TEST OF SANDERS' INFORMATION PROCESSING MODEL

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Abstract

The purpose of the present study was to investigate the effects of stimulus rotation and stimulus reversal and to determine the relationship of rotation and reversal to variables hypothesized to affect input and output stages in Sanders' (1980) model. Experiment 1 tested the effects of intensity, quality, rotation, and reversal. Experiment 2 tested the effects of foreperiod duration, rotation, and reversal. Initial results suggested that the task may have been too difficult for subjects, so the data of each experiment were reanalyzed excluding reversal as a factor. The first and second analyses of Experiment 1 revealed a consistent interaction between quality and rotation. Therefore, the results of Experiment 1 could not be fully explained by Sanders' (1980) model. The initial analysis of Experiment 2 revealed results which indicate that rotation and reversal affect a stage which is independent of a stage affected by foreperiod duration. However, the main effect for foreperiod duration was not significant in the second analysis. It is recommended that future experiments investigate the attentional demands of the rotation and reversal manipulations.

Test of Sanders' Information Processing Model

There have been several attempts to describe how humans process information. Discrete, linear stage models represent one, well-investigated approach to explain human information processing. Discrete models assume that information is processed in a serial sequence of stages. Each stage is assumed to involve cognitive processes which are unique to that stage. Additionally, information is assumed to be processed in a forward flow (i.e., bottom-up) direction with no feedback between stages (Sanders, 1990).

In 1967, Sternberg introduced the additive factor method, which was formalized in 1969, to study information processing from a discrete, linear stage model perspective. According to Sternberg (1969), additivity occurs when overall reaction time is equivalent to the sum of stage durations. However, if variables show interactive effects on mean reaction time, these variables are interpreted as affecting at least one common stage. Based on the presence of additivity between memory set size and stimulus quality in Sternberg's (1967) experiment, Sternberg concluded that these two variables affect two independent stages of information processing. These two stages were postulated to be encoding and memory comparison.

Sternberg's (1969) additive factor method is based on several assumptions. Each stage of information processing is assumed to begin only when the preceding stage has ended. The additive factor method also assumes that information is processed in a serial sequence of stages with no feedback between stages. The output of a stage is assumed to be constant across all levels of each independent variable, and each stage's output is assumed to serve as the input for the next stage. Finally, subjects are assumed to use their full resources to perform the task, and these available resources are assumed to be fixed (cf. Everett, Hochhaus, & Brown, 1985).

However, given that some of these assumptions are rarely met as indicated by experimental results, there has been an attempt to develop alternative models to explain information processing. In addition to discrete models of information processing, parallel or continuous flow models have been suggested (McClelland, 1979). These models assert that more than one subprocess may be operating at any given time, and that information builds up continuously and may be passed on continuously from one subprocess to the next. There has been a recent debate in the literature about whether information is processed discretely or continuously, but Miller (1988) suggests that this debate is not a particularly meaningful one. He suggests that information processing models should be conceptualized as existing on a continuum with continuous models at one end and discrete models at the opposite end.

One of the strongest proponents of discrete information processing models is Sanders. In 1980, Sanders postulated that information is processed in six stages: preprocessing, feature extraction, identification, response choice, motor programming, and motor adjustment. The six stages are defined as follows:

<u>preprocessing</u> is a stage in which the visual image is converted into a representation that is held in short-term memory; in the <u>feature extraction</u> stage, the stimulus represented is compared with letter representations stored in long-term memory; in the <u>identification</u> stage, analysis of percepts as a whole rather than analysis of percepts as features or components occurs; in the <u>response choice</u> stage, information from the prior stage is used to select one of several motor programs to be executed; in the <u>motor programming</u> stage, motor parameters such as speed, direction, and force are specified; finally, in the <u>motor adjustment</u> stage, actual motor preparation for response occurs (cf. Sanders, 1980, 1983, 1990).

In 1983, Sanders suggested a four-stage, cognitive-energetic model in which preprocessing, feature extraction, response choice, and motor adjustment are stages which are affected by the variables stimulus intensity, stimulus quality, stimulus-response (S-R) compatibility, and time uncertainty, respectively. Stimulus intensity is the degree of contrast between the signal and background; stimulus quality is the effect produced by degrading the visual signal with a random dot pattern or grid mask as opposed to keeping the signal intact; S-R compatibility is the contrast between compatible responses and incompatible responses and refers to the degree of natural or overlearned relationships between signals and responses; finally, time uncertainty is defined as uncertainty about when an imperative stimulus will be presented. Time uncertainty is usually accomplished by presenting both short and long foreperiods or many varied and unpredictable foreperiods.

Sanders' (1980, 1983) models fall within the category of discrete information processing models. These models assume that information is processed in a series of stages which occur sequentially with no temporal overlap. Sanders' models like other discrete information processing models utilize the additive factor method of Sternberg (1969) to deduce the independent existence of stages.

There have been several investigations (Daniell, 1991; Everett, Hochhaus, & Brown, 1985; Sanders, 1980, 1983) that support the existence of the four stages that Sanders suggested in his 1983 cognitive-energetic model. It is noteworthy that earlier, Sanders (1980) developed a more elaborate six-stage model of information processing, but included only the four stages with the most data to support their existence in his 1983 model.

Although Sanders' (1983) cognitive-energetic model has been well-investigated, there has been little investigation of the identification and motor programming stages in his 1980 model. With respect to the motor programming stage, one study (Hasbroucq, Guiard, & Kornblum, 1989), utilizing a tactile reaction time task, found additivity between the effects of S-R compatibility, stimulus intensity, and finger repertoire, a variable believed to affect the motor programming stage. The present research will focus on investigation of the identification stage. The identification stage is a pattern recognition stage that is postulated to be affected by such variables as signal discriminability, mental rotation, and word frequency (cf. Sanders, 1990). In one study (Stanners, Jastrzembski,

& Westbrook, 1975), additivity was found between stimulus quality and stimulus frequency. However, the evidence for this stage appears to be largely based on a study by Shwartz, Pomeratz, and Egeth (1977) in which additive effects were found between signal quality, a variable believed to affect the feature extraction stage, and signal discriminability, a variable believed to affect the identification stage.

Conversely, Logsdon, Hochhaus, Williams, Rundell, and Maxwell (1984) did not find additivity between signal discriminability (defined as character difficulty) and signal quality. The Cooper and Shepard (1973) mental rotation task used by Logsdon et al. (1984) forms the central method of the present experiment. The Cooper and Shepard (1973) mental rotation task utilizes the presentation of stimuli in either an upright position (i.e., zero degrees rotation) or in a rotated position (i.e., at 180 degrees rotation). Subjects are then forced to mentally rotate the stimuli 180 degrees in the viewing plane when presented with rotated stimuli (e.g., upside down letters) in order to answer questions about certain aspects or qualities of the letters.

In the Logsdon et al. (1984) study, stimulus reversal and stimulus orientation had an additive effect with stimulus quality but the former two variables interacted with signal discriminability. This suggested that two stages were operating, as well as the possibility that mental rotation, mental reversal and signal discriminability may all be factors which affect the identification stage. Other investigators (Stoffels, van der Molen, & Kuess, 1989) have suggested that variables affecting the identification stage might interact with S-R compatibility. This suggests that the identification stage may not exist as an independent process. It appears that the literature is unclear about the existence of the identification stage as an independent stage in Sanders' (1980) model. Moreover, the variables which may affect the identification stage have not been thoroughly investigated and as a result have not been definitively identified.

Experiment 1

The purpose of the present study was to identify variables that affect the identification stage and determine their additivity with other variables that have been shown to have effects on other early processing stages in Sanders' (1980) model. The present study also hoped to determine if the identification stage could be isolated from other stages proposed in Sanders' (1980) model.

Experiment 1 tested the hypothesis that stimulus intensity, stimulus quality, and stimulus reversal affected the processing time of three independent stages. Simultaneously, the hypothesis that stimulus reversal and stimulus rotation affect the same stage, as would be predicted from the results of Logsdon et al. (1984) was investigated. A multifactor approach was used to investigate these hypotheses. Sanders (1980) recommended the use of multifactor experiments as a more rigorous test of his model than piecemeal evaluation. Therefore, it would seem that an experiment which manipulated two or more factors would be the most stringent experimental test of additivity between the identification stage and other stages in Sanders' (1980) model. If factors believed to affect the identification stage show interactive effects with each other but additivity with factors believed to affect more well-established stages in Sanders' (1980) model, it can be concluded that these factors identify a stage that is independent of other components in Sanders' (1980) model.

If Sanders' (1980) model is correct, stimulus intensity affects a preprocessing stage; stimulus quality affects a feature extraction stage; and stimulus reversal as well as stimulus rotation affect an identification stage. A 2 x 2 x 2 x 2 repeated measures design was used initially to evaluate the effects of stimulus intensity, stimulus quality, stimulus rotation, and stimulus reversal. According to the additive factor method, it was predicted that both stimulus rotation and stimulus reversal would be independent of stimulus intensity and stimulus quality. It was also predicted that stimulus intensity would be independent of stimulus quality. However, stimulus rotation was predicted to interact with stimulus reversal.

Method

Subjects. Subjects were 30 undergraduate college students enrolled in introductory psychology classes at a midwestern university. The subjects were given points of extra credit for participation. Each subject was tested for one practice block of 48 trials and five test blocks of 48 trials each. Total participation time was 30 to 40 minutes. Participants were informed that they would perform a letter recognition task via a computer. All participants were treated in accordance with the "Ethical Principles of Psychologists (American Psychological Association, 1981).

Apparatus. An Apple II microcomputer modified according to Reed (1979) connected to a Sony monitor was used to project block letters (2.7 x 2 cm) onto a 15 x 19.5 cm screen. Reed's (1979) modification makes it possible to obtain timing within one millisecond of response signals. Six assymetrical letters (F, P, R, G, J, or L) were presented by means of the APPLE. A device described by Hochhaus, Carver, and Brown (1984) controlled intensity. Intensity measurements were as close to those in Everett et al. (1985) as possible. Intensity measurements in the high condition were approximately 0.03 cd/m^2 (black background) and 141.51 cd/m^2 (white letter). In the low intensity condition, measurements were approximately 0.05 cd/m^2 (grey background) and 3.77 cd/m^2 (dim letter).

Stimulus quality degradation was provided by the superimposition of a 2.5 x 2 cm black and white checkerboard mask over a printed letter. Squares within the mask were 5mm in height and 4mm in width. Subjects were instructed to hold the index finger of each hand on the keyboard with their palms resting on the table. The task was to indicate whether the letter was correct or reversed by pressing one of two keys (the "Z" if the letter was correct or the "/" if the letter was reversed). Reaction time was defined as the time from the onset of the visual stimulus to the press of a microswitch. A software clock (Price, 1979) was used to measure all timing operations.

