedure differs from experiments on transformations such as zooming and panning (Bundesen et al., 1981) where subject's images are always centered about a midpoint in the visual field. Generating images in different locations of the visual field might inhibit image transformations. Also, instructions in the Single-letter task were for generating ten images, one for each of the ten squares. Again, it is unlikely that subjects were simply transforming previously generated images. It is concluded that in both tasks, generation time results reflect image generation processes, not image transformation processes.

Third, the principal results fro theory are the switching time values. Across both modes the switching time for the greatest size alternation (SL:LS) was the largest. For perception, the adjacent size alternations (SM:MS and ML:LM) were not different. For imagery the larger adjacent alternation (ML:LM) took longer than the smaller adjacent alternation (SM:MS) so that the extent to which a greater size alternation affects processing time is more pronounced for imagery than perception. These results support the claim that the switching effects in imagery are a function of processes unique to imagery whereas the switching effects in perception are a function of processes unique to the visual components of the task. For imagery, a symbolic model of size scaling is contraindicated, and an analog model is supported--where size representation is positioned on a size continuum. The analog model implies that a central mechanism like a moving pointer appears to locate and insert the desired size into the image generation programs. An alternative conceptualization of the analog model is where images are stored as small analog entities and are then "blown up" to fit the required size. Finally, the switching effect for imagery can be defined with an additive analog model where the time required to switch size values increases proportionally with the change in area.

General Discussion

The experiments presented in this dissertation, when coupled with Weber et al.'s experiments, demonstrate that the switching phenomenon is a general effect which occurs for at least three response systems: speech, handwriting, and imagery. Consider comparing the magnitude of the switching effect as a function of the time per character in its own right. Figure 14 presents these relative switching time results for each demonstration of the switching phenomenon: (1) Speech Switching (magnitude/intensity), (2) Handwriting Switching, (magnitude/size), (3) Image Switching (magnitude/size). The measure of mean relative switching time is shown on the left ordinate in Figure 14. It represents a percent which is derived by dividing the mean time per switch by the mean time per character in the constant conditions. The right ordinate represents absolute mean switching time.

Insert Figure 14 about here

It is apparent that the relative switching effect is much more pronounced for the response systems requiring motor movement (speaking and writing) than for the purely cognitive system (imagery). One possible explanation for this difference is that altering motor programs may require active inhibition of ongoing behavior. Image production programs may not require inhibition. To be viable, this hypothesis requires a method of independently measuring inhibition rates in the different response systems. A second explanation centers on the complexity of the response programs, where increased complexity results in increased programming time (Kerr, 1978) or increased subprogram compiling time (Sternber, Mosell, Knoll, & Wright, 1978). For motor movements such as speaking and writing, the programs may be complex. Image production programs on the other hand may be relatively simple even though image <u>generation</u> time is relatively large. This 'complexity' hypothesis would predict that image switching time would be faster than motor switching time--which was found. Of course, such a hypothesis must remain vacuous until there is some independent method of determining complexity. In any case, there is a need for more specification on the relationship between switching time and character execution time.

Regarding mean character execution time, the results showed substantial increases for speaking, writing, and imagining, where the mean times were .251 (Weber, et al., Experiment 4, in press), .797 (constant sizes in Experiment 1), and 1.230 (constant sizes in Experiments 3 & 4 combined), respectively. Weber and Castleman (1970) demonstrated that image production takes longer than speech production, with essentially the same pattern of results. There is now evidence that fundamental differences exist in the rates and ways in which information is processed in imagery and the motor-related modes of speech and writing. Moreover, the present studies indicate that generation time and switching time are very different processes for each response mode.

Consider now applying results from the experiments to the question of locating the switching function in information processing. Stage models of cognitive processing have received considerable attention since the demonstration of additive factors logic in reaction time data (Sternberg, 1969). Using the framework of stage models, many interesting questions have emerged. For example, Cooper (1980) reviewed recent literature in visual information processing. She concluded that qualitatively different modes of information processing can operate within a single stage. Cooper claimed that early visual processing may be either global (holistic) or analytic (where attention is towards detailed local information). A second interesting line of research (Logsdon, Hochhaus, & Williams, Note 2) considered the effects of specific drugs on the operation of functions in cognitive stages. Results from their experiments indicated that secobarbital effects early stages whereas alcohol effects later stages of processing.

Which stages of processing are implicated in the present series of experiments? Clearly the switching effect in imagery occurs in a central location. This is precisely why studying mental imagery is so difficult. In speech and handwriting, the form of the model which describes the switching phenomenon is symbolic. Again, a central location is implicated because the symbolic model is contrary to any theory that would claim that the size switching effect is due to rapid activation and damping of peripheral components (muscles, jaws, etc.). Peripheral effects for motor-related tasks may be involved only in this sense: as the size for handwriting increases to the Large condition, the peripheral components may be overdriven and the time per character increases. However, for imagery, a purely central system, the time per character for Large is also greater than for Small. Therefore, peripheral muscle overloads may not be responsible for the size effect in handwriting because the same effect is found in imagery.

A second explanation for the size effect assumes that an early visual stage is affecting processing time in handwriting and imagery. In Experiments 1 and 2, for handwriting and the trace modes, a size effect exists for constant size conditions. It is possible that in both of these modes the visual components are overdriven with large sizes. However, in the imagery experiments the perception mode did not show a size effect--where the task was primarily visual. Thus the hypothesis that early visual stages affect processing for increasing sizes is not supported. In summary, the precise identification of components responsible for the pure size effect for handwriting and image size switching remains for future work.

One conclusion that can be discussed with some precision is the form of the model that describes the switching phenomenon. In the present experiments two models, analog and symbolic, were compared. This comparison addressed a current concern of cognitive psychology which questions analog versus propositional descriptions of internal mental events. As a prefatory note, in the present context it seems more succinct and accurate to say that size is represented by passing a size parameter to a size function rather than saying that size is represented propositionally. Describing a function as symbolic leaves open the question of the format for representing information.

One study which tested analog and symbolic models was performed by Shulman, Remington and McLean (1979). They asked whether movements of attention across the visual field are symbolic or analog in form. This question was appropriate considering evidence linking internal mental processes with an analog model. (For example, Cooper and Shepard (1973) found analog-like processing in rotation of visual images. Similarly, Rosch (1975) argued for an analog model describing the effects of distance between semantic categories.) In Shulman, et al.'s study, subjects fixed their attention on a point in the middle of the visual field. An arrow was then presented which cued subjects to move attention (without moving the eyes) either left (towards a visual target) or right (away from the target). A visual detection stimulus was presented on less than 10% of the trials at various distances between the fixation point and the target. The detection stimulus was also presented at various times after subjects were cued to move their attention. Subjects were to respond as quickly as possible by pressing a button when the detection stimulus appeared. Results showed that reaction time to the stimulus was facilitated if it was presented at specific times and locations between fixation on the starting point and attending to the peripheral target. Facilitation effects followed a rule which corresponding to continuous linear movement of attention across the visual field. These results were interpreted as support for an analog model of attention switching.

Posner (1980) commented that Shulman et al. (1979), did not find results which supported an analog model of attention switching when the probe occurred on the side of the fixation point opposite from the visual target. In an unpublished work, Posner demonstrated that when no arrow was presented to cue the direction for attention to travel, then reaction time for detection of probes at different distances from fixation was uniform. Thus, Posner argued that Shulman et al.'s (1979) results for detecting probe stimuli while moving attention to a target depend on instructions to move attention in a particular direction.

Posner's reinterpretation of Shulman, et al.'s study is important for the present imagery experiments. The perception mode in the combined imagery experiments clearly showed an analog switching effect. It does not seem likely that such effects are attributable to the peripheral motor components of the task. Otherwise, an analog effect would be predicted for the handwriting experiment. Therefore, it seems plausible that the analog effect for the perception mode results from a switching process in visual perception (Shulman, et al., 1979). If Posner (1980) is correct, then the analog effect for the perception mode occurred because subjects were instructed to shift their perception to different size squares in the response strings. On the basis of this reasoning, the analog switching effect found in the perception mode may be an artifact of the instructions to move visual attention.

Consider now the analog switching effect found in mental imagery. Arguments concerning analog versus symbolic descriptions of internal mental events exist in the mental imagery literature. For example, Cooper and Shepard's (1973) demonstration of a positive linear relationship between response time and angle of image rotation may not be strictly interpretable as support for an analog model. Kosslyn (1980) argued that image transformation processes occur in an incremental fashion. Rotations of a surface image may therefore be manipulated digitally a portion at a time.

Results from the present image studies suggest that analog processes do exist in image generation. The pattern of results for generating constant size images demonstrates a simple size effect. In addition, the image switching effect is described with an analog model where image area and generation time are positively and linearly related. (Note that the switching time equation subtracts out any effects due to generation time.) In summary, the present experiments provide evidence for analog processing in both image size switching and image generation time.

At this point it is important to discuss the dynamics behind the switching phenomenon. Motor programming concepts (Keele & Summers, 1980) provide a succinct rationale for switching effects. Keele and Summers discussed studies which imply that sequences of movements in at least some instances are centrally represented as a motor program. When these programs are executed, a series of neural commands are sent to the muscles. The execution of the response does not in this case require peripheral feedback from prior movements. Another investigator, Martenuik (1976), discussed evidence suggesting that motor programs are formed from the integration of multiple codes that represent rules of movement. According to Sternberg et al. (1978), the integration of these rules may be a set of linked subprograms, one for each unit of the response. For size switching, one subprogram might be responsible for globally defining the sizes of the parts of the response. This entire line of research provides a parsimonious theoretical explanation for the switching effect.

Using programming concepts, the motor-related switching experiments (speech and writing) may be interpretable as instances where the value of a code (or movement parameter) is represented symbolically. The symbol is inserted into the response program (or subprogram) centrally. The switching effect in this case is a measure of the time taken by the control functions to change magnitude symbols where those control functions are themselves unaffected by the meanings of the symbols that they handle. The result is a symbolic model of magnitude switching.

The non-motor switching experiments (imagery) may be interpretable as an instance where the value of the image size is represented on a continuum. The control function for changing the value of the size parameter must execute a serial search through the continuum until the correct value is found. In a serial or analog search procedure, each step is dependent upon the one preceeding it. Thus, the switching time is a function of the 'distance' traveled through the continuum. Once the correct value is addressed, it is presumably inserted into a response program which when executed, initiates image generation. Sternberg et al. (1978) postulated that a search and retrieval process through a word list may be self-terminating. This postulation leads here to a prediction that programming time and magnitude of change are positively and linearly related--which was found.

