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THE USE OF STIMULUS DISCRIMINABILITY AND S-R COMPATIBILITY AS FACTORS TO EXPAND THE SEQUENTIAL MODEL OF HUMAN INFORMATION PROCESSING

DISSERTATION

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By

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The Ohio State University
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INTRODUCTION

Within recent years there has been a substantial revival of the use of the choice-reaction time experiment for the study of human cognitive processes, such as decision making and memory retrieval (see Smith, 1968). In a typical reaction-time experiment the subject is required to make one of several responses depending upon which of several possible stimuli has appeared. The interval between stimulus onset and response initiation is measured as the choice reaction time, and from these data inferences can be made concerning the nature of the subject's perceptual and/or decision processes.

The reaction time approach to the study of cognitive processes can be traced to Donders (1868). In that paper Donders made the assumption that the time intervening between stimulus and response is occupied by successive, nonoverlapping mental operations. Furthermore, he thought that the time required by each of these distinct mental components could be measured via a subtraction method. Basically, this method required the creation of two tasks, the second of which contained an additional mental "step" relative to the first task. The excess time required to perform the second task then was considered an estimate of the duration of this additional mental "step" and could be used in inferring the nature of this particular component. For example, Donders showed that reaction times were longer when a subject had to both distinguish between two stimuli (stimulus categorization) and then emit
one of two responses (response selection) than when two stimuli had to be distinguished but a response was required to only one of them (stimulus categorization but supposedly no response selection). Donders stated that the extra time required for the more demanding task was the time needed to choose the appropriate response since in all other aspects the two tasks were believed to be identical. The results also indicated that the less complex task (categorization only) produced latencies longer than those recorded when the subject merely responded to a single stimulus. Hence, the time required for the stimulus categorization step presumably also could be obtained through the subtraction method.

Due to its quantification aspects, the Donders method initially was appealing to psychologists who were concerned with cognitive events (see Jastrow, 1890); however, it soon was subjected to strong criticism by Kulpe (1895) and later by Woodworth (1938). Kulpe argued against the subtraction method by suggesting that when a task is altered by the addition of another cognitive stage there is no guarantee that the other stages in the task are not also changed. Hence, if the two reactions would not be identical except for the extra stage, then obviously the subtraction method would not be a valid procedure.

It should be noted that Kulpe's argument was similar to that incorporated in Moray's (1968) recent model of human performance—the limited channel model. Moray suggests that the capacity of the human processing resources is of a fixed size and that the allocation of these resources is dictated by the task itself. Therefore, it follows that any change in task requirements could produce a reallocation of processing resources
and hence time estimates based upon a subtraction method would be un-
reliable. Similarly, Welford (1960) points out the possibility that
task requirements determine the perceptual or decision strategy to be
employed, and so, again, a change in the task characteristics could lead
to the utilization of a different strategy.

Despite these shortcomings in methodology, Donders' basic idea that
cognitive events occur in a sequential fashion has survived to become
the theoretical basis of several recent models, e.g., Welford (1960),
Neisser (1963), Sternberg (1966), and Smith (1968). While there may be
some disagreement as to whether processing is serial or parallel within
each cognitive stage, or as to whether the stages are completely non-
overlapping, all of these models assume that information flows through
the human system encountering one stage after another in a sequential
manner. For example, Welford (1960) proposed the model of human pro-
cessing shown in Fig. 1, which is based upon research on human choice
and movement reaction times, on tracking, and on studies of the psycho-
logical refractory period.

The perceptual mechanism of Fig. 1 receives neural impulses from
the sense organs which it then integrates and identifies. The decision
making or selection role is assigned to the translation mechanism which
chooses the proper response, given the identified signal. The effector
mechanism merely relays this choice to the appropriate organs in order
that the response can be executed. A feedback loop is assumed to ex-
tend from the effector side to regulate the flow of information from the
perceptual to translational stages allowing data from a new signal to
pass once the response to the previous signal is initiated. The
Fig. 1. Diagram of mechanisms involved in sensory-motor performance. (Welford, 1960)
sequential nature of Welford's model is obvious.

After an extensive review of the choice reaction time literature, Smith (1968) advanced the general four-stage model of human processing depicted in Fig. 2. In the preprocessing stage the raw stimulus is encoded and preprocessed until a "stimulus representation" is formed. Stage 2 then represents the process of comparing this stimulus representation with the memorial representations of the possible alternatives. This categorization then leads to selection of the proper response in Stage 3, and, finally, the response is emitted in the last stage.