Task and Procedure. The task that was used in the present study incorporated the Cooper and Shepard (1973) mental rotation task. In the Cooper and Shepard (1973) task, visual stimuli (i.e., letters) are presented at various degrees of orientation in either a correct or mirror-image form. According to previous research (Cooper & Shepard, 1973; Logsdon et al., 1984), the task requires subjects to identify the letter and its degree of rotation before being able to mentally rotate the letter to an upright orientation. Following the mental rotation of the letter, it is assumed that the subject is then able to make a determination as to whether the letter is correct or reversed.

Before beginning the task, the experimenter read the instructions aloud to the subjects for clarity. Subjects were told that the letters F, P, R, G, J, or L would be presented one at a time in a correct or mirror-image (reversed) form. They were told that each letter would be either upright or rotated 180 degrees in the viewing plane. They were told that different stimulus intensities would be shown and that a mask would sometimes be present. The subjects were instructed to respond as quickly as possible while maintaining at least 95% accuracy.

After each presentation, the subjects were given computer generated feedback concerning their accuracy on that trial. Each presentation of the stimulus letter remained on the screen until the subject responded. The report of accuracy (i.e., the word "correct" or "error") was then presented on the screen for 0.5 seconds. Feedback was designed to maintain the desired 95% accuracy on each block of trials and was provided on both practice and experimental trials.

Subjects completed five different experimental blocks of trials, each consisting of 48 letter presentations. These 48-letter blocks were composed of eight presentations of each of the six previously mentioned letters. Equal numbers of each letter in each experimental condition were presented in a random order during each block and across blocks. Each combination of treatment conditions was presented equally often within each block and across blocks. Each block of trials lasted approximately five to seven minutes. Subjects were first given one practice block of trials, followed by a five minute rest period. Following the rest period, subjects were given five test blocks of trials. The response measures on each subject were the mean reaction times (correct responses only) and accuracy scores for each treatment combination.

Results

To test the model, the two dependent variables, reaction time and accuracy, were analyzed using a 2 x 2 x 2 x 2 analysis of variance initially, then a 2 x 2 x 2 analysis of variance for each dependent variable. The analyses included data from each of the five experimental blocks for each participant, but did not include data from the practice block. Data from subjects with less than 95% overall accuracy were excluded from all analyses. As a result, data from four subjects were excluded. All error trials were excluded from the reaction time analyses.

The four independent variables of stimulus intensity, stimuli quality (i.e., degradation), stimulus rotation, and stimulus reversal were all within-subject variables. All main effects and interaction terms were evaluated in repeated measures analyses of variance. Based on concerns that the effects of the reversal variable might be different than other variables in the analysis because the nature of the experimental task required the subjects to respond each time by indicating if the stimulus was in a correct or reversed (i.e., mirror-image) form, the decision was made to do a second analysis of variance (ANOVA) that excluded reversal as a factor in a 2 x 2 x 2 design for both reaction time and accuracy. Reversal was excluded as a factor in the second analysis through the exclusion of trials in which the stimulus was reversed. Results of the two analyses of variance using reaction time as a dependent variable will be discussed first, followed by results of the ANOVAs using accuracy scores as a dependent variable.

Reaction Time

Initial Analysis. A 2 x 2 x 2 x 2 (stimulus intensity - low vs. high, stimulus quality - intact vs. masked, stimulus rotation - upright vs. rotated, and stimulus reversal - correct vs. reversed) analysis of variance with reaction time as the dependent variable was completed initially. The F values are listed in Table 1.

Insert Table 1 about here

The three main effects were found to be significant. A significant main effect was confirmed for stimulus intensity, $F(1,25) = 171.99$, $p < 0.0001$. As shown in the table of means (Table

2), participants' mean reaction times were significantly faster in the high intensity condition than in the low intensity condition.

Insert Table 2 about here

The second significant main effect was for stimulus quality, F (1,25) = 70.14, $p < 0.0001$. The mean reaction time was significantly faster in the intact condition as compared to the masked condition. The final main effect that was significant was for stimulus rotation, F (1,25) = 12.80, $p < 0.01$. Mean reaction time was significantly faster for stimuli in the upright position than stimuli in the rotated position. The main effect for stimulus reversal was not significant in this analysis. Mean reaction time was not significantly different for stimuli that were correct when compared with stimuli that were reversed. In fact, correct stimuli had a mean reaction time that was slightly slower than the mean reaction time for stimuli that were reversed. The uniqueness of the reversal variable from other variables in the analysis (due to the fact that the task required subjects to respond by indicating whether the stimulus was reversed or not) may have resulted in a masking of the expected slowing effect of reversed letters on reaction time.

According to stage model logic, it was predicted that only one interaction would be significant: stimulus reversal by stimulus rotation. However, all two-way and higher order interactions were found to be significant in this analysis (See Table 3). The

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Insert Table 3 about here

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significant two-way interactions were stimulus intensity by stimulus quality, F (1,25) = 78.66, $p < 0.0001$; stimulus intensity by stimulus rotation, F (1,25) = 170.24, $p < 0.0001$; stimulus intensity by stimulus reversal, F (1,25) = 92.00, $p < 0.0001$; stimulus quality by stimulus rotation, F (1,25) = 7.47, $p < 0.01$; and stimulus quality by stimulus reversal, F (1,25) = 96.36, $p < 0.0001$. The one predicted two-way interaction, stimulus rotation by stimulus reversal was also significant, F (1,25) = 104.12, $p < 0.0001$.

The three-way interactions that were significant were stimulus intensity by stimulus quality by stimulus rotation, F (1,25) = 98.37, $p < 0.0001$; stimulus intensity by stimulus quality by stimulus reversal, F (1,25) = 100.00, $p < 0.0001$; stimulus intensity by stimulus rotation by stimulus reversal, F (1,25) = 64.68, $p < 0.0001$; and stimulus quality by stimulus rotation by stimulus reversal, F (1,25) = 122.97, $p < 0.0001$. The four-way interaction term, stimulus intensity by stimulus quality by stimulus rotation by stimulus reversal, was significant, F (1,25) = 70.73, $p < 0.0001$.

Because all interaction terms reached significance which is not predicted by Sanders' (1980) model, it was considered that given the nature of the experimental task (which made the reversal variable unique due to the requirement that participants make a determination as to whether the stimulus was correct or reversed on each trial), reversal may have contaminated the results. It is noteworthy that the reversal variable is perfectly correlated with "yes" (correct) and "no" (reversed) responses. Therefore, the data were reanalyzed excluding all trials with reversed letters in the second analysis. That is, the level of reversal that was expected to be the most difficult was removed, and only the data for "yes" responses were examined.

Second Analysis. For this analysis, reversal was removed as a variable, making this a 2 x 2 x 2 design. The *F* values for this analysis are reported in Table 4. This ANOVA found significance for

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Insert Table 4 about here

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two main effects. The main effect of stimulus quality reached significance with $F\ (1,25) = 103.90$, $p < 0.0001$. As can be seen by the list of means in Table 5, mean reaction time was significantly

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Insert Table 5 about here

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faster in the intact condition as compared to the masked condition. The main effect for stimulus rotation was also significant, $F\ (1,25) = 53.01$, $p < 0.0001$. Reaction times were significantly faster for stimuli in the upright position than stimuli that were rotated. One main effect, stimulus intensity was not significant, $F\ (1,25) = .09$, $p > .05$. As indicated by the means table (Table 5), mean reaction time when the video screen was at the high intensity level was not significantly different from mean reaction time for the low intensity condition. Although mean reaction time was faster in the high intensity condition, as expected, the difference was very slight.

In this second reaction time analysis (2 x 2 x 2), only one of the interaction terms was significant (see Table 4). The two-way interaction of stimulus quality by stimulus rotation remained significant, F (1, 25) = 71.50, $p < 0.0001$. As can be seen in Table 6, when stimuli were masked, mean reaction time was significantly

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Insert Table 6 about here

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higher for the rotated condition as compared to the upright condition. However, in the intact condition, mean reaction time was higher for upright stimuli in comparison to rotated stimuli.

<u>Accuracy</u>

<u>Initial Analysis</u>. This set of analyses uses accuracy scores as the dependent variable. The first ANOVA using accuracy scores was run with a 2 x 2 x 2 x 2 design, which included reversal as a variable. The F values for all of the main effects and interactions are reported in Table 7. Significant main effects were found for

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Insert Table 7 about here

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three of the four independent variables. One significant main effect was that of stimulus quality, F (1,25) = 13.82, $p < 0.001$. Means (see Table 8) indicate that the participants were significantly more

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Insert Table 8 about here

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accurate when the stimuli were intact than when stimuli were masked. Another significant main effect was that of stimulus rotation, F (1,25) = 6.93, $p < 0.01$. Participants' responses were more accurate in the upright condition than in the rotated condition. Additionally, a main effect was found for stimulus reversal, F (1,25) = 17.50, $p < 0.001$. Participants showed more accuracy when stimuli were correct than when stimuli were reversed.

One two-way interaction reached significance, stimulus quality by stimulus rotation, F (1,25) = 11.86, $p < 0.01$. The accuracy interaction means (see Table 9) reveal that in the intact condition

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Insert Table 9 about here

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accuracy means are virtually the same for stimuli in the upright position and the rotated position. However, in the masked condition, accuracy is significantly higher for stimuli in the upright position than for stimuli in the rotated position.

The three-way interaction reached significance, stimulus quality by stimulus rotation by stimulus reversal, F (1,25) = 3.95, $p < 0.05$.

As can be seen in Table 9, the accuracy interaction means show that when stimuli are intact and not reversed, accuracy means are the same for stimuli in the upright and rotated position. However, when stimuli are intact but reversed, mean accuracy is slightly higher for the rotated condition in comparison to the upright condition. Conversely, when stimuli are masked but not reversed, accuracy means are significantly higher for stimuli that are upright as opposed to stimuli that are rotated. In the masked and reversed condition, accuracy means are significantly higher for stimuli in the upright condition as compared to the rotated condition.

Second Analysis. As with the reaction time data, reversal was removed as a factor, and a 2 x 2 x 2 ANOVA with accuracy as the dependent variable was run. See Table 10 for the *F* values. The

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Insert Table 10 about here

ANOVA yielded two significant main effects. The effect of stimulus intensity was significant, $F(1,25) = 5.30$, $p < 0.05$, with responses slightly more accurate in the low intensity condition than the high intensity condition (see Table 11). The main effect of stimulus

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Insert Table 11 about here

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quality also remained significant, $F(1,25) = 8.30$, $p < 0.01$. Means (see Table 11) show that responses were significantly more accurate in the intact condition than in the masked condition. No two-way or higher order interactions reached significance in this analysis (see Table 12).

Insert Table 12 about here

Discussion

The present study used a multifactor approach to investigate Sanders' (1980) theory that the identification stage exists as a stage that is independent of all other stages in his model. Experiment 1 tested the effects of stimulus intensity, stimulus quality, stimulus rotation, and stimulus reversal. Both reaction time data and accuracy scores were used as dependent variables in analyzing data from the experiment.