Another possible explanation for the switching effect would feature response generalization and facilitation as opposed to response programming. For the moment, suppose that a comparator function is responsible for switching effects. The comparator would test whether a chosen magnitude (size or intensity) is correct before the actual response is initiated. Presumably more comparisons would be necessary as the discrepancy between the previous response size and the following response size increased. Therefore, switching time would increase. Response sizes that were close together would facilitate each other leading to faster switching times. The resulting data would support the analog model. This facilitation hypothesis is not substantiated because it would predict analog results for writing and speaking--which were not found.

As a note, the results of the present experiments do not support the view that the basic code by which movement-related information is stored is an image (Posner, 1969). If movement information were stored as an image, then the analog switching effect found for imagery would occur as well in writing--because images underlying writing movement would have to be changed in order to change the size of writing. Since image size switching and writing size switching were found to be essentially different processes, it is argued that movement information is not fundamentally related to imagery.

An interesting conjecture may be formed by considering the relationship between vocal intensity switching and handwriting size switching. Harris, Owens, and North (1978) and McLeod (1977, 1978) used the dual-task paradigm to test a multiprocessor model of attention. Subjects in these experiments performed a continuous manual task. Simultaneously they monitored for an auditory signal. When an auditory probe was presented, subjects either responded manually with the other hand or responded verbally. Performance on the continuous manual task decreased when responses to the probe were manual. Performance was relatively unaffected when responses were vocal. It was concluded that manual and vocal responses are produced by independent processes. The results from Weber et al. and Experiments 1 and 2 in this series suggest that manual and vocal responses are related in at least one way. Both response systems coordinate changes in magnitude via symbolic functions. It seems possible that the switching control processes in each case may be synchronized. One might predict that because of this synchronization vocal and manual responses may be programmed in parallel, and thus would not interfere with each other.

As an additional general comment, much of the reasoning in this series of experiments centered on being able to go from a theoretical prediction of sameness to saying that empirical results for two or more conditions took the same time. Those schooled exclusively in statistical hypothesis testing will be very uncomfortable about such a pattern of reasoning. Nonetheless, it is a common pattern of reasoning in other sciences (Polya, 1954), and it of course involves plausible (scientific) rather than logical inference. Indeed, it is a pattern of reasoning that is required whenever a prediction from theory is tested against data. There are no obvious statistical tests of sameness, but various switching times 'look the same', and they are not significantly different.

As a concluding remark, it is evident that the switching time paradigm has considerable potential for the study of those control processes that must be at work in the selection of response characteristics. For the future, it would be interesting to discover (1) what role the visual system plays in scaling sizes of manual responses such as handwriting--which might be tested by blindfolding subjects, (2) what role the auditory system plays in scaling intensity of vocal responses--which might be tested by masking audition, and (3) what magnitude representations operate in purely cognitive response systems other than mental imagery--such as distance in semantic networks. Perhaps the most important unanswered question remains. Why should the nervous system represent magnitude scaling of different attributes in different ways?

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Figure Captions

1. Experiment 1, Handwriting. Illustration of response forms for Small, Large, Small/Large, and Large/Small sizes.

2. Experiment 1, Handwriting. Illustration of the method for measuring accuracy using the single letter 'h' (enlarged for clarity).

3. Experiment 1, Handwriting. Mean generation time for constant and alternate sizes.

4. Experiment 2, Handwriting and practice. Mean generation time and switching time across days.

5. Experiment 3, Mental image size - multiple letter task. Illustration of response squares for Small, Large, Small/Large and Large/ Small sizes.

6. Experiment 3, Mental image size - multiple letter task. Mean generation time for constant and alternate sizes.

7. Experiment 4, Mental image size - single letter task. Illustration of stimulus and response squares for a constant size. (Asterisks indicate the response sequence. They were not present for subjects and are shown here for expository purposes only.)

8. Experiment 4, Mental image size - single letter task. Illustration of response squares for Small, Large, Small/Large, and Large/ Small sizes (for each size two layouts are presneted - one with the first square lower and one with the first square higher).

9. Experiment 4, Mental image size - single letter task. Illustration of the three test stimuli (N, G, F) and the practice stimulus (Z).

10. Experiment 4, Mental image size - single letter task. Mean generation time for constant and alternate sizes.

11. Experiments 3 & 4 combined, Mental image size. Mean generation time for Small, Medium, and Large constant sizes.

12. Experiments 3 & 4 combined, Mental image size. Mean generation time for constant and alternate sizes.

13. Experiments 3 & 4 combined, Mental image size. Mean switching time for SM:MS, ML:LM, and SL:LS switches.

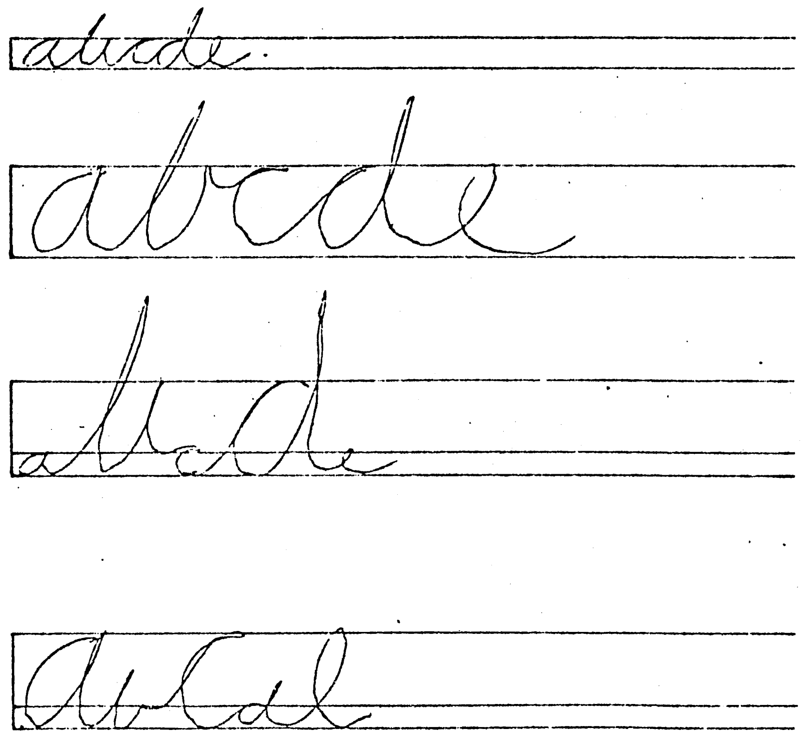
14. Relative switching time (left ordinate) and absolute switching time (right ordinate) for three demonstrations of the switching phenomenon - voice, handwriting, and imagery. (a. Based on formula dividing mean time per switch by mean time per character. b. Results from Weber, Blagowsky, & Mankin, in press.)