Again, Smith's model is an extension of Donders' original proposition that cognitive events occur in a sequential manner.

A major step in arriving at an alternative to the subtraction method for measuring the cognitive stages in a sequential model was made by Hick (1952) who proposed, on the basis of his own data and those of Merkel (1885), that in a choice reaction situation the subject gains information at a constant rate in the information theory sense. More specifically, Hick reported a linear relationship between choice reaction time and information transmitted which could be expressed by the following equation:

\[ \text{CRT} = K \log (n_e + 1) \]  
(Eq. 1)

Here, \( n_e \) represented the equivalent number of alternatives present in the task and the constant 1 was added to \( n_e \) to account for the additional temporal uncertainty of stimulus onset. The proportionality constant \( K \) was empirically determined. If \( N \) can represent the sum of all possibilities including "no signal" (or if temporal uncertainty is reduced to near zero by letting the subject "know" when the signal will
Fig. 2. A sequential model of human information processing. (Smith, 1968)
occur), then Eq. 1 can be rewritten as:

$$\overline{CRT} = K \log N$$  \hspace{1cm} (Eq. 2)

This formulation is Hick's law.

In general, Hick's law was found to hold in different choice reaction tasks by Crossman (1953) and by Hyman (1953). However, both found that there was less agreement between their data and the predictor equation when the temporal uncertainty constant was included in the equation. Therefore, Crossman, who used a card sorting task, has suggested that

$$\text{Mean time per card} = \text{movement time} + K \log N$$  \hspace{1cm} (Eq. 3)

where again $K$ is a proportionality constant and $N$ represents the number of alternative responses. Finally, Hyman (1953) and later Bricker (1955) proposed another alternative to Hick's original equation, which is the form most widely accepted today:

$$\overline{CRT} = A + B \log N$$  \hspace{1cm} (Eq. 4)

Initially $A$, the intercept value in the linear equation, was considered as the time required by a simple reaction. That is, when the degree of choice equals one. (Note that this interpretation is similar to Crossman's movement time in Eq. 3.) The $B \log N$ term then represented the increase over simple reaction time due to the necessity of discriminating among the possible stimuli and deciding upon the proper response. Thus, as Briggs (1969) points out, Eq. 4 is a modern expression of Donders' additivity principle in which reaction time is decomposed into two distinct components.

It was noted by Welford (1968) that there is some tendency for Hyman's formula (Eq. 4) to underestimate simple reaction times. As a result, the equation does not fit the data as well at a degree of choice
below about four as it does when the number of alternatives is large. This underestimation lends credence to Sternberg's (1967) suggestion that the $A$ intercept in Eq. 4 does not represent simple reaction time at all. Rather, Sternberg argues, the intercept should be interpreted as the total time consumed by all events other than those involving the comparison of input with memorial information. Presumably, this means the intercept represents initial (stimulus encoding) and terminal (response decoding) stages in processing which occur regardless of the degree of choice. These correspond quite closely with Stages 1 and 3 of Smith's (1968) model. Therefore, since even simple reactions probably require some central processing time (Welford, 1968), it can be seen that the $A$ intercept would be lower than simple reaction time if the intercept includes only encoding and decoding times.

A major advance in the use of choice reaction time for the study of cognitive events stems from Sternberg (1967). In this paper he suggested a method of analysis, the so-called additive factor method, which circumvents the often criticized necessity of adding or deleting entire stages to a reaction task in order to infer the underlying processes as in the Donders procedure. The major characteristic of the additive factor method is that it requires only that the amount of processing of a stage, and thus its duration, be manipulated systematically under experimental control. The primary assumptions of the Sternberg method are (1) that total reaction time can be decomposed into a series of additive components, (2) that each component represents a stage of processing, and (3) that only the duration of a particular component stage is a function of the processing load placed on that particular stage. A
critical test of Sternberg's assumptions is that there be a linear relation between reaction time and processing load.

Sternberg suggests that the additive factor method be implemented by searching for pairs of factors which have additive (noninteractive) effects on reaction time. (Here a factor is defined as an experimentally manipulated variable or as a set of treatment levels.) Once such a pair is found, it can be inferred that there exist at least two stages of processing between stimulus and response since each factor can be thought of as influencing a different stage. The basic assumption here is that when factors influence no stages in common they will have independent and additive effects on reaction time since stage durations are also additive. That is, the effect of one factor, and correspondingly the duration of one stage, will be independent of the level of the other factor. On the other hand, if two factors are found to have nonindependent effects on RT, that is, there is an interaction between them, then it can be inferred that there exists some processing stage which is commonly influenced by both factors—but not two separate stages. In summary, Sternberg's additive factor method states that independent effects of factors imply separate processing stages while nonindependent effects or interactions suggest one such stage which is influenced by two or more factors.