The initial analysis of Experiment 1 did not support the hypothesis that three independent states (i.e., preprocessing, feature extraction, and identification) were operating in the current version of the Cooper and Shepard (1973) task. The initial analysis revealed that only three of the four variables had a significant main effect on reaction time, stimulus intensity, stimulus quality, and stimulus rotation. The absence of a significant main effect for stimulus reversal indicates that the reversal manipulation did not affect the hypothetical identification stage in the current task. There were also several unpredicted interactions that were significant, intensity by quality, intensity by rotation, intensity by reversal, quality by rotation, quality by reversal, intensity by quality by rotation, and intensity by quality by reversal. According to the additive factor method, interactions are evidence leading to the deductive conclusion that at least one common stage is affected. Therefore, an additive factor interpretation of the unpredicted interactions is of one stage affected by stimulus intensity, stimulus quality, stimulus rotation, and stimulus reversal. The lack of a main affect for stimulus reversal indicates that stimulus reversal affects processing only in interaction with stimulus interval, stimulus quality, and stimulus rotation. The only variables predicted to have a common locus of effect were stimulus rotation and stimulus reversal. Support for the hypothesis that these variables affect the same stage is provided by the interaction of rotation and reversal.

The main effect and interaction means from the initial analysis using accuracy data as the dependent variable do not suggest that participants were making speed accuracy trade-offs. In fact, the means indicate that subjects typically had higher mean accuracy percentages when reaction time was faster than when speed was slowed. Speed-accuracy trade-offs would be important since there is evidence that small changes in accuracy (especially when accuracy is high) can cause significant changes in reaction time (Pachella, 1974). Shifts in speed-accuracy curves can mask interactions or additivity, which would interfere with the validity of results. In addition, shifts in speed-accuracy curves change the speed of responses in such a way that main effects may also be invalid.

In the second analysis, reversal was removed as an independent variable in order to avoid using an independent variable (i.e., "yes" vs. "no" response) which is integral to performance of the task. Subjects had to make a determination as to whether the stimulus was correct or reversed on each trial. As a result, the inclusion of reversal as a variable may have confounded the results. There was also a concern about the inconsistency of the results with many other studies that have reported additivity between stimulus intensity and stimulus quality (Everett et al., 1985; Frowein, Galliard, & Vary, 1982; Sanders, 1980, 1983). Therefore, a second analysis was done in which reversal was excluded as a variable through including only the trials where the stimulus was correct (i.e., "yes" responses only).

The second analysis yielded significance for two of the three main effects. Stimulus quality and stimulus rotation remained significant. However, stimulus intensity was insignificant in this analysis. There was one significant interaction, stimulus quality by stimulus rotation. The interaction of stimulus quality and stimulus rotation is evidence that these two variables affect a common stage. No interactions were expected to be significant in the second analysis. Therefore, the presence of a significant interaction means that the results are not fully supportive of Sanders' (1980) model. Nevertheless, the removal of stimulus reversal as a factor provided a useful look at changes in the effects of variables. A noteworthy change was the drastic decrease in the number of significant interactions.

As with the first analysis, the second analysis of accuracy data indicates that faster reaction times were typically associated with higher accuracy scores. The one exception to this trend was the effect of stimulus intensity on mean accuracy percentages. Accuracy data from the second analysis indicate that mean accuracy was slightly higher for the low intensity condition (which was associated with slower mean reaction times) than the high intensity condition (which was associated with faster mean reaction times). The evidence that there was a speed-accuracy trade-off associated with the stimulus intensity manipulation suggests that results obtained on the effects of stimulus intensity are potentially invalid. As a result, definitive conclusions about the main effect of stimulus intensity and the relationship of stimulus intensity to stimulus quality and stimulus rotation cannot be made in the second analysis of Experiment 1.

Overall, it appears that the mental rotation task may be too complex for a simple interpretation according to the discrete stage model of reaction time (cf. Logsdon et al.). Before evaluating the claim that discrete stage models do not apply to mental rotation, however, it would be wise to examine the data of Experiment 2 which examines the response side of processing in the mental rotation task.

Experiment 2

Sanders (1990) information processing model postulates that the identification stage is a perceptual stage that is independent of other stages in the model. However, a review of the literature indicates that no experiments have tested the additivity of the identification stage with motor stages. The aim of the present experiment is to determine if additivity exists between variables posited to affect the identification and motor adjustment stages. Determination of the relationship of the identification stage to the motor adjustment stage in Sanders' (1980) model was done in Experiment 2 for the following reasons: 1) to provide another independent test of the implications of the identification stage, and 2) to guard against overcomplicating the task in Experiment 1 with too many stimulus manipulations (i.e., stimulus intensity, stimulus quality, stimulus rotation, stimulus reversal, and foreperiod duration), which might overburden subjects.

The existence of the motor adjustment stage is suggested by Sanders' (1980, 1983) models. As previously mentioned, Sanders postulated that the motor adjustment stage is affected by time uncertainty. For the purposes of the present experiment, Sanders' time uncertainty variable will be manipulated by foreperiod duration.

Additive contributions have been observed between time uncertainty and stimulus intensity (Bernstein, Chu, Briggs & Schurman, 1973; Raab, Fehrer, & Hershenson, 1961; Sanders, 1975) and between time uncertainty and S-R compatibility (Posner, Klein, Summers, & Buggie, 1973; Sanders, 1977). Additive effects have also been observed between stimulus quality, S-R compatibility, and time uncertainty in a multifactor experiment (Daniell, 1991; Frowein & Sanders, 1978). Sanders (1979) found that time uncertainty interacted with muscle tension, a factor believed to affect motor adjustment. These results suggest that time uncertainty affects the motor adjustment stage. As a result, time uncertainty is an ideal variable to test the additivity of stimulus reversal and stimulus rotation with a motor stage.

The present experiment examined the effects of stimulus reversal, stimulus rotation, and foreperiod duration (which was used to manipulate time uncertainty) on mean reaction time using Cooper and Shepard's (1973) mental rotation task. The current experiment tested the hypothesis that stimulus rotation and stimulus reversal have a common locus of effect that is independent of the effects of foreperiod duration. Based on Sanders' (1980) model, foreperiod duration was expected to affect the motor adjustment stage. Stimulus reversal and stimulus rotation were expected to affect the hypothetical identification stage (Logsdon et al., 1984).

A 2 x 2 x 2 repeated measures design was used initially to evaluate the effects of stimulus reversal, stimulus rotation, and foreperiod duration. It was predicted that foreperiod duration would be independent of stimulus rotation and stimulus reversal. However, stimulus reversal and stimulus rotation were predicted to interact. This pattern of results would indicate that at least two independent stages of processing are operating.

Method

Subjects. Subjects were 30 undergraduate college students enrolled in introductory psychology classes at a midwestern university. The subjects were given points of extra credit for participation. Each subject was tested for one practice block of 48 trials and five test blocks of 48 trials each. Each subject was informed that total participation time would be approximately 35 to 45 minutes, and that they would perform a letter recognition task via a computer. As with Experiment 1, all participants were treated in accordance with the "Ethical Principles of Psychologists" (American Psychological Association, 1981).

Apparatus. An APPLE II microcomputer modified according to Reed (1979) connected to a Sony monitor was used to project block letters onto a screen identical to that described in Experiment 1. The same six assymetrical letters (F, P, R, G, J, or L) were presented by means of the APPLE. Subjects were instructed to position their hands in an identical manner to that described in Experiment 1. Pressing either the left or right microswitch ("Z" or "/", respectively) signalled a response. Reaction time was defined as the period from the onset of the visual stimulus to the press of a microswitch.

Subjects began each trial by pressing the "Z" and "/" keys simultaneously. Foreperiod duration was defined as the period from the pressing of the "Z" and "/" keys simultaneously to the onset of the visual stimulus. Foreperiod duration varied randomly between the immediate and delayed condition. Foreperiod duration in the immediate condition was .5 s and 7.5 s in the delayed condition. These time parameters were used in conjunction with Sanders' (1975) suggestion that the use of long vs. short foreperiods produces time uncertainty. Furthermore, several studies (Bernstein et al., 1973; Daniell, 1992; Frowein & Sanders, 1975, 1979) have reported significant main effects on reaction time using short vs. long foreperiods. A software clock (Price, 1979) was used to measure all timing operations.

Task and Procedure. The task in the present experiment was identical to the Cooper and Shepard (1973) task of Experiment 1. Subjects were to indicate whether each letter was correct or reversed by pressing the "Z" key if the stimulus was correct or the "/" key if the stimulus was reversed. Subjects were instructed to respond as quickly as possible while maintaining at least 95% accuracy. Each time stimulus letters were presented in a correct form or mirror-image (reversed) form. Subjects were told that each letter would be upright or rotated 180 degrees in the viewing plane. The subjects were also told that foreperiod duration would vary.

Each presentation of a stimulus letter remained on the screen until the subject responded. The report of accuracy (i.e., the words "correct" or "error") was then presented on the screen for 0.5 s, followed by a message on the computer screen to "press both keys and release to begin." When the subject was ready to begin, the subject pressed the "Z" and "/" keys simultaneously. After the subject pressed these two keys, there was either a 0.5 s or 7.5 s pause during which the screen was blank before presentation of the next stimulus.

Subjects completed one practice block of trials, followed by a five minute rest period. Following the rest period, subjects completed five test blocks of trials. The blocks were composed of 48 letter presentations identical to that described in Experiment 1. Each combination of treatment conditions was presented equally often within each block and across blocks.

Results

As with Experiment 1, the two dependent variables, reaction time and accuracy were evaluated using two analyses of variance - first a 2 x 2 x 2 analysis of variance (foreperiod duration by stimulus rotation by stimulus reversal) then a 2 x 2 analysis of variance (foreperiod duration by stimulus rotation). The analyses included data from each of the five experimental blocks for each participant but did not include data from the practice block. All error data were excluded from reaction time analyses. The response measures on each subject were the mean reaction times (correct responses only) and accuracy scores for each treatment combination. Data from subjects with less than 95% overall accuracy were excluded from all analyses. This resulted in two subjects being excluded.

The three independent variables of foreperiod duration, stimulus rotation, and stimulus reversal were all within-subject variables. All main effects and interaction terms were evaluated in repeated measures analyses of variance. In the initial analyses of variance, all three of the above mentioned independent variables were used. However, as with Experiment 1, a second set of analyses were done in which reversal was removed as an independent variable due to its uniqueness from other variables by means of inclusion of judgments about whether the stimulus were reversed or not on each trial. Reversal was removed as a factor through excluding all trials in which the stimulus was reversed (i.e., excluded all "no" responses). Results of the 2 x 2 x 2 analysis of variance and the 2 x 2 analysis of variance using reaction time as the dependent variable will be discussed first, followed by results of these analyses of variance using accuracy as the dependent variable.

Reaction Time

Initial Analysis. A 2 x 2 x 2 (foreperiod duration - immediate vs. delayed, stimulus rotation - upright vs. rotated, and stimulus reversal -correct vs. reversed) analysis of variance was completed initially for Experiment 2 The F values can be seen in Table 13.