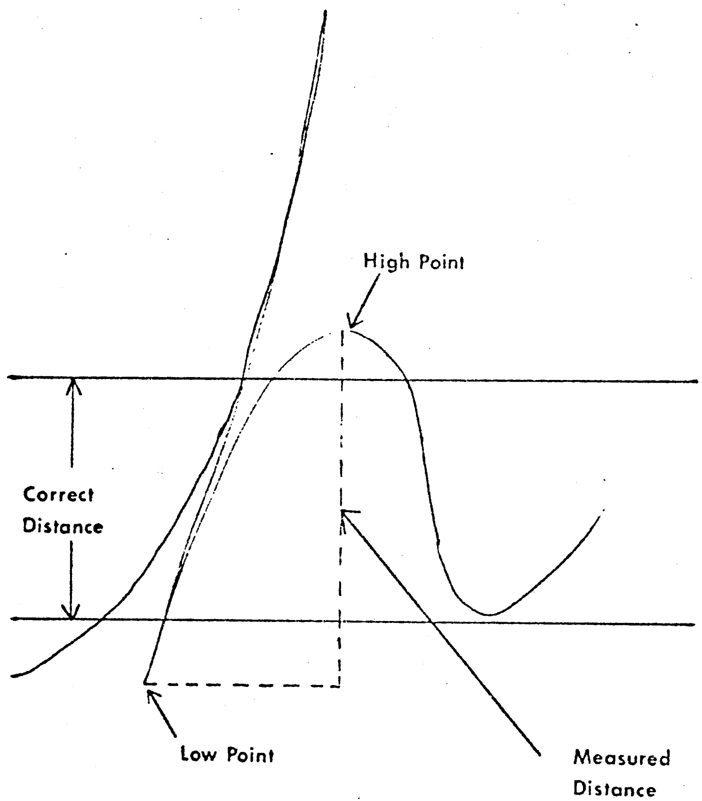
Small

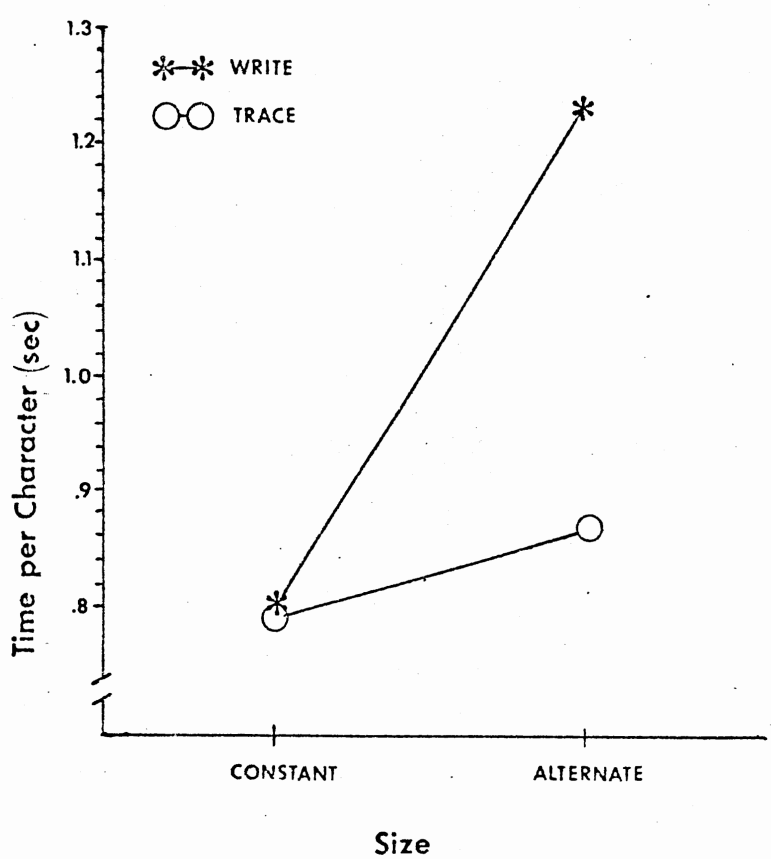
Large

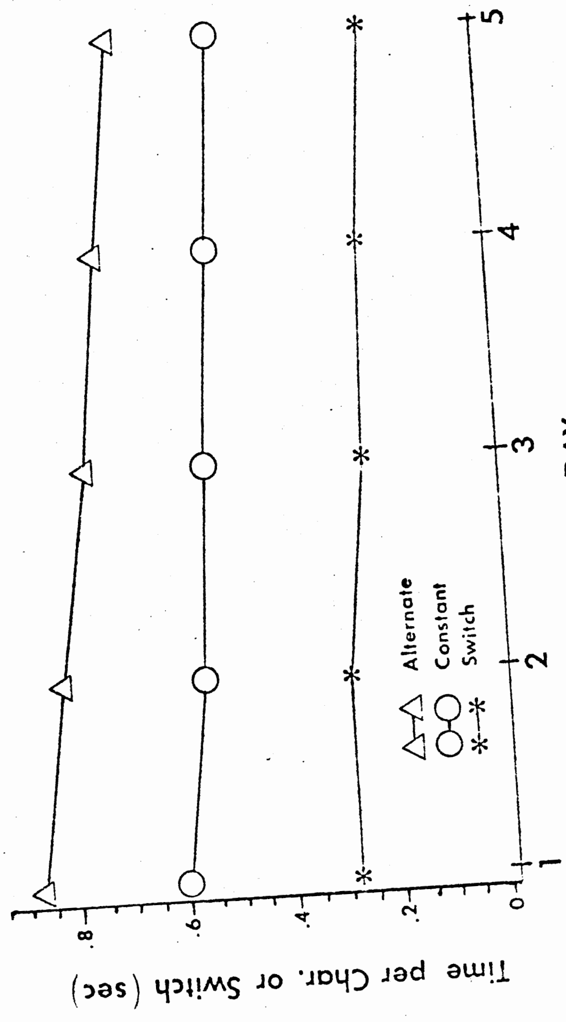
Small/Large

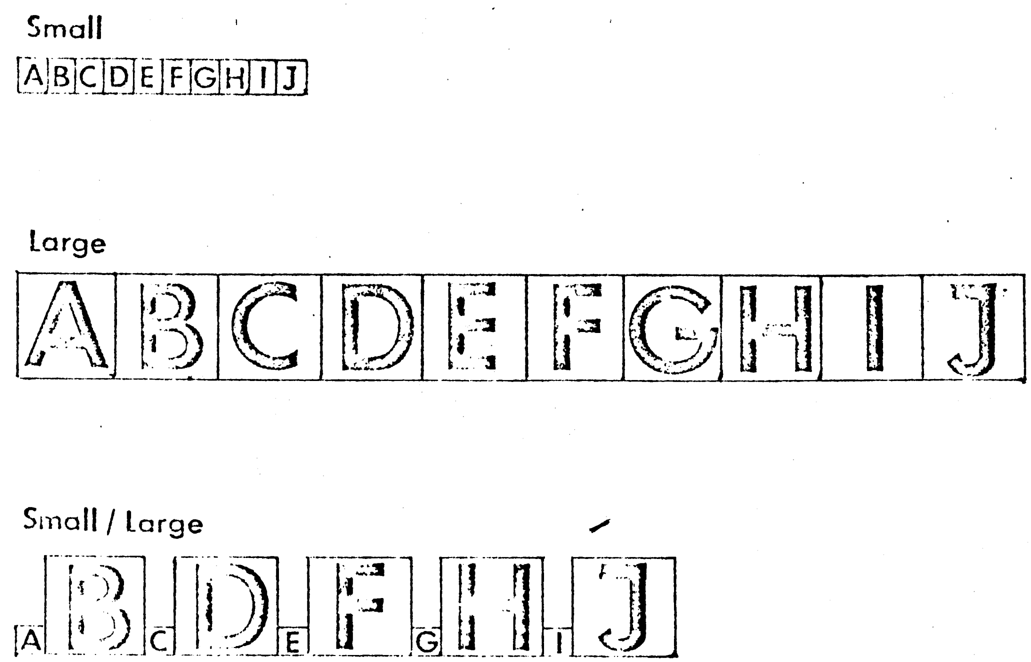
Large/Small

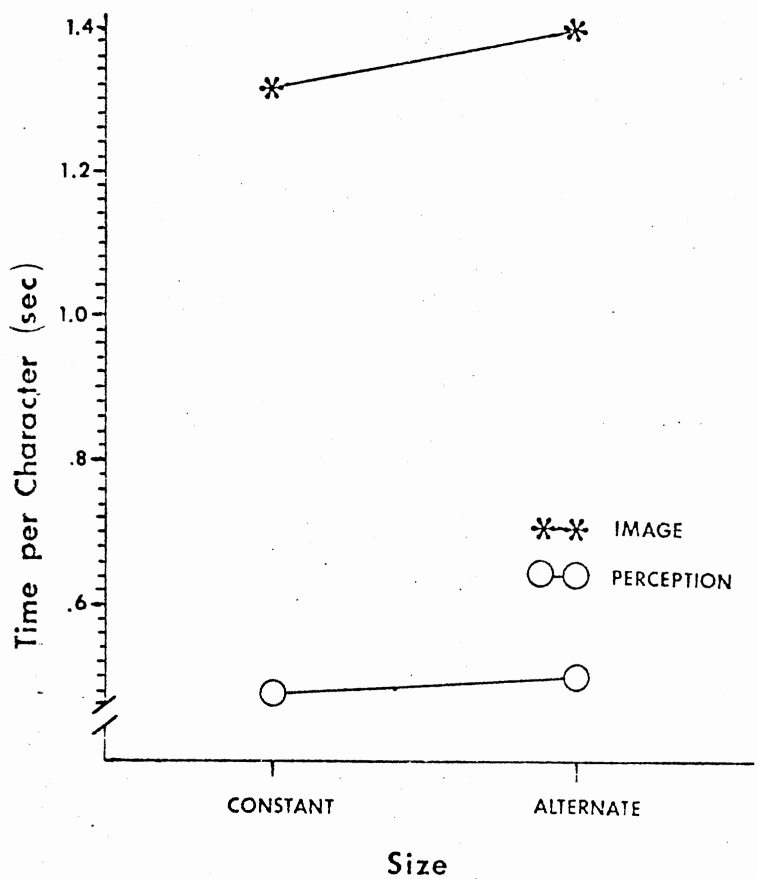



High Point
Correct
Distance
Low Point
Measured
Distance

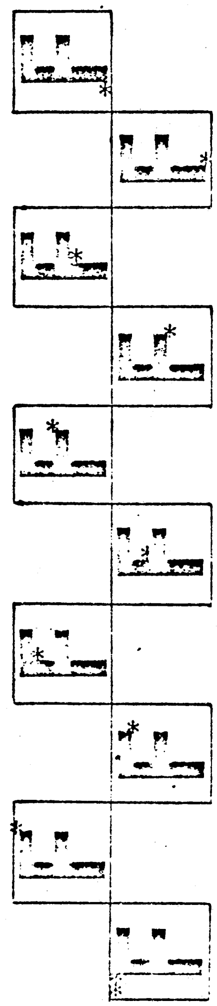

1.3
1.2
1.1
1.0
.9
.8
WRITE
TRACE
Time per Character (sec)
CONSTANT
ALTERNATE
Size

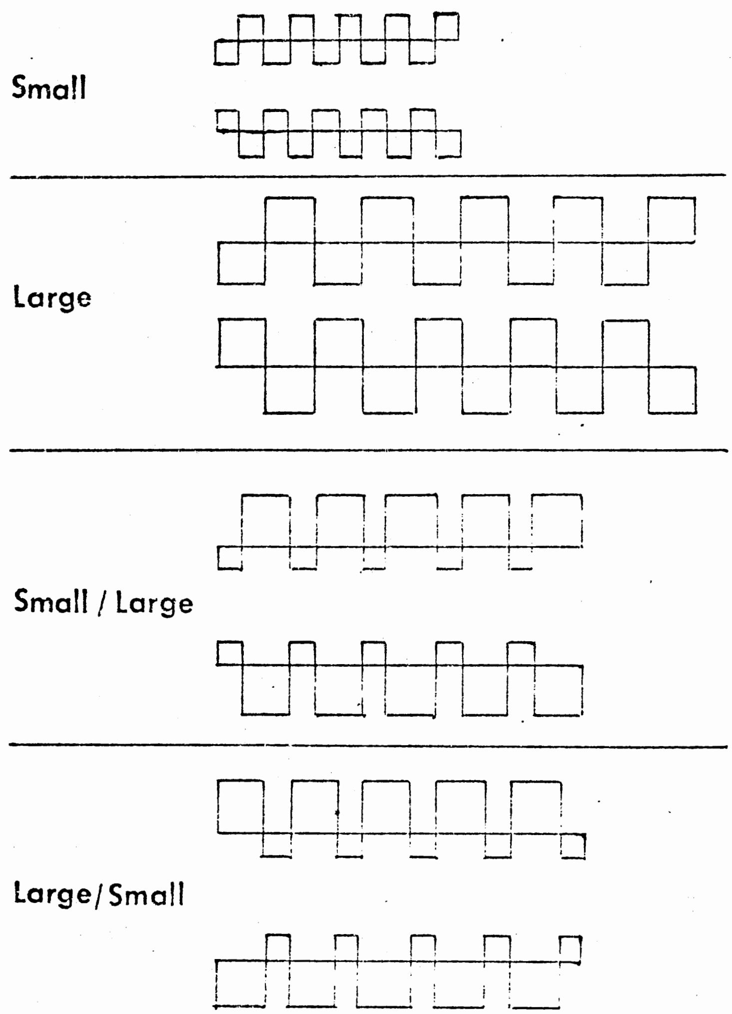

Time per Char. or Switch (sec)
.8
.6
.4
.2
0
1
2
3
4
5
DAY
Alternate
Constant
Switch