The logic underlying the additive factor method is not impeccable as Sternberg himself admits. For example, it is possible that two factors may have additive effects on mean reaction time and yet they both influence the same processing stage. However, such a conclusion would require an interpretation similar to Moray's suggestion that as processing
in one stage becomes more difficult, then more capacity is brought to bear on this stage with the net result that there is no interaction between the two factors. Likewise, two factors may have a nonindependent effect on reaction time and yet not directly influence the same processing stage. For example, if Factors 1 and 2 directly affected the durations of two successive stages, A and B respectively, and Factor 1 also controlled the quality of the output of Stage A, then it is quite possible that Factor 1 would indirectly influence Stage B, and hence Factors 1 and 2 would interact statistically.

Despite these possible shortcomings, the additive factor method has been shown to be a useful research vehicle in the differentiation of cognitive stages in information processing (see Sternberg, 1967 and 1968, and Briggs, 1969). The validity of the method depends to a large extent upon the identity and theoretical interpretation placed upon the various stages after they have been defined by the statistical techniques mentioned above.

In summary, the proposition advanced by Donders over a century ago was that human information processing can be viewed as a series of non-overlapping mental stages. This basic notion is still held today as evidenced in recent models of human performance. However, Donders' original means of measuring these stages, the subtraction method, has been replaced by theory based on functional relationships such as Hick's law and by the consequences of Sternberg's additive factor method. Thus, the use of the choice reaction time experiment in the search for and the identification of human processing stages continues.
In his classic paper Hick (1952) related human information processing to the concepts of information theory. Since then there has emerged a large and steadily growing body of research using the choice reaction time methodology to study man as an information processor. This chapter will attempt to review selectively this research by emphasizing those variables which have been found to have a reliable effect on mean choice reaction time. In order to impose some organization on the review, the studies will be grouped with respect to the degree to which the independent variables they employed were primarily stimulus variables, response variables, or task variables, and were thereby concerned with the relationships between stimulus and response.

**Stimulus Variables.** If the number of possible responses or response uncertainty is kept constant while the number of stimuli (input uncertainty) is allowed to vary, then any change in choice reaction time (CRT) can be attributed to the time associated with stimulus identification. Using a 1:1 mapping of stimuli onto responses, Hick (1952) and Hyman (1953) found that mean CRT increased linearly with the log of the number of alternative stimuli and with stimulus uncertainty, respectively. The latter study manipulated uncertainty by changing the probability of occurrence of the various stimuli.

Several studies have employed many:1 mappings of stimuli onto responses (e.g., Crossman, 1953; Cameron, 1964; Fitts & Biederman, 1965;
Morin, Forrin, & Archer, 1961). The general conclusion produced by this type of task is that CRT is a function of the number of perceptually or conceptually different stimuli. For example, Crossman required that the subject (S) sort cards into two piles (red pictures and black plain into one pile and black pictures and red plain into a second pile). He found that the mean time for this task was quite similar to the time required to sort the cards into four suits and greater than the time required to sort all cards into the two color categories. He suggested the reason for these results is attributable to a discrepancy between nominal and effective stimulus uncertainty. That is, in the first task S perceived four conceptually different classes of stimuli just as he did when sorting into four suits. On the other hand, when sorting on the basis of color, S perceived only two different classes of stimuli, and hence the nominal and effective uncertainties were comparable in this case.

In an attempt to differentiate the effects of stimulus and response uncertainty on CRT, LaBerge and Tweedy (1964) had Ss respond with one hand to a green light and with the other hand to both a red and blue light. When the relative frequency of red and blue was varied, it was found that response latency was a function of stimulus probability and not response uncertainty.

Other studies have investigated stimulus categorization with many:1 mappings, but in a slightly different manner (Nickerson & Feehrer, 1964; Chase & Posner, 1965; Smith, 1967). Their Ss memorized a set of the possible target stimuli. A signal was then presented and S had to make a "yes-no" response depending on whether or not the
signal was one of the target set. In general, it was found that mean CRT increased logarithmically with $s$, the number of targets. On the other hand, Sternberg (1963, 1964, 1967, 1968), using the same type of task, has repeatedly found a linear relationship between CRT and the number of targets. This type of relation has also been supported by Briggs (1969).