Insert Table 13 about here

All main effects were found to be significant. There was a main effect for foreperiod duration, F (1,27) = 6.01, $p < 0.05$.
The table of means (Table 14) illustrates that mean reaction time was significantly faster in the immediate condition than in the delayed condition. A second main effect was found for stimulus rotation, F (1,27) = 43.97, $p < 0.0001$. Table 14 shows that, as expected,

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Insert Table 14 about here

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subjects had a significantly faster mean reaction time in the upright condition as opposed to the rotated condition. The final main effect was for stimulus reversal, F (1,27) = 34.89, $p < 0.0001$. As can be seen in Table 14, mean reaction time was faster for stimuli presented in the correct form than for stimuli that were reversed.

The predicted two-way interaction between stimulus reversal and stimulus rotation was significant, F (1,27) = 7.89, $p < .01$. As can be seen in Table 15, when stimuli were presented in the upright

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Insert Table 15 about here

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position, mean reaction time was significantly faster when the stimuli were correct than when the stimuli were reversed. However, in the rotated position, mean reaction time was similar for correct and reversed stimuli. This pattern of means is evidence of an underadditive interaction (see Discussion for an elaboration). All other two-way or higher-order interactions (i.e., foreperiod duration x stimulus rotation, foreperiod duration x stimulus reversal, and foreperiod duration x stimulus rotation x stimulus reversal) were nonsignificant.

Second Analysis. Reversal was removed from the analysis to look at the effects of variables without the reversal variable since reversal was also integral to responses in the experimental task. Only the reversed trials were removed since this is where the reversal variable had its largest effects. The second analysis resulted in a 2 x 2 (foreperiod duration -immediate vs. delayed and stimulus rotation -upright vs. rotated) design. The F values can be seen in Table 16.

Insert Table 16 about here

Only one main effect reached significance, stimulus rotation, $F(1,27) = 42.78$, $p < 0.0001$. As can be seen in Table 17, mean

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Insert Table 17 about here

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reaction was significantly faster when stimuli were upright than when stimuli were rotated. The main effect for foreperiod duration did not reach significance in this analysis (see Table 16).

The one interaction term, stimulus rotation by foreperiod duration, was not significant (see Table 18).

Insert Table 18 about here

Accuracy

Initial Analysis. This set of analyses used accuracy scores as the dependent variable. The first analysis of variance using accuracy scores was run with a 2 x 2 x 2 design which included reversal as an independent variable. The values for all of the main effects and interactions are reported in Table 19.

Insert Table 19 about here

Significant main effects were found for two of the three independent variables. A significant main effect was found for stimulus rotation, F (1,27) = 4.57, $p < 0.01$. The means (see Table 20) show that participants were more accurate in their responses when

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Insert Table 20 about here

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the stimuli were presented in an upright position and less accurate when stimuli were presented in a rotated position. The other significant main effect was for stimulus reversal, F (1,27) = 6.37, $p < 0.01$. The means (see Table 20) show that participants were more accurate when the stimuli were correct and less accurate when the stimuli were reversed.

No two-way or higher-order interactions reached significance (see Table 21).

Insert Table 21 about here

Second Analysis. As with the reaction time data, reversal was removed as a factor in this analysis. A 2 x 2 ANOVA was done with accuracy as the dependent variable. Table 22 can be seen for a listing of F values.

Insert Table 22 about here

This ANOVA yielded one significant main effect. The main effect of stimulus rotation remained significant, F (1,27) = 6.38, $p < 0.01$. Responses were again more accurate when stimuli were presented in an upright position than when stimuli were presented in the rotated position (see Table 23). The main effect for foreperiod duration did not reach significance in this analysis.

Insert Table 23 about here

Additionally, the one interaction term, foreperiod duration by stimulus rotation, did not reach significance (see Table 24).

Insert Table 24 about here

Discussion

The present data provide supplemental evidence to Experiment 1 on the locus of effect of the identification stage. Experiment 2 investigated the additivity of variables posited to affect the identification stage (i.e., stimulus rotation and stimulus reversal) with a variable posited to affect the motor adjustment stage (i.e., foreperiod duration). These data also provide an additional test of the relationship between stimulus reversal and stimulus rotation.

The results of Experiment 2 are slightly supportive of a discrete linear stage model interpretation of the mental processes involved in performing the Cooper and Shepard (1973) mental rotation task. The existence of independent stages is illustrated by the relationship between foreperiod duration, stimulus reversal, and stimulus rotation. The initial analysis showed that each of these variables had a significant main effect on reaction time, but the effects of foreperiod duration did not interact with the effects of stimulus rotation or stimulus reversal. The initial analysis of Experiment 2 also revealed a significant interaction between stimulus reversal and stimulus rotation. The interaction between stimulus rotation and stimulus reversal is underadditive. Most interactions in additive factor testing are overadditive, which means that one variable is having its largest effect on the slowest level of another variable. Underadditivity suggests the temporal overlap of stages (Sanders, 1980; Stanovich & Pachella, 1977). Therefore, the underadditivity between stimulus rotation and stimulus reversal provides further support for the hypothesis that stimulus rotation and stimulus reversal affect a common stage. This finding lends direct support to the findings of Logsdon et al. (1984) that stimulus rotation and stimulus reversal are interactive, and thus affect a common stage.

The fact that the effects of foreperiod duration were independent of the effects of stimulus rotation and stimulus reversal supports the hypothesis that at least two independent stages of processing were operating in the current experiment. Sanders' (1980) model suggests that these stages are the motor adjustment stage, which is affected by foreperiod duration, and the identification stage, which is affected by stimulus rotation and stimulus reversal. The accuracy data for the initial analysis of Experiment 2 indicate that there were no speed-accuracy trade-offs operating in the current task.

The second analysis of Experiment 2 is not as supportive of Sanders' (1980) model. While the main effect for stimulus rotation remained significant, there was not a significant main effect for foreperiod duration. The results yielded no significant interactions between the two variables in the second analysis of Experiment 2 (i.e., stimulus rotation and foreperiod duration). The absence of a main effect for foreperiod duration and the lack of interactive effects of this variable with stimulus rotation suggests that foreperiod duration did not have a significant effect on any stage in the current task. Therefore, by the most conservative interpretation the data from the second analysis of Experiment 2 provide no evidence for the existence of two stages. As with the first analysis of accuracy data for Experiment 2, there was no evidence of speed-accuracy trade-offs that would interfere with the validity of the data.

General Discussion

As more data become available on human information processing, the models to explain information processing become more advanced. One such model is Sanders' (1980) information processing model. This model goes beyond most information processing models in that it attempts to account for information processing mechanisms, such as stages and also deals with the functional components of processing, such as attention and alertness.

Sanders (1980) suggests that information is processed in six stages: preprocessing, feature extraction, identification, response choice, motor programming, and motor adjustment. Considerable research supports the existence of at least four stages in information processing: preprocessing, feature extraction, response choice, and motor adjustment (see Sanders, 1983; 1990, for a review). These stages are postulated to be affected by the variables: stimulus intensity, stimulus quality, S-R compatibility, and time uncertainty, respectively. There are studies (Daniell, 1991; Everett et al., 1985; Sanders, 1980, 1983) which suggest that these variables have additive effects on reaction time, which supports the existence of at least four stages of information processing.

However, there has been less investigation of the motor programming and identification stages. The present research focused on investigation of Sanders' (1980) hypothetical identification stage. Two experiments were performed to identify the variables that affect the identification stage and determine their additivity with the effects of variables that have been associated with other stages in Sanders' (1980) model. Experiment 1 tested the effects of variables posited to affect the identification stage, stimulus reversal and stimulus rotation, with the effects of stimulus intensity and stimulus quality which are variables that are usually believed to affect early processing stages in Sanders' (1980) model. Experiment 2 focused on investigation of the effects of stimulus reversal, stimulus rotation, and foreperiod duration, a variable believed to affect motor adjustment, a late processing stage in Sanders' (1980) model.

<u>A Test of Sanders' Model</u>

Experiment 1 revealed results that were not supportive of Sanders' (1980) model. The unpredicted interactions (i.e., intensity by quality, intensity by rotation, intensity by reversal, quality by rotation, quality by reversal, intensity by quality by rotation, and intensity by quality by reversal) in the initial analysis of Experiment 1 suggest that stimulus reversal and stimulus rotation do not have effects that are independent of stimulus intensity and stimulus quality. The unpredicted interactions indicate that stimulus intensity, stimulus quality, stimulus rotation, and stimulus reversal affect a common stage. The interaction of stimulus quality and stimulus rotation in the second analysis of Experiment 1 as well as a significant main effect for stimulus quality and stimulus rotation suggest the existence of one stage which is affected by both variables.

Experiment 2 revealed results which were slightly more supportive of Sanders' (1980) model. In the initial analysis of Experiment 2, stimulus reversal and stimulus rotation interacted, but the effects of each variable were independent of the effects of foreperiod duration. This pattern of results supports the hypothesis that stimulus reversal and stimulus rotation affect a common stage that is independent of a stage affected by foreperiod duration. In the second analysis of Experiment 2, there were no significant interactions between the variables (i.e., stimulus rotation and foreperiod duration). This suggests that stimulus rotation and foreperiod duration affect independent stages. However, the lack of any significant effects (i.e., a main effect or interaction) for foreperiod duration in the second analysis of Experiment 2 is not fully consistent with Sanders' (1980) model.

Additionally, the results of both experiments revealed intermittent significance in main effects for three independent variables, stimulus reversal, stimulus intensity, and foreperiod duration. Although, the initial analysis of Experiment 1 revealed significant main effects on reaction time for stimulus intensity, stimulus quality, and stimulus rotation, there was not a significant main effect for stimulus reversal. This result is counter to the results of the initial analysis of Experiment 2 in which stimulus reversal had a significant main effect on reaction time. A second incidence of inconsistency in significant effects across analyses involved the main effect for stimulus intensity. Stimulus intensity had a significant main effect on reaction time in the initial analysis of Experiment 1 but was not significant in the second analysis of Experiment 1. In addition, foreperiod duration had a significant main effect on reaction time in the first analysis of experiment 2. However, the effect of this variable on reaction time was insignificant in the second analysis of Experiment 2.

In contrast to these results, there is previous literature that supports main effects for each of these variables on reaction time. The findings of Logsdon et al. (1984) support the expectation of a main effect for stimulus reversal on reaction time. Additionally, several studies support the existence of main effects for stimulus intensity (Bernstein et al., 1973; Daniell, 1991, 1991; Everett et al., 1985; Frowein et al., 1982; Sanders, 1975, 1977, 1980, 1983; Shwartz et al., 1977; Expt. 1) and foreperiod duration (Bernstein et al., 1973; Daniell, 1991; Frowein & Sanders, 1978; Sanders, 1975, 1979, 1980, 1983; Spijkers, 1990).