Small
ABCDEFGHIJ
Large
ABCDEFGHIJ
Small / Large
ABCDEFGHIJ

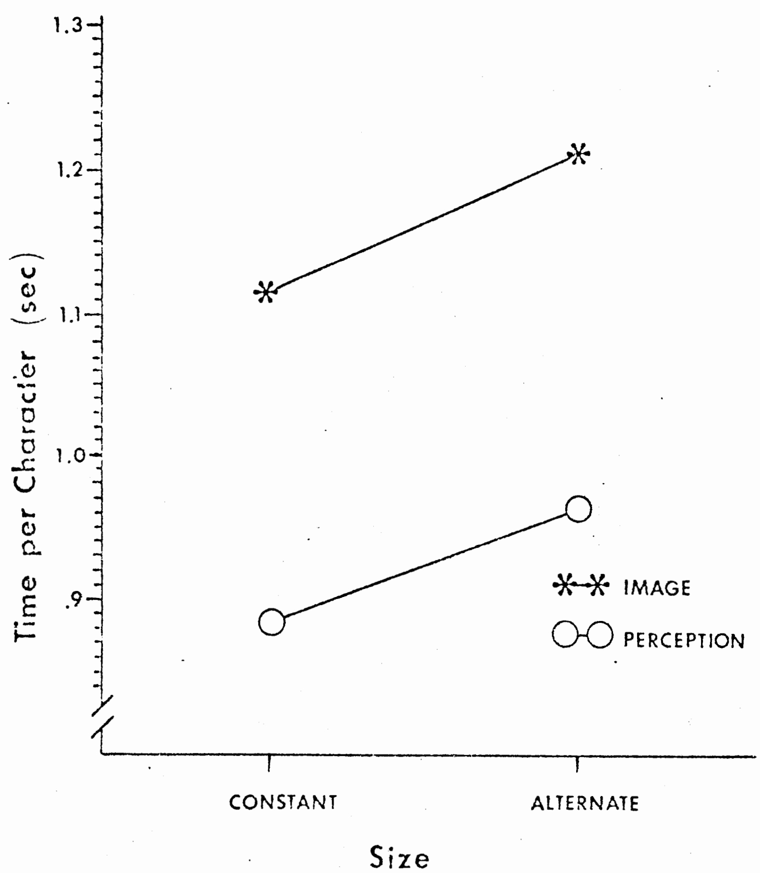


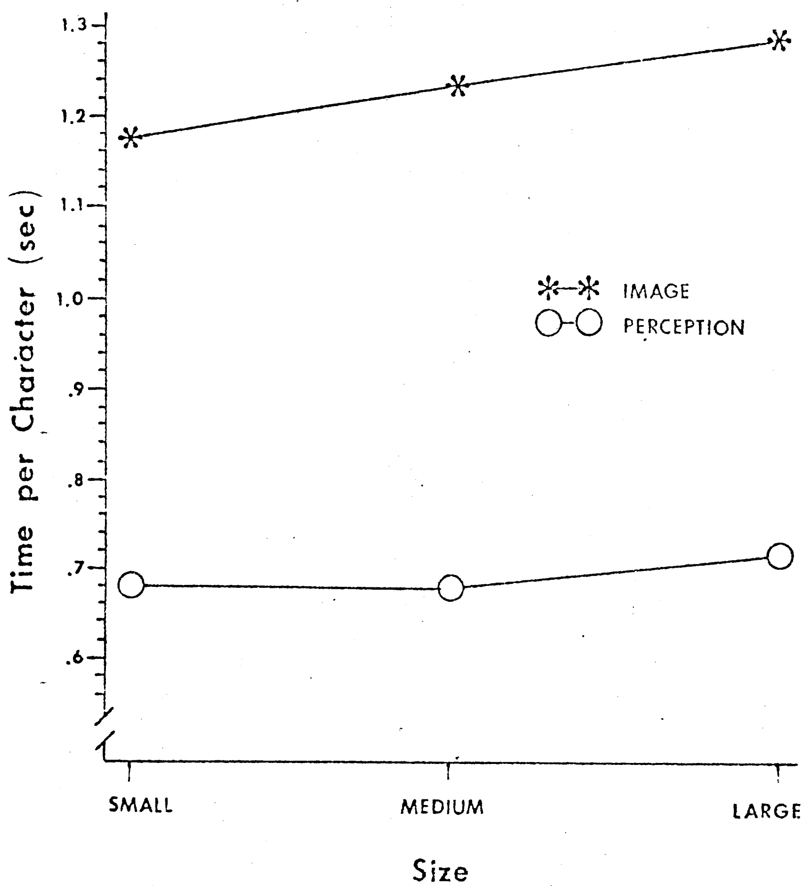
1.4
1.2
1.0
.8
.6
Time per Character (sec)
IMAGE
PERCEPTION
CONSTANT
ALTERNATE
Size

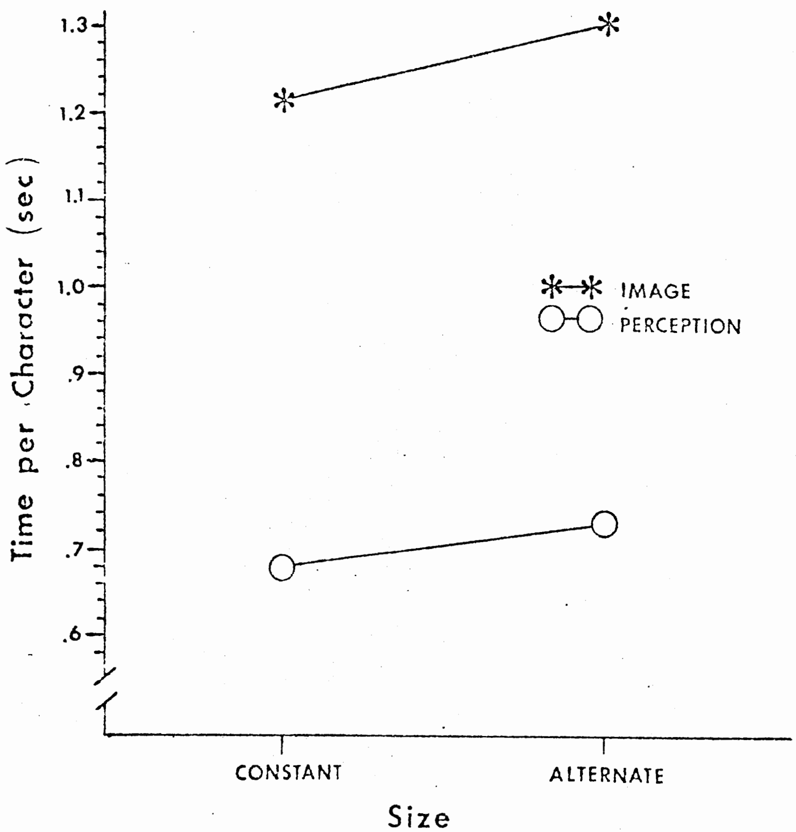


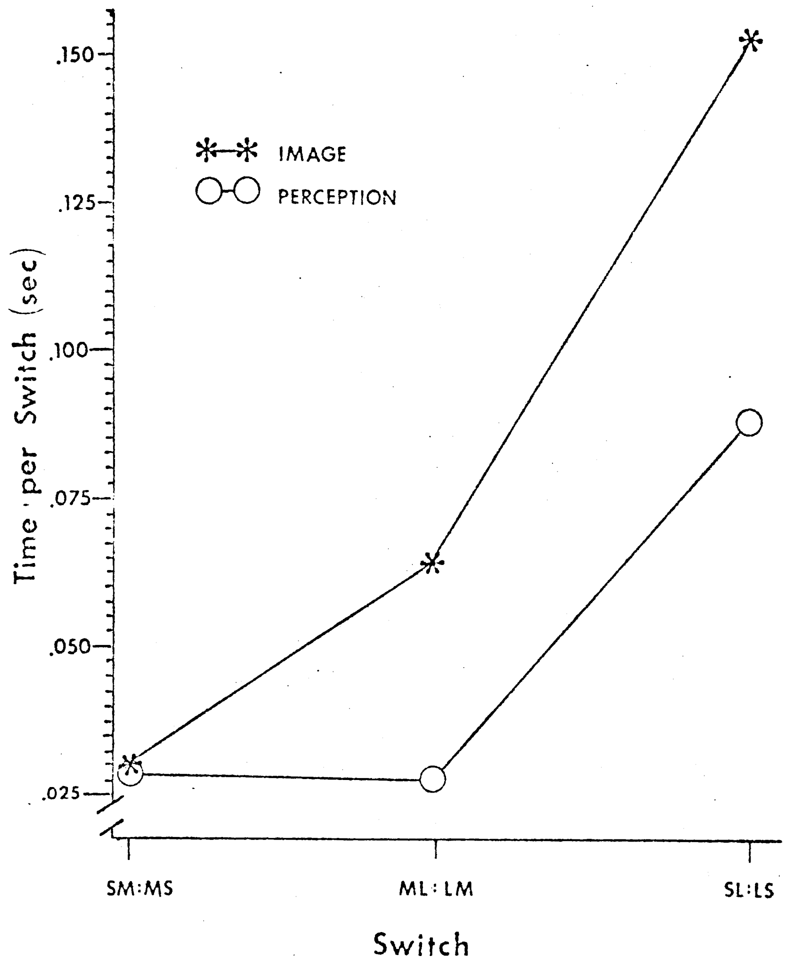

Small
Large
Small / Large
Large/Small

NZ
CF

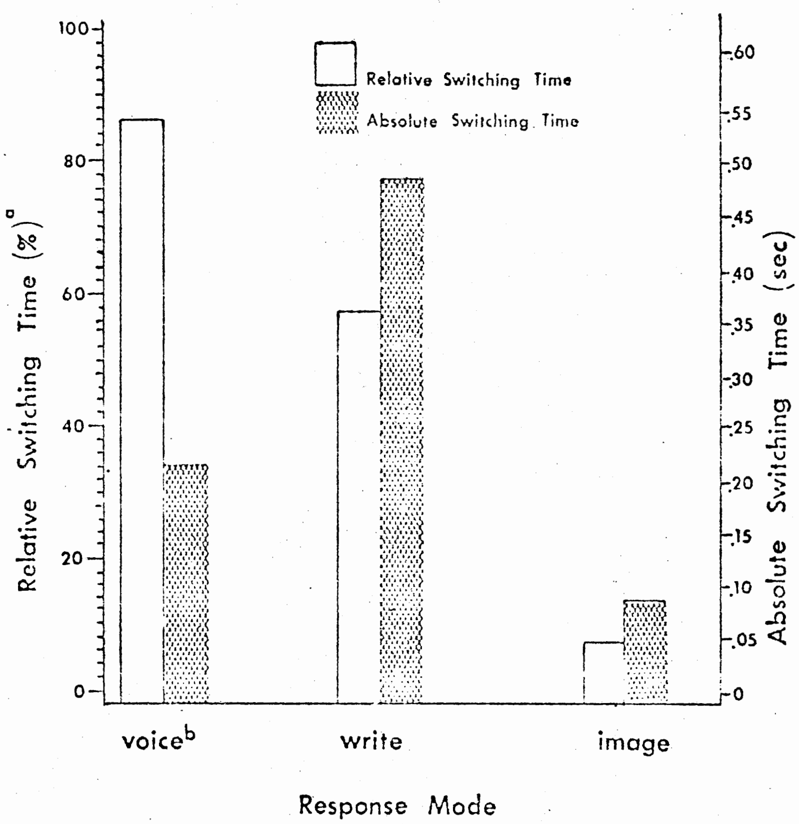

1.3
1.2
1.1
1.0
.9
Time per Character (sec)
IMAGE
PERCEPTION
CONSTANT
ALTERNATE
Size