Stimulus discriminability has been investigated in several experiments (see Sternberg, 1964, 1968; Chase & Posner, 1965; and Crossman, 1955). Sternberg (1968) used a 1:1 mapping, digit-naming task, and he varied discriminability by adding random noise to the visual stimulus. He found a systematic increase in mean CRT as discriminability was decreased. Further, this increase in CRT was reflected primarily in the intercept of the function relating CRT to the degree of choice. This led Sternberg to attribute the discriminability effect to a preprocessing or encoding stage of processing, i.e., to Stage 1 of Smith's (1968) model. Chase and Posner (1965) also reported an increase in CRT due to lower discriminability levels; however, unlike Sternberg (1968), they found a significant interaction between discriminability and memory load, i.e., discriminability produced changes in the slope of the function between CRT and the degree of choice; hence, it could be interpreted as affecting Stage 2 of Smith's (1968) model. The salient difference between Sternberg's and Chase and Posner's manipulations of discriminability seems to be that the latter study varied the discriminability level by changing the similarity between the stimulus elements while Sternberg added random visual noise to the stimuli.

Finally, the value or payoff associated with a particular stimulus
has been shown to affect its categorization time (see LaBerge, 1964). If several stimuli, each having different values, are mapped onto the same response, those stimuli which yield higher payoffs will produce shorter latencies.

In summary, the studies reviewed above have in general suggested that the difficulty of stimulus categorization (and the corresponding CRT) is a function of the effective number of stimuli or stimulus uncertainty. Furthermore, this function has typically been found to be logarithmic in nature except in a few types of memory and visual search tasks in which a linear relationship has been observed.

Response Variables. Of the processing stages in Smith's (1968) model, response selection has by far received the least amount of attention. This is not surprising since it is conceptually and methodologically the most difficult to differentiate. In discussing stimulus categorization, it was noted that a many:1 mapping task can be used easily to estimate the variables involved in stimulus identification. However, the converse does not hold. A task employing a 1:many mapping is quite difficult to control. Nevertheless, two experiments have used 1:many mappings in an attempt to study response selection (Morin & Forrin, 1963; Schlessinger, 1964). Both of these studies paired several responses with each stimulus and instructed S to be unsystematic in choosing his responses. In general, the results indicate that with stimulus uncertainty held constant CRT increases with response uncertainty. However, as Smith (1968) points out this increase in CRT might also possibly be due to an increase in memory requirements since to be "unsystematic" S had to remember his previous responses and this memory
requirement would also increase as a function of response uncertainty.

Neisser (1967) takes a considerably different approach to the problem of response selection: Essentially he ignores it. With his "analysis by synthesis" hypothesis he proposes that a stimulus is identified by an active reconstruction process; therefore, by the time identification has been completed, the response has also been constructed.

A recent study by Avant, Bevan, and Wing (1968) utilized a 1:many mapping and the results seem to be considerably more meaningful than are those of the previous studies cited here. Avant et al. required that S rate the size of projected squares on a multiple-point scale. The number of points or categories into which S could place the square corresponded to response alternatives and these were varied independently of the number of stimuli. In general, Avant et al. found a monotonic increase in latency with an increase in the number of response alternatives. However, the function relating CRT to response uncertainty was not strictly linear in form as is the relationship between CRT and stimulus uncertainty.

Translation Variables. The effects of stimulus-response (S-R) compatibility and of practice on CRT are concerned primarily with the translation from stimulus to response. Fitts defined S-R compatibility as "a term used to specify the relative effectiveness with which people learn to make one of a particular class of responses to one of a particular class of stimulus events, i.e., to use different stimulus and response codes" [1959, p. 3]. He viewed compatibility as the number of recoding steps between stimulus and response. However, Fitts himself
suggested that no direct test of this assumption was possible, and hence the magnitude of compatibility or the number of recoding steps must be inferred from behavioral end products (RT and transmission rate). Consequently, most studies investigating S-R compatibility have done so by pairing sets of stimuli with different response sets and then recording the efficiency of each unique S-R ensemble (Mowbray, 1960; Fitts, 1964; Broadbent & Gregory, 1965; Fitts & Deininger, 1954; Garvey & Knowles, 1954).