The main effect for stimulus intensity changed from significant in the initial analysis to insignificanct in the second analysis of Experiment 1. However, there was a possible speed-accuracy trade-off associated with the stimulus intensity manipulation in the second analysis of Experiment 1, which would suggest great caution in interpreting the results obtained on the effects of stimulus intensity. Pachella (1974) asserts that even small shifts in speed-accuracy curves can distort the reaction time effects of variables. Therefore, the changes in speed that accompany a speed-accuracy shift could affect the differences in mean reaction time for the low and high intensity conditions. As a result, significant effects on mean reaction time for the stimulus intensity manipulation could be masked by this speed-accuracy trade-off. With regard to the inconsistent significance for foreperiod duration in Experiment 2, it appears that this stimulus manipulation did not have a significant main effect on reaction time when reversed figures were removed from the analysis.

Furthermore, the stimulus reversal manipulation only had a significant main effect in Experiment 2 when there were only two additional manipulations (i.e., foreperiod duration and stimulus rotation). With future research, it may be beneficial to provide an additional test of the effects of stimulus reversal in an experiment that involves only two other stimulus manipulations. An example would be an experiment which tested the effects of stimulus intensity, stimulus rotation, and stimulus reversal, or an experiment which tested the effects of stimulus quality, stimulus rotation, and stimulus reversal. The results of such experiments would provide useful information about whether the main effect for stimulus reversal in the initial analysis of Experiment 1 was affected by the manipulation of too many independent variables (i.e., stimulus intensity, stimulus quality, stimulus rotation, and stimulus reversal).

Another possible implication of these studies is that the addition of multiple variables in a single task changed the structure of the task for subjects (c.f., Sanders, 1980), particularly given the inherent complexity of the Cooper and Shepard (1973) mental rotation task. Subjects may not routinely and automatically deal with the task when variables such as stimulus rotation and stimulus reversal are added. Instead subjects may use different strategies (e.g., may tend to focus their attention on only the most difficult aspects of the task), especially when stimuli are rotated or reversed.

One method to test the hypothesis that attentional demands change with the addition of stimulus reversal or stimulus rotation would be to use physiological measures of arousal (i.e., heart rate, breathing) to assess attentional levels and determine whether or not these are significantly different for rotated as opposed to upright stimuli and reversed as opposed to correct stimuli. The next step would be to compare these attentional levels to those of other stimulus manipulations (e.g., masked vs. intact, low intensity vs. high intensity, etc.) to see if in fact stimulus reversal and stimulus rotation have any attentional demands that are significantly different from other variables.

In conclusion, it appears that the complexity of the task due to multiple variable manipulations, particularly in Experiment 1, may be a factor in the large number of variable interactions that reached significance in Experiment 1. This is a hypothesis that is worth considering given the fact that the studies (Everett et al., 1985; Frowein & Sanders, 1978; Van Duren & Sanders, 1988; Williams, Rundell, & Smith, 1981) which lend full support to Sanders (1980, 1983) models tend to manipulate no more than three variables at a time.

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Table 1

ANOVA: Reaction Time Initial Analysis - Experiment 1

Source	df	SS	*F*	Pr>*F*
Reaction Time				
Main effects:				
SI	1	3091097.52	171.99	0.0001*
SQ	1	3267958.27	79.14	0.0001*
SR	1	593082.73	12.80	0.0015*
SV	1	2170.38	0.05	0.8218
Error	25			
Two-way interactions:				
SI*SQ	1	2410026.20	78.66	0.0001*
SI*SR	1	3456127.62	170.24	0.0001*
SI*SV	1	2824111.70	92.00	0.0001*
SQ*SR	1	352564.02	7.47	0.0113*
SQ*SV	1	3198138.52	96.36	0.0001*
SR*SV	1	3073743.93	104.12	0.0001*
Error	25			
Three-way interactions				
SI*SQ*SR	1	2545498.91	98.37	0.0001*
SI*SQ*SV	1	2327810.51	100.00	0.0001*
SI*SR*SV	1	1889707.28	64.68	0.0001*
SQSR*SV	1	5429754.10	122.97	0.0001*
Error	25			
Four-way interaction:				
SI*SQ*SR*SV	1		70.97	0.0001*
Error	25			

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation
SV = Stimulus Reversal
* = P $\leq$ .05
Pr > *F* = probability value for *F*

Table 2

Means from Initial Analysis Reaction Time - Milliseconds

Condition	M	SD
Stimulus Intensity		
High	677.22	375.80
Low	849.62	331.06
Stimulus Quality		
Intact	674.78	176.71
Masked	852.05	467.91
Stimulus Rotation		
Upright	725.66	218.89
Rotated	801.18	463.66
Stimulus Reversal		
Correct	765.70	351.78
Reversed	761.13	376.83

Table 3

Reaction Time Interaction Means Initial Analysis - Experiment 1

Source	M	SD
SI - High		
SQ - Intact	664.70	177.82
Masked	689.73	501.89
SR - Upright	730.73	243.49
Rotated	623.71	467.72
SV - Correct	761.89	350.05
Reversed	592.53	383.16
SI - Low		
SQ - Intact	684.87	174.79
Masked	1014.36	367.29
SR - Upright	720.59	192.23
Rotated	978.64	386.90
SV - Correct	769.51	355.17
Reversed	929.73	284.88
SQ - Intact		
SR - Upright	666.14	150.89
Rotated	683.43	198.64
SV - Correct	589.38	176.52
Reversed	760.18	176.52
SQ - Masked		
SR - Upright	785.18	257.62
Rotated	918.92	603.82
SV - Correct	942.01	411.63
Reversed	762.08	504.19
SR - Upright		
SV - Correct	641.98	215.20
Reversed	809.33	189.31

Table 3 (Continued)

Source	M	SD
SR - Rotated		
SV - Correct	889.02	414.11
Reversed	712.93	494.81
SI - High		
SQ - Intact		
SR - Upright	667.57	153.47
Rotated	661.82	200.72
SV - Correct	586.73	141.48
Reversed	742.67	177.33
SQ - Masked		
SR - Upright	793.88	296.73
Rotated	585.59	631.31
SV - Correct	937.06	406.06
Reversed	442.41	468.08
SI - Low		
SQ - Intact		
SR - Upright	664.70	149.75
Rotated	705.04	196.08
SV - Correct	592.05	115.19
Reversed	777.70	175.67
SQ - Masked		
SR - Upright	776.48	214.08
Rotated	1252.25	333.50
SV - Correct	946.97	421.03
Reversed	1081.76	293.11

Table 3 (Continued)

Source	M	SD
SI - High		
SV - Correct		
SR - Upright	662.05	272.80
Rotated	861.74	398.79
SV - Reversed		
SR - Upright	799.40	188.93
Rotated	385.67	416.59
SI - Low		
SV - Correct		
SR - Upright	621.92	135.23
Rotated	917.09	438.24
SV - Reversed		
SR - Upright	819.26	191.01
Rotated	1040.19	320.22
SQ - Intact		
SV - Correct		
SR - Upright	609.03	144.30
Rotated	569.75	108.12
SR - Reversed		
SR - Upright	723.45	136.05
Rotated	797.12	204.06
SQ - Masked		
SV - Correct		
SR - Upright	674.94	265.50
Rotated	1209.09	355.33

Table 3 (Continued)

Source	M	SD
SV - Reversed		
SR - Upright	895.42	196.88
Rotated	628.75	662.11
SI - High		
SQ - Intact		
SV - Correct		
SR - Upright	621.16	160.58
Rotated	552.30	112.20
SV - Reversed		
SR - Upright	713.98	133.37
Rotated	771.34	211.30
SI - High		
SQ - Masked		
SV - Correct		
SR - Upright	702.93	350.09
Rotated	1171.18	315.89
SR - Reversed		
SR - Upright	884.82	199.66
Rotated	1105.22	212.79
SI - Low		
SQ - Intact		
SV - Correct		
SR - Upright	596.90	128.03
Rotated	587.19	103.09

Table 3 (Continued)

Source	M	SD
SV - Reversed		
SR - Upright	732.51	140.68
Rotated	822.88	197.27
SQ - Masked		
SV - Correct		
SR - Upright	646.95	140.04
Rotated	1246.99	393.44
SV - Reversed		
SR - Upright	906.02	197.45
Rotated	1257.50	268.41

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation
SV = Stimulus Reversal

Table 4

ANOVA: Reaction Time Second Analysis - Experiment 1

Source	df	SS	*F*	Pr>*F*
Reaction Time				
Main effects:				
SI	1	3014.17	.09	0.7648
SQ	1	6465908.31	103.90	0.0001*
SR	1	3183592.74	53.01	0.0001*
Error	25			
Two-way interactions:				
SI*SQ	1	274.62	0.01	0.9300
SI*SR	1	118496.41	3.53	0.0718
SQ*SR	1	4274754.36	71.50	0.0113*
Error	25			
Three-way interactions				
SI*SQ*SR	1	17148.12	0.46	0.5038
Error	25			

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation
* = $P \leq .05$
Pr > *F* = probability value for *F*

Table 5

<u>Means from Second Analysis Reaction Time - Milliseconds</u>

Condition	M	SD
Stimulus Intensity		
High	761.89	350.05
Low	769.51	355.17
Stimulus Quality		
Intact	589.38	128.40
Masked	942.01	411.63
Stimulus Rotation		
Upright	641.98	215.20
Rotated	889.42	414.10

Table 6

Reaction Time Interaction Means Second Analysis - Experiment 1

Source	M	SD
SI - High		
SQ - Intact	586.73	141.48
Masked	937.06	406.06
SR - Upright	662.05	272.80
Rotated	861.74	390.79
SI - Low		
SQ - Intact	592.05	115.19
Masked	946.97	421.04
SR - Upright	621.92	135.23
Rotated	917.09	438.24
SQ - Intact		
SR - Upright	609.03	144.30
Rotated	569.75	108.12
SQ - Masked		
SR - Upright	674.94	265.50
Rotated	1209.09	355.33
SI - High		
SQ - Intact		
SR - Upright	621.16	160.56
Rotated	552.30	112.20
SQ - Masked		
SR - Upright	702.93	350.09
Rotated	1171.18	315.89
SI - Low		
SQ - Intact		
SR - Upright	596.90	128.03
Rotated	587.19	103.09

Table 6 (Continued)

Source	M	SD
SQ - Masked		
SR - Upright	646.95	140.04
Rotated	1246.99	393.44

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation

Table 7

ANOVA: Accuracy Initial Analysis - Experiment 1

Source	df	SS	*F*	Pr>*F*
Accuracy				
Main effects:				
SI	1	0.0116	1.52	0.2285*
SQ	1	0.2501	13.82	0.0010*
SR	1	0.1047	6.93	0.0143*
SV	1	0.1616	17.50	0.0003
Error	25			
Two-way interactions:				
SI*SQ	1	0.0024	0.40	0.5326
SI*SR	1	0.1625	1.72	0.2017
SI*SV	1	0.0078	0.83	0.3711
SQ*SR	1	0.1778	11.86	0.0020*
SQ*SV	1	0.0216	1.93	0.1775
SR*SV	1	0.1625	1.25	0.2751
Error	25			
Three-way interactions				
SI*SQ*SR	1	0.0216	1.80	0.1920
SI*SQ*SV	1	0.0216	2.16	0.1545
SI*SR*SV	1	0.0509	.74	0.3992
SQSR*SV	1	0.0509	3.95	0.0578*
Error	25			
Four-way interaction:				
SI*SQ*SR*SV	1	0.0116	1.16	0.2919
Error	25			