1.3
1.2
1.1
1.0
.9
.8
.7
.6
Time per Character (sec)
IMAGE
PERCEPTION
SMALL
MEDIUM
LARGE
Size


1.3
1.2
1.1
1.0
.9
.8
.7
.6
Time per Character (sec)
IMAGE
PERCEPTION
CONSTANT
ALTERNATE
Size



.150
.125
.100
.075
.050
.025
Time per Switch (sec)
IMAGE
PERCEPTION
SM:MS
ML:LM
SL:LS
Switch



Relative Switching Time
Absolute Switching Time
Relative Switching Time (%)[a]
Absolute Switching Time (sec)
100
80
60
40
20
0
.60
.55
.50
.45
.40
.35
.30
.25
.20
.15
.10
.05
0
voice[b]
write
image
Response Mode

APPENDIXES

APPENDIX A

CONTROL PROCESSES IN COGNITION

Introduction

The purpose of this discussion is to present a theoretical foundation for the concept of 'control processes' as the term is used in the present series of experiments. The first section presents an historical perspective by outlining pre- and post-behavioristic work in cognitive psychology. Section two discusses major advances in human information processing mainly within the last decade. This section is composed of three subdivisions: (1) Information Processing, (2) Control Processes, and (3) Control Processes in Response Generation.

The notion of "control processes" is a general term refering to cognitive functions that 'handle' information. In the present series of experiments, control processes are functions which select and pass the values of response parameters (such as size) to response programs. These control processes are themselves independent of the response programs. They merely serve to construct programs which are necessary for executing specific actions.

Alfke and Larson (1973) in an introduction to integrated circuits and computer design provided ample metaphors which help conceptualize human control processes. Control processes that organize and assemble information in computers are: adders/subtractors, multipliers/dividers, comparators, error detectors, and code converters. Human control processes may operate in much the same manner. Atkinson and Shiffrin (1968) used the computer analogy as follows. Cognitive structures or mechanisms are like the computer hardware. Control processes are the functions that determine the operation of the computer. Control processes are not the structural hardware of the system, nor are they the information that is processed. Rather they are functions which serve to route, translate, and otherwise handle information. Examples would include processes like: FIND x, MOVE to a, COPY x, TEST (x,y), ASSOCIATE (x,y), ATTEND TO CHANNEL x, SWITCH BETWEEN (x,y), etc.

Chase (1978) defined control processes as those processes that group together to organize and assemble the information which is required to perform tasks. Control processes are therefore task-independent. Norman (1976) distinguished between two types of information processing structures: fixed structures and flexible structures. Fixed structures are specific neurological entities such as sensory and storage systems. Control processes are one kind of flexible structure. They are the general rules, operations, and strategies a person uses to operate upon information.

Historical Perspective

The following discussion begins with the earliest work on mental operations and control processes, and ends with the most contemporary work. Thus, the organizationof the discussion is by time, not necessarily by subject matter.

In an era when philosophers and physiologists were occupied with mental phenomena, Donders (1869) performed quantitative experiments designed to analyze the nature of connections between mental processes. This line of research provided a theoretical foundation for later work on cognitive control processes. Donders' subtractive technique assumed that mental processes were organized into a series of discrete stages. The technique was supposed to measure the time required for performing the mental processes within each stage. If a pair of tasks could be devised, one of which had one less stage than the other, then by subtracting the shorter task from the longer task, the time to process information in the missing stage could be determined. In one experiment, Donders determined the time required to respond to an expected versus an unexpected vowel sound. The stimulus was the sound of a vowel and the response was the repetition of the same vowel. The two experimental conditions were: (1) where the subject knew what vowel was to be presented, and (2) where the subject did not known which vowel was to be presented. Results for the cue condition showed that mean response time was 0.180 seconds. Mean response time for the no cue condition was 0.268 seconds. Thus recognition of vowels and the time required to access the vowel name was, by subtraction, 0.088 seconds.

Donders' approach was founded on the belief that it is possible to isolate and measure lementary processes incognition. One limitation of the subtractive technique is that it assumes serial processing. Therefore, stages that partially overlap in time are obscured. A second problem exists. If a given task has one less component than a second task, then Donders assumed that the components remaining in the initial task were unchanged. It may be argued that inserting or deleting a component of a task might alter the total structure of the behavior. Using this argument Woodworth (1938) argued for the invalidity of the subtractive procedure. For example, Woodworth described introspective reports which supposedly showed that a preparatory set or adjustment was unique to the kind of reaction being tested.

Investigations were conducted by a number of early researchers who conceptualized attention as a control process. Hamlin (1896) combined physiological, philosophical, and psychological theories to compare three explanatory theories of attention. The first theory regards attention as a facilitator of ideas. This theory explains that attention is the outcome of an increase in nervous activity and that the 'mind' absorbs energy in an effort to reproduce earlier sensations. Therefore, attention facilitates memories and helps the mind attend to new sensations. The second theory regards attention as an inhibitory control process. Following Wundt's accounts, attention acts to inhibit all but selected impressions and memory-images. Hamlin rejected this theory on the grounds that inhibition itself is an excitation since it actively exerts influence upon ongoing processes. Thirdly, Hamlin described a theory in which attention is a combined facilitation and inhibition process. This theory is based upon early neurological descriptions of the action of the nervous system, where a given movement is enacted by simultaneous excitation and inhibition of nerve cells. Hamlin concluded by suggesting that attention is a mental control process which intensifies sensations by both inhibition and excitation of ongoing activity. Intensification is independent from increased physical stimulation. Consequently, attention processes are centrally located.

Of particular interest to the present study are experiments on handwriting. Downey (1908) studied various processes in handwriting. The investigations were undertaken to analyze control processes relative to the nature of (a) mental imagery, (b) the function of feedback in motor control, (c) dual-modality performance, and (d) the question of individual differences in imagery and attention. Like others during this period, Downey used trained introspectionists as subjects. The method called for subjects to write or speak a given phrase under different conditions, then to report on changes which occurred in making their responses. Downey considered that vision, attention, and time controlled handwriting. Three series of experiments were conducted: (1) Writing--where subjects wrote blindfolded, left handed, using mirro images of the writing hand, and writing in a strained position; (2) Writing under Distractions--where objects were distracted by counting aloud, reading mentally, reading aloud, counting aloud while blindfolded, and counting the number of times a specific word occurs in list; (3) Time-Lapse--where a time lapse occurred between specifying the experimental condition and performing the task. Results from introspections indicated that no general conclusions could be drawn that applied to all subjects. Downey then categoriezed subjects into various groups in an attempt to explain her results. Unfortunately, categorizing subjects on the basis of introspections does not address the issue of the general nature of control processes in cognition.

An objective experimental analysis of writing movements was reported by Freeman (1914). Although not explicitly designed to study control processes, this experiment presents an ingenious method which demonstrates that complex motor responses are controlled by a rhythmic grouping of elementary responses. Subjects were children and adults. An apparatus was constructed which measured the speed and pressure of writing. Speed was measured in the following manner. A piece of paper continuously moved underneath the sheet of paper that subjects wrote upon. The writing movement was transferred from the top sheet to the moving sheet by means of an inked ribbon much like a typewriter ribbon. An electric motor marked the moving paper every tenth of a second. By measuring the marks on the moving strip an indication of the speed and size of the writing was obtained. Writing pressure was measured using a response table which was connected to a lever. Changes in writing pressure were transmitted to a stylus which recorded on a moving strip of smoked paper. Detailed results showed that parts of each letter are written at different speeds and pressures. In addition, size of writing affects speed positively and linearly. A comparison of writing from children versus adults indicated that generally children write slower than adults. Adults also demonstrate a uniformity in writing when connecting letters with each other. Finally, children do not rhythmically group elementary strokes into units. Freeman concluded that adult writing is characterized by an organizing factor which unites successive strokes into groups. This organization affects the series of innervations which compose the writing movement by controlling the translation of meaning into the appropriate output.

During the period from the 1920's to the early 1950's psychology was dominated by behaviorism. Processes and mechanisms in cognition were ignored while behaviorists were busy deriving stimulus--response laws that would serve to predict behavior. Chase (1978) commented that the decline of behaviorism was due in part to its failure to account for findings from research on the limits of human performance. For example, S-R concepts were inadequate for explaining phenomena such as selective attention, immediate memory span, vigilance decrement, and attention switching. The failure of behaviorism and advances in communication theory created an environment which fostered modeling man as a communication channel (Broadbent, 1958). Within this rubric researchers postulated the existence of internal mechanisms which systematically process information.

Information Theory

An important next step towards specifying control processes in cognition followed use of quantitative methods borrowed from communication theorists. Presumably control processes are behind the processing of information. Hick (1952) attempted to measure man's information handling capacity by postulating that the time it takes to process symbols is proportional to the information content of the symbols. According to Welford (1976) this provides insight into the problem of why reaction time rises with degree of choice. In a choice reaction-time study, Hick found that reaction time increases linearly with amount of information; that is, increases logrithmically with the number of choices that are available. This function could be adequately described with the formula

$$H = \log 2 N \quad (3)$$

where H = the amount of informationconveyed by one of N equally likely events and the unit of information is the binary digit.

Hyman (1953) extended Hick's results by varying the probability that signals will occur. He made subjects' choices more or less probable by changing the sequential probabilities until stimuli could be anticipated from stimuli that preceeded them. The results of these manipulations allowed theorists to posit the 'Hick-Hyman Law' which states

$$\text{Reaction Time} = a + b*H \quad (4)$$

where H is the stimulus information, a describes the input and output times for the system, and b is an estimate of the central processing channel capacity in bits per second. In summary, each increase in the stimulus information results in an increase in the time it takes the processing channel to operate. The extra time then becomes an estimate of the channel capacity measured in seconds per bit.

The communication model for information processing set the stage for serious investigation into control processes in cognition. However, Chase (1978) mentioned several reasons for its failure. First, there appears to be no set rate for information transmission. Rate depends upon familiarity with the stimulus material, repetition or priming effects, and compatibility between stimuli and the response codes. Second, problems arose with the concept of a binary digit as the measure of information. Miller (1956) introduced the concept of the chunk which means that information processing capacity may vary in terms of bits but not in terms of larger units.