Fitts and Deininger (1954) paired four different types of eight-element stimulus displays (two-dimensional spatial, two-dimensional symbolic, one-dimensional spatial, and nondimensional symbolic) with a two-dimensional eight-alternative response arrangement via three different types of mapping rules: direct, mirrored, and random assignment. With the direct mapping they found that the two-dimensional spatial stimulus was by far superior to the other arrangements. However, as the relationship between stimulus and response progressed to mirrored and then random assignment, the relative superiority of the two-dimensional stimulus decreased to the point that it was no faster than the other stimulus sets when random mappings were used.

A much larger task was employed by Garvey and Knowles (1954). They factorially combined two stimulus displays of 100 elements each with two response arrangements: One stimulus display consisted of a 10x10 matrix of lights with the onset of a single light indicating the particular signal; the other display was a 10x2 array with a combination of two lights indicating the stimulus. The response arrangements were similar (10x10 or 10x2), with one or two buttons,
respectively, defining a unique response. They found that the various
display-response combinations produced different RTs with the spatially
equivalent S-R pairs being the fastest. This "compatibility effect"
was fairly permanent in that the initial differences between pairings
were maintained over 25 days of practice even though all pairings showed
a decrease in RT over this time. Similar results have been obtained by
Fitts and Seeger (1953), Kay (1955), and Brainard, Irby, Fitts, and
Alluisi (1959).

When compatibility has been varied in a task along with the number
of S-R alternatives, the consistent finding is that a Hick-type rela-
tionship holds with compatibility level determining the rate of trans-
mission—that is, the slope of the linear function between RT and
information transmitted (H_t) is a function of compatibility. Crossman
(1956) was among the first to investigate this relationship. He demon-
strated that with the type of response held constant (button pressing),
the slope of the RT-H_t function varied with the type of signal display
employed: The transmission rates were 5 and 15 bits/sec. for symbolic
vs. nonsymbolic signals, respectively. Other studies have reported
varying transmission rates which can be attributed to the compatibility
between stimulus display and response mode. For example, using lights
as signals and key presses as the response, Merkel (1885), Hick (1952),
and Hyman (1953) obtained transmission rates remarkably constant at
about 5-7 bits/sec. Verbal responses in naming objects, colors, or
designs have produced rates from 14 to 17 bits/sec. (Morin et al.,
sets ranging from 2 to 1000 elements, Pollack (1963) found Ss could
transmit 40 bits/sec. by repeating briefly shown words.

Another group of compatibility studies have been primarily interested in testing the generality of Hick's law. The basic premise of these studies is that if S-R compatibility is very high, then the slope constant in Hick's law would approach zero. Thus, Leonard (1959) employed a CRT task in which he held his fingers lightly on the armatures of a set of relays. The signals were the vibrations of the relays, and responded by depressing the same relay which was vibrating. The results indicated no increase in RT from two to four to eight choices suggesting a slope constant of zero, at least out to 3 bits of stimulus information. Several other studies have found RT to be independent of the number of stimuli in tasks having direct relationships between stimuli and responses (Mowbray, 1960; Morin & Forrin, 1962; Brainard et al., 1962). In these designs responded by verbally naming the digits contained in subsets of two, four, or eight alternatives. However, as Fitts and Switzer (1962) point out, all of these studies utilized "unfamiliar subsets" for the two- and four-alternative conditions. That is, subsets containing nonconsecutive digits. When Fitts and Switzer then repeated these studies comparing familiar and unfamiliar subsets, they reported that with the familiar subsets RT increased in a manner corresponding to Hick's law; however, when unfamiliar subsets were used, the RTs to two and four alternatives were artificially elevated such that it appeared as if RT was independent of the degree of choice. They attributed this discrepancy between familiar and unfamiliar subsets to a difference between nominal and effective uncertainty. In his review of the CRT literature Smith (1968) concludes that
whether the slope constant can ever be reduced to zero is a moot question. The studies which have found such a relationship have been few and difficult to replicate.

After reviewing several studies which found varying transmission rates, Welford (1968) concludes that the flattening of the slope relating RT to degree of choice is associated with increased familiarity or compatibility of the relation between signal and response, and that the steepness of the slope can be identified as due largely to the involvement of a translation mechanism. He further suggests that "... this [flattening] is due to the connection between various identifications and their corresponding responses becoming 'built-in' and thus ready for immediate use instead of having to be to some extent worked out afresh for each trial" [p. 87].