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation
SV = Stimulus Reversal
* = P $\leq$ .05
Pr > *F* = probability value for *F*

Table 8

Means from Initial Analysis Accuracy - Percent Correct

Condition	M	SD
Stimulus Intensity		
High	98.33	.0374
Low	98.69	.0396
Stimulus Quality		
Intact	99.33	.0240
Masked	97.69	.0475
Stimulus Rotation		
Upright	99.04	.0299
Rotated	97.98	.0449
Stimulus Reversal		
Correct	99.16	.0299
Reversed	97.85	.0453

Table 9

Accuracy Interaction Means Initial Analysis - Experiment 1

Source	M	SD
SI - High		
SQ - Intact	99.23	0.0268
Masked	97.44	0.0439
SR - Upright	98.65	0.0364
Rotated	98.01	0.0382
SV - Correct	98.85	0.0365
Reversed	97.82	0.0377
SI - Low		
SQ - Intact	99.42	0.0210
Masked	97.95	0.0509
SR - Upright	99.42	0.0210
Rotated	97.95	0.0509
SV - Correct	99.49	0.0179
Reversed	99.88	0.0519
SQ - Intact		
SR - Upright	97.16	0.0289
Rotated	99.49	0.0179
SV - Correct	99.74	0.0129
Reversed	98.91	0.0310
SQ - Masked		
SR - Upright	98.91	0.0309
Rotated	96.47	0.0572
SV - Correct	98.59	0.0379
Reversed	96.79	0.0542
SR - Upright		
SV - Correct	99.49	0.0258
Reversed	98.59	0.0331

Table 9 (Continued)

Source	M	SD
SR - Rotated		
SV - Correct	98.85	0.0314
Reversed	97.12	0.0540
SI - High		
SQ - Intact		
SR - Upright	99.10	0.0324
Rotated	99.36	0.0198
SV - Correct	99.74	0.0129
Reversed	98.72	0.0350
SQ - Masked		
SR - Upright	98.21	0.0399
Rotated	96.67	0.0467
SV - Correct	97.95	0.0486
Reversed	96.92	0.0384
SI - Low		
SQ - Intact		
SR - Upright	99.23	0.0252
Rotated	99.61	0.0157
SV - Correct	99.74	0.0130
Reversed	99.10	0.0265
SQ - Masked		
SR - Upright	99.62	0.0157
Rotated	96.28	0.0666
SV - Correct	99.23	0.0215
Reversed	96.67	0.0667

Table 9 (Continued)

Source	M	SD
<u>SI - High</u>		
<u>SV - Correct</u>		
SR - Upright	99.10	0.0350
Rotated	98.59	0.0381
<u>SV - Reversed</u>		
SR - Upright	98.21	0.0376
Rotated	97.44	0.0377
<u>SI - Low</u>		
<u>SV - Correct</u>		
SR - Upright	99.87	0.0092
Rotated	99.10	0.0230
<u>SV - Reversed</u>		
SR - Upright	98.97	0.0276
Rotated	96.79	0.0667
<u>SQ - Intact</u>		
<u>SV - Correct</u>		
SR - Upright	99.74	0.0129
Rotated	99.74	0.0129
<u>SR - Reversed</u>		
SR - Upright	98.59	0.0381
Rotated	99.23	0.0215
<u>SQ - Masked</u>		
<u>SV - Correct</u>		
SR - Upright	99.23	0.0341
Rotated	97.95	0.0408

Table 9 (Continued)

Source	M	SD
<u>SV - Reversed</u>		
SR - Upright	98.59	0.0275
Rotated	95.00	0.0672
<u>SI - High</u>		
<u>SQ - Intact</u>		
<u>SV - Correct</u>		
SR - Upright	99.74	0.0131
Rotated	99.74	0.0131
<u>SV - Reversed</u>		
SR - Upright	98.46	0.0434
Rotated	98.97	0.0245
<u>SI - High</u>		
<u>SQ - Masked</u>		
<u>SV - Correct</u>		
SR - Upright	98.46	0.0474
Rotated	97.44	0.0502
<u>SR - Reversed</u>		
SR - Upright	97.95	0.0314
Rotated	95.90	0.0425
<u>SI - Low</u>		
<u>SQ - Intact</u>		
<u>SV - Correct</u>		
SR - Upright	99.74	0.0131
Rotated	99.74	0.0131
<u>SV - Reversed</u>		
SR - Upright	98.72	0.0328
Rotated	99.49	0.0181

Table 9 (Continued)

Source	M	SD
SQ - Masked		
SV - Correct		
SR - Upright	100.00	0.0000
Rotated	98.46	0.0287
SV - Reversed		
SR - Upright	99.23	0.0217
Rotated	94.10	0.0850

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation
SV = Stimulus Reversal

Table 10

ANOVA: Accuracy Second Analysis - Experiment 1

Source	df	SS	*F*	Pr>*F*
Accuracy				
Main effects:				
SI	1	0.00213	5.30	0.0300*
SQ	1	0.00692	8.30	0.0080*
SR	1	0.00213	2.28	0.1435
Error	25			
Two-way interactions:				
SI*SQ	1	0.00213	3.68	0.0667
SI*SR	1	0.00008	10.11	0.7389
SQ*SR	1	0.00213	1.92	0.1784
Error	25			
Three-way interactions				
SI*SQ*SR	1	0.00008	0.11	0.7389
Error	25			

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation
* = $P \leq .05$
Pr > *F* = probability value for *F*

Table 11

<u>Means from Second Analysis Accuracy - Percent Correct</u>

Condition	M	SD
Stimulus Intensity		
High	98.84	.0365
Low	99.49	.0178
Stimulus Quality		
Intact	99.74	.0128
Masked	98.59	.0379
Stimulus Rotation		
Upright	99.49	.0257
Rotated	98.85	.0314

Table 12

Accuracy Interaction Means Second Analysis - Experiment 1

Source	M	SD
SI - High		
SQ - Intact	99.74	0.0129
Masked	97.95	0.0485
SR - Upright	99.10	0.0350
Rotated	98.59	0.0381
SI - Low		
SQ - Intact	99.74	0.0129
Masked	99.23	0.0215
SR - Upright	99.87	0.0092
Rotated	99.10	0.0230
SQ - Intact		
SR - Upright	99.74	0.0129
Rotated	99.74	0.0129
SQ - Masked		
SR - Upright	99.23	0.0340
Rotated	97.95	0.0407
SI - High		
SQ - Intact		
SR - Upright	99.74	0.0130
Rotated	99.74	0.0130
SQ - Masked		
SR - Upright	98.46	0.0473
Rotated	97.44	0.0501
SI - Low		
SQ - Intact		
SR - Upright	99.74	0.0130
Rotated	99.74	0.0130

Table 12 (Continued)

Source	M	SD
SQ - Masked		
SR - Upright	100.00	0.0000
Rotated	98.46	0.0286

SI = Stimulus Intensity
SQ = Stimulus Quality
SR = Stimulus Rotation

Table 13

ANOVA: Reaction Time Initial Analysis - Experiment 2

Source	df	SS	F	Pr>F
Reaction Time				
Main effects:				
FD	1	301791.45	6.01	0.0210*
SR	1	4108252.80	43.97	0.0001*
SV	1	1867267.60	34.82	0.0001*
Error	27			
Two-way interactions:				
FD*SR	1	5520.29	0.29	0.5947
FD*SV	1	20859.44	10.89	0.3548
SR*SV	1	526438.50	7.89	0.0091*
Error	27			
Three-way interactions				
FD*SR*SV	1	19410.98	0.56	0.4623
Error	27			

FD = Foreperiod Duration
SR = Stimulus Rotation
SQ = Stimulus Reversal
* = P ≤ .05
Pr > F = probability value for F

Table 14

Means from Initial Analysis Reaction Time - Milliseconds

Condition	M	SD
Foreperiod Duration		
Immediate	933.90	364.32
Delayed	1007.31	363.48
Stimulus Rotation		
Upright	835.18	352.99
Rotated	1106.03	325.51
Stimulus Reversal		
Correct	879.30	369.78
Reversed	1061.91	337.65

Table 15

Reaction Time Interaction Means Initial Analysis - Experiment 2

Source	M	SD
FD - Immediate		
SR - Upright	803.44	379.29
Rotated	1064.37	298.94
SV - Correct	852.25	377.89
Reversed	1015.56	333.92
FD - Delayed		
SR - Upright	866.93	324.91
Rotated	1108.27	337.95
SV - Correct	906.36	362.87
Reversed	1108.27	337.95
SR - Upright		
FD - Correct	695.40	315.93
Reversed	974.96	334.47
SR - Rotated		
SV - Correct	1063.21	327.54
Reversed	1148.86	320.67
FD - Immediate		
SR - Upright		
SV - Correct	682.62	395.88
Reversed	974.26	325.64
SR - Rotated		
SV - Correct	1021.89	272.93
Reversed	1106.85	322.20
FD - Delayed		
SR - Upright		
SV - Correct	708.19	215.09
Reversed	1025.66	341.34

Table 15 (continued)

Source	M	SD
<u>SR - Rotated</u>		
SV - Correct	1104.54	374.84
Reversed	1190.87	319.36
<u>FD - Immediate</u>		
<u>SV - Correct</u>		
SR - Upright	682.62	935.88
Rotated	1021.89	272.93
<u>SR - Reversed</u>		
SR - Upright	974.26	325.64
Rotated	1106.85	322.20
<u>FD - Delayed</u>		
<u>SV - Correct</u>		
SR - Upright	708.19	215.09
Rotated	1104.54	374.84
<u>SV - Reversed</u>		
SR - Upright	1025.66	341.34
Rotated	1190.87	319.36

FD = Foreperiod Duration
SR = Stimulus Rotation
SV = Stimulus Reversal

Table 16

ANOVA: Reaction Time Second Analysis - Experiment 2

Source	df	SS	*F*	Pr>*F*
Reaction Time				
Main effects:				
FD	1	81983.14	1.54	0.2253
SR	1	3787972.20	42.78	0.0001*
Error	27			
Two-way interactions:				
FD*SR	1	22817.16	0.51	0.4830
Error	27			

FD = Foreperiod Duration

SR = Stimulus Rotation

* = $P \leq .05$

Pr > *F* = probability value for *F*

Table 17

<u>Means from Second Analysis Reaction Time - Milliseconds</u>

Condition	M	SD
Foreperiod Duration		
Immediate	852.25	377.89
Delayed	906.36	362.87
Stimulus Rotation		
Upright	695.40	315.93
Rotated	1063.21	327.54