At this point, work on control processes has been reviewed from the Nineteenth Century to the present time. In summary, early investigations did not specify control processes directly. Instead, theory aimed at identifying the 'hardware' features of cognition. Thus, control processes seemed to be lumped under the general concept of 'attention'. The next section of this discussion reviews the use of computer analogies in cognition. This trend leads directly to the present series of experiments on control processes in response generation programming.

Human Information Processing

Chase (1978) noted that the switch from information theory to information processing theory involved not only attending to much smaller parts of the cognitive system but involved a general move towards computer analogies. In addition, as Sanders (1980) remarked, information processing research arose from a general sophistication of cognitively oriented theories. This section shows how the information processing trend in cognitive psychology provides a foundation for an analysis of control processes as exemplified by the present series of experiments.

Information Processing

Sternberg (1969) presented a paper which provided two immediate benefits: (1) a more complete description of information processing underlying memory scanning, and (2) a methodology for studying mental processes. The methodology was based on the principles of Donders' subtractive technique and Sternberg's own additive factors method. The main feature of the additive factors method is the search for non-interacting effects of experimental factors or tasks on mean reaction time. Factors which do not interact are hypothesized to affect different stages in information processing. Factors which do interact must therefore be affecting common stages in processing.

Sternberg's experimental paradigm was as follows. Subjects memorized a small set of digits. On each trial a test digit was presented to which subjects responded positively if the digit was a member of the memorized set and negatively if it was not. The factors considered in this experiment were: (1) stimulus quality, where the test digit was presented either intact or degraded; and (2) set size, where the memorized set of digits ranged in size. Sternberg found that reaction time linearly increased with set size at a rate of 38 msec per item.

Degrading the test stimulus increased subject's overall reaction time by about 100 msec. The important result was that the slope of the line for degraded stimuli was identical to the slope for intact stimuli. It was concluded that degradation and set size affect two discrete stages in information processing where degradation affects stimulus encoding and set size affects memory search.

Sternberg (1969) realized one important limitation of the additive factors method. He stated that it can not distinguish between processes but only processing stages. For example, a control process such as 'feedback' may occur across stages. Typically, an interaction in the data is used to imply that manipulations affect a single stage. An interaction, though, does not rule out the possibility that a process is common to two or more stages. Sanders' (1980) recognized a second limitation of the method. Additive effects do not necessarily imply separate stages. For example, selecting the response mode (vocal or manual) and programming the parameters of that response (intensity or size) may occur in the same stage and still show additivity in the results.

The information processing approach has led to a wide range of investigations into mental phenomena. Chase and Clark (1972) studied verification tasks where people decided whether a verbal description matches some visual display. Anderson and Bower (1973) extended research into the area of human associative memory by positing a propositional format for information storage. Shepard and Metzler (1971) studied how people operate upon mental images. But, as Chase (1978) has argued, there exists more than ever a need for theoretical analyses of mental processes that are common to more than one task. A common mental phenomenon that seems to underlie many cognitive tasks is the control structure of cognition. The next section will discuss two models of the control structure: (1) the production-system model of Newell and Simon (1972), and (2) the mathematical model of Atkinson and Shiffrin (1968).

Control Processes

Newell and Simon (1972) published a book on human problem solving that described operations in cognition. In Newell and Simon's experiments, subjects were given complex problems such as cryptarithmetic tasks. When trying to find rules which subjects used to solve these problems, Newell and Simon identified certain thought processes called production systems. A production is a rule which states that if a given condition is present, then a specific course of action should follow. For example, if condition 'A' has occurred, then action 'B' should be performed. Conditions are knowledge states, whereas actions are mental operations. The existence of the new condition (following action 'B') gives rise to a new action protocol. In this manner goal directed behavior is organized by a control structure. A computer simulation was conducted to actually test Newell and Simon's predictions. The computer model was important because it modeled control processes which function across tasks. It was limited, though, because it simulated reaction time by arbitrarily assuming how elementary psychological processes operate.

Chase (1978) argued that Newell and Simon's account of cognitive control structures is valuable for complex behaviors. On the other hand, the real time measurements of these behaviors are not of a magnitude that allow study of elementary cognitive processes. That is, processing time for production systems is on the order of several seconds.

A mathematical model which focused on the details of control processes was presented by Atkinson and Shiffrin (1968). The model begins with assumptions that short-term and long-term memory exist as fixed structures. Control processes (flexible structures) include, (a) decisions about which sensory register to attend to, (b) what to rehearse, (c) what to chunk and group in short-term memory, (d) search and retrieval processes from long-term memory, and (e) use of mnemonic devices for storage in long-term memory. In a companion publication, Atkinson and Shiffrin (1969) extended the mathematical model to storage and retrieval processes in long-term memory. Control processes in this analysis consisted of sorting what to store, when to store, and how to store information in long-term memory.

Consideration of a large number of memory tasks allowed Atkinson and Shiffrin to study the organization of control processes. However, some objections to their model have emerged. According to Chase (1978) the analyses do not bear directly upon real time aspects of elementary control processes. Rather than specifically considering the specific mechanisms underlying the flow of information, the model defers to stochastic explanations. For example, the probability that a subject will correctly identify a primed word is a function of buffer size (r), probability of entering an item into the buffer (alpha) growth rate of the buffer (theta), and decay rate of long term strength (T). In this example, Atkinson and Shiffrin do not really consider the mechanisms that underlie information control such as how items are selected for rehearsal. A second objection was raised by Reynolds and Flagg (1977). They claimed that Atkinson and Shiffrin's duplex theory of memory can be reinterpreted in the framework of a 'levels of processing' approach. According to this account control processes are not allocated to operate discretely in short-term and long-term storage jobs. Rather, observed differences in the data are due to differences in strategies that individuals use in performing experimental tasks (q.v., Reynolds and Flagg, Chapter 6).

Despite objections, models such as Atkinson and Shiffrin's provide useful theoretical guides for further research on control processes. The next section will discuss the most current developments in this area.

Control Process in Response Generation

This section deals specifically with control processes that provide selection, order, and regulation to movement. The language of the discussion relies heavily upon programming concepts. This approach is consistent with that of Kelso (1981) who noted that programming theorists no longer question the existence of motor programs. Rather, they question how such programs are structured and composed.

Newell (1978) stated that during the 1970's research efforts in the area of motor control theory were beginning to recognize the importance of dynamic relationships between knowledge and action. This trend represented a move away from traditional S-R accounts of motor learning. Newell claimed that a critical feature of this trend towards more cognitively oriented theories was the revitalization of the schema as a construct for motor acts. The concept of the motor schema is important in the present discussion because it allows consideration of cognitive control processes which may operate across different response modes. In addition to operating across modes, a schema may operate across processing stages. For an elaboration of this point, see Kelso and Stelmach (1976) who argued that feedforeward and feedback control processes operating in different stages of behavior should not be viewed _ipso facto_ as mutually exclusive.

A schema for motor responses may be formed, stored, and implemented in the following manner (Schmidt, 1976). When a person makes a movement, a number of separate pieces of information are stored. First, the response specifications are stored. Second, the person stores the initial conditions prior to the response--position of the limbs, state of the environment, etc. Third, the actual outcome of the movement is recorded. Finally, the sensory consequences of making the movement are stored. The schema is built over time by experiencing relationships between actual outcomes and response specifications. When a person attempts to make a novel movement he enters a schema with the desired outcome and the initial conditions. The schema rules produce the response specifications for activating the novel movement.

Motor control theorists point to the similarity between motor schemas and motor programs (Keele & Summers, 1976; Newell, 1978). In a general sense, action schemas, like motor programs, represent a dynamic link between perception and action. Neisser (1976) stated that the schema is not only the response plan but also the executor of the plan. Kelso (1981) and Klapp, Greim, and Marshburn (1981) suggested further that the preparation of the program is reflected in measurable preparation time. It is particularly important to note that if control processes in response generation operate upon parameters which define characteristics of movement, then altering the value of a parameter might require time.

Schemas must not be thought of as a single program or small set of programs for defining one motor activity. Arbib (1980) reviewed literature which suggests that in everyday behavior a set of interacting schemas control behavior. These may be schemas for perception, planning action, integrating effectors, updating the plans, and finally continuing to perceive. By analyzing studies on the physiology, behavior, and anatomy of frogs and toads, Arbib concluded that behavior is a function of simultaneous interacting processes called schemas.

The schema or motor program concept provides a useful theoretical explanation for the results reported by Weber, Blagowsky, and Mankin (in press). In their study, time for subjects to vocalize a string of characters did not change for conditions where vocal responses alternated between soft and medium intensities versus medium and loud intensities versus soft and loud intensities. Thus, the time for alternating between intensities can be attributed to time to change the value of a vocal output parameter rather than the time to move a pointer along an analog scale to the desired output intensity. Thus, the vocal response program may be constructed as a motor program where values of the intensity parameter are symbolically inserted before the response is executed.

Kerr (1978) summarized a number of experiments which focused upon task factors that influence selection and preparation for movements. The experiments dealt with time for initiating discrete movements, relationships between initiation and execution stages, and factors that influence programming time. After discussing a wide range of studies, some of which produced conflicting evidence, Kerr concluded with the following points. First, the length of time that passes before movement execution reflects the complexity of decisions required to select and prepare responses. Second, this planning period includes (a) a memory stage where stimuli are recognized and preprocessed, (b) a stage where motor control parameter values are computed, and (c) a stage where the parameter values are translated into a format for actual execution. Kerr's analysis of the response planning period identified processes which organize and assemble information. Thus, here conclusions supplement current work on the nature of control processes.

A conceptual model of the optimal control process for perceptual-motor performance was offered by Pew and Baron (1978). This model utilizes information processing concepts for explaining components in skilled behavior. The structure of an optimal control process model includes four stages arranged along a single dimension. The first stage represents perceptual processing. At this level the system extracts meaningful stimuli from a field which contains noise. Noise in this case is a product of the person inadequately attending to the stimuli. Stage two represents the central elements. Here people use a schema to comprehend the incoming signal and to estimate changes that may occur at the next moment in time. Given the best estimate of the state of the system, stage three is entered and the person utilizes a control strategy in which values are assigned to parameters that define action. Finally, in stage four the motor process is actuated. As in stage one, the motor process suffers from a noise source which arises from limited output capabilities.

Pew and Baron identified one aspect of their model which bears directly on the present discussion of control processes. Switching effects may occur in two stages. First, shifting attention to a stimulus item in stage one will result in less noise and hence it will facilitate stimulus identification. Second, control processes operate to assign values to response parameters in the control strategy stage (stage three). Although Pew and Baron did not report results which test their theory, they provided a useful conceptual framework for explaining the results of the present series of experiments. For example, Weber, et al. (in press), suggested that a central stage in processing was responsible for switching effects in vocal output. According to Pew and Baron, the component of the central stage would be the control strategy component where values are assigned to output parameters (stage three).