Table 18

Reaction Time Interaction Means Second Analysis - Experiment 2

Source	M	SD
FD - Immediate		
SR - Upright	682.62	395.88
Rotated	1021.88	272.92
FD - Delayed		
SR - Upright	708.18	215.00
Rotated	1104.54	375.83
SR - Upright		
FD - Immediate	682.62	395.88
Delayed	708.18	215.00
SR - Rotated		
FD - Immediate	1021.88	272.92
Delayed	1104.54	375.83

FD = Foreperiod Duration
SR = Stimulus Rotation

Table 19

ANOVA: Accuracy Initial Analysis - Experiment 2

Source	df	SS	*F*	Pr>*F*
Reaction Time				
Main effects:				
FD	1	0.00477	3.33	0.0793
SR	1	0.05262	4.57	0.0417*
SV	1	0.02361	6.32	0.0182*
Error	27			
Two-way interactions:				
FD*SR	1	0.00060	0.85	0.3637
FD*SV	1	0.00024	0.12	0.7269
SR*SV	1	0.00004	0.02	0.9001
Error	27			
Three-way interactions				
FD*SR*SV	1	0.00179	1.16	0.2910
Error	27			

FD = Foreperiod Duration
SR = Stimulus Rotation
SQ = Stimulus Reversal
* = P $\leq$ .05
Pr > *F* = probability value for *F*

Table 20

Means from Initial Analysis Accuracy - Percent Correct

Condition	M	SD
Foreperiod Duration		
Immediate	94.67	.0838
Delayed	95.60	.0738
Stimulus Rotation		
Upright	96.66	.0526
Rotated	93.60	.0962
Stimulus Reversal		
Correct	96.16	.0660
Reversed	94.11	.0890

Table 21

Accuracy Interaction Means Initial Analysis - Experiment 2

Source	M	SD
FD - Immediate		
SR - Upright	96.37	0.0580
Rotated	92.98	0.1010
SV - Correct	95.69	0.0771
Reversed	93.75	0.0897
FD - Delayed		
SR - Upright	96.96	0.0468
Rotated	94.23	0.0918
SV - Correct	96.73	0.0530
Reversed	94.46	0.0891
SR - Upright		
FD - Correct	97.74	0.0382
Reversed	95.60	0.0630
SR - Rotated		
SV - Correct	94.58	0.0827
Reversed	92.62	0.1080
FD - Immediate		
SR - Upright		
SV - Correct	97.62	0.0383
Reversed	95.12	0.0711
SR - Rotated		
SV - Correct	93.57	0.0989
Reversed	92.38	0.1046
FD - Delayed		
SR - Upright		
SV - Correct	97.86	0.0387
Reversed	96.07	0.0529

Table 21 (continued)

Source	M	SD
SR - Rotated		
SV - Correct	95.60	0.0629
Reversed	92.86	0.1132
FD - Immediate		
SV - Correct		
SR - Upright	97.95	0.0328
Rotated	95.77	0.0593
SR - Reversed		
SR - Upright	95.90	0.0591
Rotated	94.49	0.0516
FD - Delayed		
SV - Correct		
SR - Upright	98.21	0.0368
Rotated	97.05	0.0344
SV - Reversed		
SR - Upright	96.54	0.0512
Rotated	95.13	0.0560

FD = Foreperiod Duration
SR = Stimulus Rotation
SV = Stimulus Reversal

Table 22

ANOVA: Accuracy Second Analysis - Experiment 2

Source	df	SS	*F*	Pr>*F*
Reaction Time				
Main effects:				
FD	1	0.0036	2.17	0.1519
SR	1	0.0279	6.38	0.0177*
Error	27			
Two-way interactions:				
FD*SR	1	0.0022	1.99	0.1696
Error	27			

FD = Foreperiod Duration
SR = Stimulus Rotation
* = $P \leq .05$
Pr > *F* = probability value for *F*

Table 23

Means from Second Analysis Accuracy - Percent Correct

Condition	M	SD
Foreperiod Duration		
Immediate	95.60	.0771
Delayed	96.73	.0530
Stimulus Rotation		
Upright	97.74	.0381
Rotated	94.58	.0828

Table 24

Accuracy Interaction Means Second Analysis - Experiment 2

Source	M	SD
FD - Immediate		
SR - Upright	97.62	0.0383
Rotated	93.57	0.0989
FD - Delayed		
SR - Upright	97.86	0.0387
Rotated	95.60	0.0629
SR - Upright		
FD - Immediate	97.62	0.0383
Delayed	97.86	0.0387
SR - Rotated		
FD - Immediate	93.57	0.0629
Delayed	95.60	0.0629

FD = Foreperiod Duration
SR = Stimulus Rotation

Appendix

Literature Review

Literature Review

According to Meyer, Osman, Irvin, and Yantes (1988) the earliest substantive research base for discrete information processing models seems to have begun with Donders' (1868/1969) subtraction method. Donders' (1868/1969) subtraction method involves determining the time duration for different stages by analyzing data from three types of reaction time procedures: Type A, Type B, and Type C. Type A or simple reaction time tasks involve presenting a simple stimulus with only a single response option. Type B or choice reaction tasks involve presenting multiple stimuli with multiple potential response options. Donders' (1868/1969) theorized that Type B would require two stages, stimulus discrimination and response selection. Type C or go/no go reaction time tasks involve presenting multiple stimuli but only a single response option. With Type C, a subject would be required to make a response to one stimulus while withholding reponses to all other stimuli. According to Donders (1868/1969), Type C required stimulus discrimination, but not response selection (cf. Meyer et al., 1988).

Donders (1868/1969) reasoned that by subtracting the reaction time of one type of task from the reaction time of another type of task, he could determine stage durations. For example, if Type B involved stimulus discrimination and response selection, and one subtracted the reaction time of Type C, which was postulated to just involve stimulus discrimination from Type B, he reasoned that the remainder would equal the reaction time for response selection. However, this method tended to produce inconsistent results in the laboratory. Meyer et al.(1988) attribute these inconsistencies to failure of Donders' assumption that stages of processing could be inserted or deleted in a pure fashion without changes in time course or output of other concommitant stages which are shared across different tasks.

However, the additive factor method, which was previously discussed, (see the Introduction) is a significant improvement over Donders'(1868/1969) subtraction method due to several key distinctions. The additive factor method unlike Donders' (1868/1969) subtraction method does not require inserting or deleting stages of processing, and therefore does not rely on the assumption of pure insertion. It also avoids having to compare results from different types of reaction time tasks, which according to Meyer et al. (1988) made the subtraction method more vulnerable to failures. Conversely, when assumptions of the additive factor method are violated, the results indicate that the assumptions were violated (see the Introduction for a review of AFM assumptions). However, the results do not always indicate which assumptions were violated.

History of Information Procesing

The foundation for all information processing theories is rooted in a history of the study of individual mental processes that dates back to the early 1800's, according to Meyers et al. (1988). During the early 1800's, the zeitgeist in the physiological community was that human thought was instantaneous and that the actions of humans were controlled by an indivisible mind that was separate from the body (cf. Meyers et al., 1988). The belief that human thought was instantaneous was perhaps best characterized by the belief of Johannes Muller, a noted experimental physiologist, that the rate of neural conduction was similar to that of the speed of light.

However, despite this climate in the scientific community, it was during the early 1800's that astronomers began to notice individual differences in subjective temporal judgments about the movement of stellar objects as well as other heavenly bodies. As a result, astronomers began to seek practical techniques for measuring the speed of mental processes. In 1823, Bessel, an astronomer, developed the "personal equation" which was used to measure individual differences in observers' estimates of the times at which stellar events occured. Meyer et al. (1988) suggest that this was perhaps the earliest work which indicated the existence of various mental processes which could involve varying time durations.

Herman Von Helmholtz, a noted physicist and neuropsychologist, in 1850/1853 made a discovery that would lend further support to the notion that mental events could be studied empirically. Helmholtz (1850/1853) discovered that neural conduction in humans was 50 meters per second which is much slower than the speed of light. This was further proof that human thought was not instantaneous but could be measured. Furthermore, Helmholtz (1850/1853) developed the simple reaction time procedure as an experimental tool. Helmholtz's (1850/1853) work led to further reaction time research and the eventual development of speed-accuracy tradeoff curves by Woodworth (1899), which are still applicable today (cf. Meyer et al., 1988). Woodworth's (1899) speed-accuracy tradeoff curves revealed that slower reaction times are typically associated with higher performance accuracy, and faster reaction times are typically associated with lower performance accuracy. In other words, subjects may tend to exchange speed for accuracy in reaction time tasks (see also Pachella, 1977).

During the same time period, Donders' (1868/1969) developed his previously mentioned subtraction method which utilized Type A, B, and C tasks. This led scientists to use the subtraction method to determine the existence of stages of processing and to attempt to measure the apparent duration of stages. Most notably among these scientists was Wilhelm Wundt, founder of the first experimental psychology laboratory. Wundt's (1880) endeavors to apply the subtraction method led to a new type of task called D-reaction or Type D. Like Donders (1868/1969) Type C, Type D involved multiple stimuli and a single response; however, Type D required subjects to make their response to each stimulus as soon as they thought they had identified the stimulus correctly (cf. Meyer et al., 1988).

Unfortunately, after this progression of interest in research regarding stage isolation and measurement of stage durations, a paper was published by Oswald Kulpe in 1893 which dealt a devastating blow to this line of research. Kulpe (1893), who was a student of Wundt's, published a critique of the subtraction method which indicated that the method tended to produce inconsistent results. As previously mentioned, it seemed that the assumption of pure insertion, which was critical to Donders' (1868/1969) subtraction method and Wundt's use of Type D had failed (cf. Meyer et al., 1988). As a result of the failure of the asssumption of pure insertion, reaction time experiments fell into what Meyer et al. (1988) term the Dark Age. This period lasted from the late 1800's up to the first half of the 20th century, during which there were few experiments that compared performances in simple vs. choice reaction time procedures.

In the 1950's, what Meyer et al. (1988) term the Renaissance period began. Most noted among the scientific work at the beginning of this period was Hicks' (1952) publication which described how speed-accuracy tradeoff curves may be used to measure information transmisssion rates. Later during this period, a significant contribution to the literature was made by Sternberg (1967,1969) in the form of the additive factor method which laid the foundation for a resurgence of investigation into discrete, serial information processing models.

Discrete vs. Continuous Debate

Following the development of serial stage models, such as the two stage model hypothesized by Sternberg (1967), continuous flow models were developed. A good illustration of a continuous flow model is the cascade model developed by McClelland in 1979. McClelland's (1979) cascade model like serial processing models assumes that information processing stages exist. However, unlike serial processing models, the cascade model suggests that multiple stages may take place in a parallel fashion with a continuous flow of output information that goes from one stage to the next. McClelland (1979) also demonstrated how the cascade model could produce interactions of factors that affect separate stages (i.e. are discrete), and how additivity could occur with factors that effect stages which are not strictly serial.

Parallel models tend to focus on levels or subprocesses of information flow rather than discrete stages. Since the introduction of parallel models, there has been a debate over the validity of discrete vs. parallel models in the literature. Hoewever, Miller (1988) suggests that we look at information processing models as existing on a continuum with discrete models at one pole and parallel models at the other, rather than categorizing information processing models in one of these two categories and thinking of the categories as mutually exclusive.

Miller (1988) further clarifies the controversy by arguing that there are at least three ways in which a given stage can be continuous or discrete. Similarly, Sanders (1990) suggests that each stage is discrete in some aspects while continuous in others or that each information processing model may contain some stages which are discrete and some which are continuous. According to Miller (1988), a stage can be processed continuously or discretely at the level of: 1) <u>representation</u> which is defined as the type of input or internal coding a stage receives; 2) <u>transformation</u> which is defined as the process within a stage to transfer the internal code of the stage into a form that prepares it for availability to the next stage; and 3) <u>transmission</u> which is defined as the relaying of output information from one stage to the next.

A fourth manner in which a stage can be continuous or discrete identified by Miller (1990) depends on the <u>a priori</u> state of the individual. The state is termed a priori because it is only influenced by the previous biological and informational factors impending on the individual and not the actual content of upcoming information. The a priori state affects the way a stage varies for trial to trial. Although stages are often thought of as constant across trials, there is evidence to support trial to trial variation. One example of the trial to trial fluctuation of a stage is the well known effect of practice. The a priori state determines how the stage processes the input. The a priori state may have a general influence. Examples by which this may occur include controlling the overall processing rate, determining the strategy used for transformation, or selecting the form of transmission of output to the next stage. On the other hand, the a priori state may have specific influences on input. Specific influences on input might be accomplished by influencing individual readiness for a given stimulus or response. For example, the biological arousal of an individual could influence readiness for response. Furthermore, the previous information an individual has can help the individual determine stimulus probability.

In clarifying representation, transformation, and transmission as concepts, Miller (1988) points out that a stage can be discrete or continuous at the level of the internal code (i.e., representation) by either receiving categorical or gradual quantitative representation of the input information. Stage transformation can be discrete or continuous by transforming information in either an abrupt, all-or-none fashion or a gradual incremental fashion. Stage transmission is either discrete or continuous depending on whether it transmits output to the next stage in a complete message or a long series of partial messages. With respect to a priori states, extreme discrete models would assume that a stage starts in either one of two distinct states at the begining of each trial. An example would be the fast guess model in which a subject decides at the beginning of each trial to either attend to the forthcoming iinformation and make a slow, accurate response or to ignore the upcoming information and make a quick guess (cf. Miller, 1988). However, a model at the continuous extreme would assume that a stage could start at any one of a large number of a priori states with the possibility for a continuous variation of these states within a given stage.

When physiological evidence is considered in the discrete vs. continuous arguement, Miller (1988) points out that physiological evidence seems to support continuous models, since neurons are known to fire continuously at various rates and times. However, Sanders (1990) argues against the use of physiological research in evaluating information processing models. He points out that it is not clear that physiological components reflect one type of processing and one type only and that time relations of the firing rates of neurons are comparable with the time relations of choice reaction tasks.

In spite of the continuous vs. discrete debate, which is primarily based on differences, each of these model types share some similarities. Proponents of both models share the assumption that stages or levels of processing exist and that there are different levels of operations that take place on internal information codes (Sanders, 1990). Another similarity of continuous and discrete models is the assumption of linearity. Outputs are assumed to pass in one direction through the information processing system with no bypassing of processes or subprocesses (McClelland, 1979). Additionally, response execution is assumed to be a discrete, final event according to both models (Sanders, 1990).

Reaction Time Research

Although the amount of reaction time research is extensive, the following review will be focused on studies relevant to stage model theories of information processing, particularly Sanders (1980) model. In an endeavor to clarify how information is processed, reaction time research has given rise to a variety of alternative information processing models. One such model, which is an alternative to both continuous and parallel models is Salthouse's (1981) comparative-influence method. The comparative-influence method combines Donders' (1868/1969) subtraction method and Sternberg's (1969) additive factor method (AFM). It compares a choice reaction time task (CRT) with a tachistoscopic task. The CRT task is assumed to contain all of the stages involved in the tachistoscopic task plus at least one additional stage. Results from Salthouse's (1981) experiments have found stages of information processing that are similar to stages found using Sternberg's AFM. Because these results were arrived at using a different method, they enhance results supportive of the stages found using the AFM.

After Sternberg's (1967) study in which two factors, stimulus quality and memory set size were additive for practiced subjects, several studies have reported results that are supportive of a two-stage linear model. The effects on reaction time of stimulus intensity and S-R compatibility have been shown to be additive (Sanders, 1977; Shwartz et al., 1977, Expt. 1). Similarly, S-R compatibility and stimulus quality were observed to be additive in their effects on reaction time (Blackman, 1975; Frowein, 1981; Sanders, 1978, 1979, Expt. 3; Shwartz et al., 1977, Expt. 2; Sternberg, 1969, Expt. 5). Additive effects have also been reported for stimulus intensity and stimulus quality (Everett et al., 1985; Frowein et al., 1982; Sanders, 1980). Furthermore, investigation of the effects of visual stimulus intensity, believed to be an early procesing stage, and time uncertainty, which is believed to be a late processing stage, indicates that these variables are additive in their contribution to mean reaction time (Bernstein et al., 1973; Sanders, 1975).

There is also some evidence (Everett et al., 1985; Sanders, 1980, 1983; Van Duren & Sanders, 1988;

Williams, Rundell, & Smith, 1981) that suggests a three-stage linear model of recognition processes. Preprocessing, feature extraction and response choice are reported to represent additive stages which are affected by visual stimulus intensity, visual stimulus quality, and S-R compatibility, respectively.

Investigation of the three-stage linear model led to the hypothesis that a fourth stage may exist in cognitive processing. Suppport for a fourth stage in recognition processes is given by Sanders' (1980, 1983) models in which time uncertainty is predicted to affect a motor adjustment stage. Everett et al. (1985) also concluded that days of practice would affect motor adjustment.

Further studies have revealed conflicting evidence for the effects of time uncertainty on a fourth stage in recognition processes. Frowein and Sanders (1978) observed that the effect of time uncertainty was additive to the effects of stimulus quality and S-R compatibility, but that the locus of its effect in information flow had not yet been conclusively determined. In 1979, Sanders used short and long foreperiods to manipulate time uncertainty. He evaluated the effects of time uncertainty on muscle tension and found them to be additive. This supports Sanders (1980, 1983) suggestion that time uncertainty affects motor adjustment. Sanders (1980) argues that when subjects are unsure of signal onset (i.e., time uncertainty exists), there will also be a slow down in motor adjustment, producing an increase in reaction time. Conversely, there is evidence that reaction time is nearly independent of time uncertainty with only those foreperiods of less than a few milliseconds or those longer than several seconds as exceptions (Green & Von Gierke, 1984). More recently, Spijkers (1990) found that response-specificity interacted with time uncertainty. These results suggest that both response-specificity and time uncertainty may affect the same stage.

Sanders' Information Processing Models

Initially, Sanders (1977) concluded that at least three additive stages made up the information processing sequence– encoding, response choice, and motor adjustment. In 1980, he suggested that each stage is composed of a set of functionally independent processes, but that within a stage these processes may be overlapping and parallel. He also suggested that the number of stages that exist is unknown, but that it is important to develop a model with a finite number of stages and investigate them (Sanders, 1980).

In 1980, Sanders developed a model in which information is postulated to be processed in six stages: preprocessing, feature extraction, identification, response choice, motor programming, and motor adjustment. See the Introduction of the present dissertation for a more elaborate description of Sanders' (1980) model. Following his (1980) model, Sanders, in 1981, suggested his cognitive-energetic model and elaborated on it further in 1983. He indicated that this model would include the four stages that had best been established by the existing research: 1) stimulus preprocessing; 2) feature extraction; 3) response choice; and 4) motor adjustment. He further specified that different types of energy resources are needed by each of the stages. These energy resources are arousal, activation, and effort. Sanders (1981) suggests that arousal is a phasic reponse to input. Activation is conceptualized to be a tonic readiness to respond, and effort is thought to serve as a balance between arousal and activation. Effort is hypothesized to stimulate activity when arousal and activation are low. Conversely, effort is used to decrease and moderate activity when levels of arousal and activation are high.

Given that the energy and stress components elaborated on in his (1983) model are also suggested in his earlier (1980) model, conceptually each of Sanders' (1980, 1983) models can be thought of as cognitive-energetic models. His (1980, 1983) models are designed to overcome the limitatiions of linear stage models such as Sternberg's (1969) model which utilized the AFM. Sanders (1981) believes that the assumptions of the AFM (i.e., unidimensional processing, strict serial processing between stages, no feedback loops during processing, and constant stage output) are too easily violated.

Sanders' (1980, 1983) models were also designed within the conceptual framework of resource allocation models, which are primarily concerned with how resources are allocated to various processing operations.

However, resource allocation models have as a major disadvantage a lack of specific assumptions about how resources are allocated to various processing operations; thus, making the results of virtually any experiment easily interpretable as support for resource models.

Sanders (1977) conceptual framework, which was the foundation for his (1980, 1983) models, takes into consideration both the structural components (e.g., information processing mechanisms) and functional components

(e.g., attention and alertness). His (1977) theory assumes that the total time taken to process a stage is affected by both the state of the individual and the computational demands of the stage. His theory also relates stress to performance. He conceptualizes that stress is a variable that intervenes between perceived external demands and capabilities to adapt to these demands. His (1980, 1983) models appear to be reasonable alternative models to stricter serial processing models at one extreme and continuous flow models, such as, McClelland's (1979) cascade model at the other extreme.

Summary of Evidence and Conclusions

As evidenced by the literature, several attempts have been made to explain how humans process information. Donders' (1868/1969) subtraction method and Sternberg's (1969) AFM are two well-known early approaches to explain information processing, but these models have been criticized for violating their own assumptions. Nevertheless, these models gave rise to a large body of research and the development of alternative models of information processing. Alternative models range from continuous models at one end of the spectrum to discrete models at the other end of the spectrum.

While it is apparent that much research has supported Sanders' (1983) cognitive-energetic model, it is also apparent that there has not been a thorough investigation of Sanders' (1980) model, especially with regard to the identification and motor programming stages initially postulated in his (1980) model. A study focusing on either of these two variables would seem to be a significant contribution to the information processing literature. The literature reveals that the variables affecting the identification stage are not clear. Moreover, the identification stage has not been established as a stage that exists independently of other stages in Sanders' (1980) model. Although a few studies suggest the existence of the identification stage (Shwartz et al., 1977; Logsdon et al., 1984), other research (Stoffels et al., 1989) has implied that the identification stage is not independent of other stages in Sanders (1980) model.

The studies set forth in this investigation will try to add information to the literature about the effects of variables that have been hypothesized to affect the identification stage. The present studies will also investigate whether or not the hypothesized identification stage exists as a separate stage that is additive with other components suggested in Sanders' (1980) model.

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