Consider using Pew and Baron's model to explain the speed at which subjects change pitch in vocal responses. Ohala and Ewan (1973) performed an experiment in which five adult males were asked to execute a series of continuous pitch changes as rapidly as possible. In each sequence of pitch changes subjects alternated between two notes. The range of magnitudes for switches varied between 90 and 220 Hz. Therefore on some trials the pitch change was over a small pitch interval and on other trials the switch was over a larger interval. For a given pitch interval, results showed that upward changes in pitch took significantly longer than downward changes. There was no tendency for switches involving wide pitch intervals to take longer than switches involving narrow intervals. Thus, using Pew and Baron's model, pitch switching occurs centrally in the control strategy stage. This is an important finding which suggests that pitch scaling is represented by symbolic parameters in a pitch function, just as intensity is (Weber et al., in press).

In a similar study on control processes in vocal pitch switching, Sunberg (1977) explained that upward changes in pitch take longer than downward changes because the operating peripheral muscles are different in each case. In the downward pitch changes, muscle activity is somewhat simpler than activity associated with upward changes. These results are thus explained using a peripheral model. Sunberg's most important results was that interval size did not affect speed. Speed of switches in pitch can be considered unrelated to the magnitude of the change--which confers with the present results on size switching in handwriting. Using Pew and Baron's model, the stage that is implicated in changing the value of the pitch parameter is, again, stage three--the control strategy. Apparently, changes in the value of the parameter are unaffected by the magnitude of the value. Time to generate a new motor program would be a function of the time to switch parameter values, not the time to incrementally step a pointer or counter up to the desired output value. Ohala and Ewan's results can therefore be interpreted as an example of control processes operating in central stages of information processing.

APPENDIX B

MODELS FOR CONCURRENT PROCESSING OF TASKS

The models presented in this appendix are oriented primarily towards analyzing complex behavior which involves performing more than one task. As noted earlier, though, analyses of multi-task experiments is troublesome because of possible structural interferences (Klein, 1976). The problem occurs when one task seems to interfere with the second task. Investigators typically regard this as evidence that both tasks require the same mental resource, such as attention. Structural interference occurs when two tasks, such as talking and chewing food, do not require the same mental resource but do require the same structural mechanisms. Single-task paradigms, such as those used to assess switching time in the present series of experiments, avoid the problems of structural interference.

This discussion will show how conceptual frameworks borrowed from computer science and economics may aid in interpretating performance data. Theoretical trends in cognitive psychology follow in some instances from machine information processing concepts. For example, Klapp, Greim, and Marshburn (1981) used computer terminology such as buffer storage and loops to explain data pertaining to articulation movements. Craske (1981) claimed that it is now commonplace to argue that much of behavior is the results of catalogued programs. Another developing trend in cognitive theory borrows concepts from accounting, economics, and production control (Industrial Engineering). These concepts have principally been used by Navon and Gopher (1979, 1980) to reinterpret results from dual-task performance studies.

First, consider the econometric metaphor. Navon and Gopher (1979) drew an analogy between a person performing one or more tasks and a manufacturer producing one or more products. The discussion was placed in the broad framework of economic theory. This approach utilizes the basic concepts of (a) resources, which are processing facilities; (b) demands, which are the amounts of resources required to achieve a given criteria--much like production control; (c) supply which is the limit or capacity of available resources; and (d) performance functions, which reflect the efficiency of resource investment. Two-dimensional tracking may be regarded as a time-sharing function between horizontal and vertical tracking. Tracking error may be measured in each dimension. Demand, or performance standards, may be specified by varying the tolerance levels for error. Resources required to meet the demand criteria are then assessed by manipulating task difficulty. When resource requirements exceed supply, overall decreasing performance results. This, of course, assumes that vertical and horizontal tracking draw from the same resource pool. By plotting performance functions, a measure of the efficiency of resource investment is available.

Navon and Gopher (1978) performed a two-dimensional tracking experiment which exemplified their econometric approach. In their experiment, a tradeoff was observed where subjects allocated resources for performance along one dimension to meet the demand criteria. As a function of this investment routine, performance on the second dimension suffered. Conclusions supported the use of microeconomics as an explanatory principle.

In general, the value of Navon and Gopher's econometric model is that behavior may be discussed in terms of performance/resource functions. Results may then be described by performance operating characteristics (Norman & Bobrow, 1975). Navon and Gopher (1980) concluded their investigations by suggesting that the human information processing system may contain multiple resources of similar types. This view departs dramatically from the traditional assumption that people possess single limited resource pools, such as attention, which must be shared among components of a given behavior.

Consider taking the econometric model one step further. It would be interesting to apply industrial engineering methods for productivity measurement to cognitive phenomena. The American Productivity Center (APC) in Houston, Texas, has developed a useful method for measuring and analyzing industrial productivity. By definition, productivity is the quantity of output produced divided by the quantity of input resources required to produce it. Incognitive terms, productivity is the measure of amount of error-free behavior produced by a given quantity of resources such as attention and processing time. The APC system is arranged as an accounting system. One distinguishing feature is that the indexes used to describe productivity are arranged in time series. Therefore it is possible to describe dynamic system changes. This is important if one considers applying the APC system to psychological phenomena because the output from the system is a set of curves that describe how well resources are used during discrete time periods to produce outputs. For example, consider the results from Weber, Blagowski, and Mankin's category switching experiment. Subjects were increasingly productive in generating strings of characters which alternated between numbers and letters. An APC index could quantify that fewer inputs (processing requirements) were used to produce an equal or greater amount of output. This method thus verifies the extent of increased productivity.

Digital computers may also provide concepts that help cognitive psychologists analyze behavior. One application is in the area of control processes. Nashelsky (1966) stated that the "heartbeat" of a computer is the control unit. This unit provides control over all computer operations by interpreting instructions, serving over other units, and prioritizing operations. Once information is fed into the computer, a series of control commands initiate program operations.

Klapp, Greim, and Marshburn (1981) drew heavily from computer terminology in their discussion of results from a choice reaction time experiment. The purpose of their study was to analyze the nature of short-term memory for auditory input. Subjects were asked to write eight digits in correct order immediately after they were presented. On some trials subjects simply waited until the eight digits were presented before responding. On other trials subjects were to articulate the syllable "La" silently to themselves while digits were being presented. On still another set of trials, the experimenter articulated the syllable. Results showed that irrelevant articulation by the subject did not affect time to generate the series of digits. Thus, buffer storage is not affected by articulation. Results from the condition when the experiment produced relevant auditory input revealed that interference can affect subjects ability to recall the digits. These results were interpreted as consistent with the view that buffer storage is different from an articulatory loop in short-term memory. Although Klapp et al., did not discuss executive processes in detail, they did suggest that mental operations such as auditory storage in short-term memory are controlled by central executive functions.

Finally, one additional trend has emerged in modeling human information processing concepts. This trend makes use of mechanical terms to describe elementary units of action. Gallistel (1981) defined three elementary units of action: (1) the reflex, which contains effectors, conductors, and initiators, but which does not use feedback; (2) the oscillator, driven by a pacemaker which creates rhythmic effector action; and (3) the servomechanism, which is like a reflex but which uses feedback in its functioning. These mechanical principles were used by Gallistel to propose a theory of action in cognitive psychology. The theory states that the three elementary units are organized via schemas and programs to produce movement. Handwriting, for example, is produced by executing at least two concurrent orthogonal oscillatory motions. One oscillation operates vertical motion while the other operates horizontal motion. Different letters are generated by organizing reflex motions with oscillations. The system is "tuned" by feedback through servomechanisms. This theory provides a partial understanding of why people's writing is similar if they write on paper or a blackboard. In each case the pheripheral muscle movements differ yet the form of the writing remains constant. The same point may be made in regard to size of handwriting: style is preserved across large variations in size of writing. Although hypothetical, Gallistel's theory provides a basis for the understanding of elementary components of action.

APPENDIX C

INSTRUCTIONS FOR EXPERIMENTS

Instructions for Experiment 1

Write Group

This experiment is designed to study response systems. These are the ways we behave like speaking, walking, writing, etc. What you will be doing is to write the letters of the alphabet 'a' through 't' over and over again. You will write the letters in lower-case cursive so that they all flow together into one long connected string. Do not dot the 'i' and 'j' and do not cross the 't'. Now on this blank piece of paper, I want you to try it. Go at your own pace.

I will have you write the letters nine different ways. For three of the ways, the letters will be either small, medium, or large. (Experimenter shows the subject an example of the response forms where the letters have already been written.) For the other six ways, the letters will alternate size, so that the first one might be small, the second large, the third small, and continuing on like that. Here are the six alternating ways to write. (Experimenter shows the subjects examples.)

Before we begin, I want you to practice. I will give you each of the nine ways of writing one at a time. Just write the letters as indicated on the top of each response sheet. Go at a comfortable pace. When you think that you can write faster then do so.

Now we are going to do exactly as you have just been doing, only this time I will tell you to when to start by saying "go". I want you to write as fast as you can, but do not go so fast that you start writing sloppy. On the other hand, I do not want you to go so slow that you are writing perfectly. Just push yourself as fast as is comfortable.

Trace Group

This experiment is concerned with response systems. (Narrative continues as before.)

What you will be doing is tracing over examples of your own handwriting again and again. (Narrative explains conditions and procedure as before only here the practice trials were drawn very carefully and then saved for tracing.)

Instructions for Experiment 3

Image Group

This experiment is concerned with a response system--mental imagery. What you will be doing is forming images of letters inside blank squares such as these. (Experimenter shows the subject a complete response form set that is attached to the wall.) What I mean by images is this. If I asked you to imagine the front of your house or apartment on this blank sheet of paper you probably could do so. Am I correct? If I asked you now to trace with your finger where your door and windows are you might be able to do that. See if you can do that. I am going to have you imagine uppercase stick letters, 'A' through 'J', in squares such as these. (Experimenter exhibits the conditions.) You will imagine the letters just as you have imagined your house or apartment on this paper.

(Experimenter exhibits an example of the letters drawn inside a string of ten squares.) As you can see, some of these letters have horizontal bars in them and some do not. (Experimenter demonstrates this.) We are going to agree that the letter 'B' does not have a horizontal bar. Likewise, the letter 'I' does not have a bar. Be careful to remember that the letter 'I' is only a vertical stick. Now, I want you to do this. If the letter that you imagine has a horizontal bar, then tap the top of the imagined letter with this pen. If the image of the letter does not have a horizontal bar, then touch the bottom of the image. Try it here on these drawn letters. Now I want you to do exactly the same thing that you just did, only this time imagine the letters in these blank squares. It is very important that you fit the size of your image to the size of the square.

There are nine ways that the squares will be arranged. Three of the ways are where all of the squares are the same size--only there is a small set, a medium set, and a large set. Six of the ways are where the squares alternate sizes like this (demonstrates). As you can see, the first is small, the second is large, then small, large, and so on.

Before we start, I want you to practice a bit. I will give you each of the ine ways of doing the task, one at a time.

Now we are ready to begin. I will tell you when to start by saying "go". I want you to go as fast as you can, but in no way do I want you to sacrifi-e the quality of your images. This experiment is more concerned with you forming clear images than in going fast. So please, take your time to form clear images. If at any time you need to rest please let me know.

Perception Group

(Instructions for the Perception group were exactly as those for the Image group except that subjects never had to imagine either their apartment or house, or letters.)

Instructions for Experiment 4

Image Group

This experiment is concerned with a response system--mental imagery. I am going to have you form images of letters inside squares such as these (Experimenter shows the subject a complete set of the strings of squares). First, let me show you what I mean by a clear image. If you imagine the front of your apartment or house on this blank white paper, you probably could do so. Is that correct? Now if I asked you to trace with your finger over the door and windows on your image, you might be able to do that as well. Try that once.

What you will be doing here is to form clear images of block upper-case letters such as this one (Experimenter shows the subject a drawing of the letter Z). Now as you can see, this letter has ten corners (Experimenter demonstrates). I want you now to take this pen and starting with the upper left-hand corner on this letter, tap each of the ten corners. Go clockwise around the letter. Next, I want you to draw the same letter on this white piece of paper. Now, tap the ten corners just as you did before, but this time do it on your drawing. What I want you to do now is to imagine the same letter on this white piece of paper. Tap the ten corners of your imagined letter.

Now I am going to have you do something a little bit different. As you see here, I have a paper where there is ten squares. The squares are staggered. I want you to imagine the same letter in the first square--then tap the first corner. Next, imagine the letter in the second square--then tap the second corner. Go to the third squre, imagine the letter then tap the third corner. Do this until you get to the last square and the last corner. Take your time to form good clear images of the letter. This will help you keep track of which corner you should tap. If you use good images, you will not be too confused.

As you saw before, sometimes the squares will all be the same size. Other times they will be alternating sizes. You must be sure to adjust the size of your image to fit the size of the square.

Before we start, I want you to do some practice trials. I will give you a different set of squares each time. When I say "go", you begin. (Experimenter and subject go through a set of practice trials.)

In this experiment, there will be three different letters for you to imagine. We will do each one eighteen times before going on to the next one. Remember, I want you to go as fast as you can, but in no way do I want you to sacrifice the quality of your images. I am more interested in you forming good clear images of the letters than in you speeding through the task.

Perception Group

(The instructions to subjects in the Perception group were similar to subjects in the Image group with the exception that there were no references to mental imagery.)

APPENDIX D

ANALYSIS OF VARIANCE SUMMARY TABLES

Table 1

Analysis of Variance Summary Table:

Experiment 1. Generation Time

Source	df	MS	F	p F
Between-subjects				
Mode	1	7.659	6.52	.02
Error 1 Subj(Mode)	22	1.175		
Within-subjects				
Replication (Rep)	5	1.257	55.03	.0001
Mode x Rep	5	.129	5.68	.0001
Error 2 Rep x Subj(Mode)	110	.023		
Size	5	4.691	127.78	.0001
Mode x Size	5	1.439	39.19	.0001
Error 3 Size x Subj(Mode)	110	.037		
Rep x Size	25	.023	3.07	.0001
Mode x Rep x Size	25	.011	1.49	.06
Error 4 Rep x Size x Subj(Mode)	550	.007		

Table 2

Experiment 1. Processing Time (sec)[a]

Size	Write		Trace	
	M	SD	M	SD
	Time per Character			
Constant				
Small (S)	.671	.133	.641	.151
Medium (M)	.751	.157	.742	.199
Large (L)	.969	.263	.979	.299
Alternate				
SM:MS	1.184	.259	.749	.175
ML:LM	1.268	.271	.933	.251
SL:LS	1.245	.264	.913	.237
	Time per Switch[b]			
Switch				
SM:MS	.498	.209	.061	.068
ML:LM	.430	.192	.076	.120
SL:LS	.447	.178	.108	.079

[a] n = 12 per group.

[b] Based on the switching time formula in the text, with the exception that the alternate conditions involving the same size (e.g., Small/Medium and Medium/Small) were first averaged for each subject.

Table 3

Analysis of Variance Summary Table:

Experiment 2. Generation Time

Source	df	MS	F	p F
<u>Within-subjects</u>				
Day	4	.157	15.64	.01
Error 1 Subj x Day	4	.010		
Replication (Rep)	2	.02	1.03	.49
Error 2 Subj x Rep	2	.019		
Day x Rep	8	.010	2.38	.12
Error 3 Subj x Day x Rep	8	.004		
Size	5	.518	60.18	.0002
Error 4 Subj x Size	5	.009		
Day x Size	20	.004	2.52	.02
Error 5 Subj x Day x Size	20	.002		
Rep x Size	10	.002	.54	.8
Error 6 Subj x Rep x Size	10	.003		
Day x Rep x Size	40	.001	.55	.9
Error 7 Subj x Day x Rep x Size	40	.002		

Table 4

Experiment 2. Processing Time (sec)[a]

Size	M	SD
	Time per Character	
Constant		
Small (S)	.480	.137
Medium (M)	.524	.153
Large (L)	.591	.168
Alternate		
SM:MS	.748	.134
ML:LM	.789	.164
SL:LS	.747	.171
	Time per Switch[b]	
Switch		
SM:MS	.259	.066
ML:LM	.243	.079
SL:LS	.223	.069

[a]n = 2.

[b]Based on the switching time formula in the text, with the exception that the alternate conditions involving the same size (e.g., Small/Medium and Medium/Small) were first averaged for each subject.

Table 5

Analysis of Variance Summary Table:

Experiment 3. Generation Time

Source	df	MS	F	p F
Between-subjects				
Mode	1	161.047	45.76	.0001
Error 1 Subj (Mode)	22	3.519		
Within-subjects				
Replication (Rep)	5	.573	5.84	.0001
Mode x Rep	5	.022	.23	.9
Error 2 Rep x Subj (Mode)	110	.098		
Size	5	.282	21.22	.0001
Mode x Size	5	.087	6.54	.0001
Error 3 Size x Subj (Mode)	110	.013		
Rep x Size	25	.013	1.77	.01
Mode x Rep x Size	25	.009	1.27	.2
Error 4 Rep x Size x Subj (Mode)	550	.007		

Table 6

Experiment 3. Processing Time (sec)[a]

Size	Image		Perception	
	M	SD	M	SD
		Time per Character		
Constant				
Small (S)	1.246	.418	.463	.152
Medium (M)	1.329	.454	.467	.125
Large (L)	1.364	.491	.499	.133
Alternate				
SM:MS	1.326	.429	.481	.122
ML:LM	1.407	.470	.507	.125
SL:LS	1.400	.491	.515	.123
		Time per Switch[b]		
Switch				
SM:MS	.043	.155	.018	.044
ML:LM	.067	.164	.024	.049
SL:LS	.150	.196	.037	.052

[a] n = 12 per group.

[b] Based on the switching time formula in the text, with the exception that the alternate conditions involving the same size (e.g., Small/Medium and Medium/Small) were first averaged for each subject.

Table 7

Analysis of Variance Summary Table:

Experiment 4. Generation Time

Source	df	MS	F	p F
Between-subjects				
Mode	1	6.416	6.04	.02
Error 1 Subj(Mode)	22	1.063		
Within-subjects				
Replication (Rep)	2	2.056	49.67	.0001
Mode x Rep	2	.046	1.11	.3
Error 2 Rep x Subj(Mode)	44	.041		
Size	5	.263	22.32	.0001
Mode x Size	5	.162	1.51	.2
Error 3 Size x Subj(Mode)	110	.012		
Rep x Size	10	.017	2.18	.02
Mode x Rep x Size	10	.007	.90	.5
Error 4 Rep x Size x Subj(Mode)	220	.008		

Table 8

Experiment 4. Processing Time (sec)[a]

Size	Image		Perception	
	M	SD	M	SD
		Time per Character		
Constant				
Small (S)	1.105	.241	.897	.158
Medium (M)	1.134	.248	.889	.187
Large (L)	1.202	.314	.934	.191
Alternate				
SM:MS	1.137	.327	.931	.179
ML:LM	1.223	.341	.940	.191
SL:LS	1.292	.306	1.040	.219
		Time per Switch[b]		
Switch				
SM:MS	.019	.123	.042	.065
ML:LM	.062	.113	.032	.040
SL:LS	.154	.077	.138	.088

[a] n = 12 per group.

[b] Based on the switching time formula in the text, with the exception that the alternate conditions involving the same size (e.g., Small/Medium and Medium/Small) were first averaged for each subject.

Table 9

Analysis of Variance Summary Table: Experiments

3 & 4 Combined. Generation Time

Source	df	MS	F	p F
Between-subjects				
Task	1	1.416	3.01	.09
Mode	1	22.067	46.91	.0001
Task x Mode	1	6.913	14.69	.0004
Error 1 Subj(Task Mode)	44	.470		
Within-subjects				
Size	5	.127	41.19	.0001
Task x Size	5	.008	2.66	.02
Mode x Size	5	.017	5.54	.0001
Task x Mode x Size	5	.003	1.11	.4
Error 2 Size x Subj(Task Mode)	220	.003		

Table 10

Experiments 3 & 4 Combined. Processing Time (sec)[a]

Size	Image M	Image SD	Perception M	Perception SD
		Time per Character		
Constant				
Small (S)	1.175	.324	.680	.263
Medium (M)	1.231	.355	.678	.264
Large (L)	1.283	.340	.717	.272
Alternate				
SM:MS	1.232	.377	.706	.272
ML:LM	1.315	.401	.722	.269
SL:LS	1.366	.375	.777	.317
		Time per Switch[b]		
Switch				
SM:MS	.031	.107	.030	.049
ML:LM	.064	.105	.028	.033
SL:LS	.152	.083	.088	.082

[a] n = 24 per group.

[b] Based on the switching time formula in the text, with the exception that the alternate conditions involving the same size (e.g., Small/Medium and Medium/Small) were first averaged for each subject.

VITA

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