The implications of Welford's conclusion are that transmission rate is a function of the load on a central translation processor. This load in turn depends upon the strength or directness of the association between stimulus and response and that with practice or experience the association becomes stronger thereby reducing the load and increasing the transmission rate. In fact, several studies have found that extended practice affects the relation between RT and information transmitted in a way quite similar to the effect of compatibility. Treisman (1961) had Ss respond verbally to sets of two, four, or eight nonsense syllables. With practice there was a decrease in the slope constant as if the task were becoming more compatible. Neisser, Novick, and Lazar (1963) used a visual search task and found that the initial differences in RT for searching for from one to ten targets
simultaneously decreased systematically over the 12 days of practice. Similar results were obtained by Egeth and Smith (1965). Noticing the likeness of the results from variations in compatibility and practice led Broadbent and Gregory (1965) to conclude that compatibility merely reflects prior (preexperimental) practice on similar tasks.

In summary, the difficulty of the translation from stimulus to response seems to determine the S-R compatibility level. Furthermore, compatibility has typically been found to interact with the degree of choice and hence affects the slope constant in a Hick-type relationship. It should be recalled that this slope constant is usually considered an estimate of processing time in Stage 2 of Smith's model—the stimulus categorization stage. Intuitively, it does not seem obvious how a variable such as compatibility could affect the time needed to identify a stimulus; however, it does suggest the interesting proposition that Stage 2 might be profitably subdivided into two (or more) substages—one representing stimulus categorization and the other the translation from the identified stimulus to the response. Finally, it has been found that practice affects RT in a manner very similar to that of compatibility. That is, by producing slope changes. Again, it seems important to further specify the locus of these effects within Stage 2. Can they be attributed to a categorization stage, a translation stage, or to both?
THE DIFFERENTIATION OF CENTRAL PROCESSING STAGES

As noted previously, the slope of the linear function relating CRT to the degree of choice typically has been interpreted as an estimate of the processing rate in Stage 2 of Smith's (1968) model—stimulus categorization. It is suggested that this process is far too specific a procedure to which to attribute all factors that produce a change in this slope, or its inverse the transmission rate. That is, there appears to be a necessity that Stage 2 be differentiated into two (or more) components in order that processes may be identified which are more likely to be affected by the several factors producing changes in the transmission rate. A significant contribution was made in this direction by Briggs and Blaha (1969). By factorially combining display load and memory load in a CRT task, they were able to subdivide Stage 2 into a memory retrieval and a central comparison process. Furthermore, they observed that both of these stages were sensitive to the variable of practice such that the time required by each of these processes decreased systematically over time.

The studies reviewed in the previous chapter suggested that S-R compatibility also is a factor which affects Stage 2 of the Smith model since it consistently produces a change in transmission rate. However, it seems unlikely that compatibility, or the strength of the relationship between stimulus and response, should affect a process such as stimulus categorization, or even affect the processes identified by
Briggs and Blaha—memory retrieval and central comparison. Therefore, an additional substage needs to be identified within Stage 2 in order to theoretically account for the effects of S-R compatibility upon RT and information processing.

Sternberg (1968) applied the additive factor method to a study in which S-R compatibility was varied along with stimulus discriminability and the number of S-R alternatives. It is important to note here that discriminability was manipulated by the addition of random visual noise. Previously, this type of manipulation had been found to produce a constant increment in CRT and thus affect the initial stage of processing, stimulus encoding. By analysis of the statistical interactions in the data, Sternberg was able to isolate two stages of processing: a stimulus encoding stage, which was affected solely by the level of discriminability (although there was a very weak interaction between discriminability and the number of alternatives), and a central stage, which he labeled "translation and response organization." The latter was found to be a function of both S-R compatibility and the number of alternatives—two variables which interacted strongly. The isolation of these two stages was made possible due to the additive effects of discriminability and compatibility upon CRT. The defining of the central stage as a "translation" process appears to have been rather fortuitous since only one stage was isolated within Stage 2 and even this one stage was very sensitive to the number of alternatives, a factor which previously had been interpreted as affecting the stimulus categorization or identification process. Therefore, it is impossible to say whether compatibility affects categorization time or that the
number of alternatives affects translation time.

Furthermore, there is a suggestion in the literature that compatibility may interact with discriminability under some conditions. Garvey and Knowles (1954), in the study reviewed above, varied S-R compatibility in a task containing 100 stimulus and response alternatives. A post hoc contour analysis resulted in the conclusion that those stimulus elements toward the center of the signal display consistently produced slower RTs than did those near the periphery. This gradient effect was explained by noting that there were more "extra-perceptual" cues such as edges and corners near the periphery, and therefore the peripheral stimulus elements were more readily distinguishable from one another than were the central stimuli which lacked these extra-perceptual cues. In other words, a discriminability gradient can be assumed to have existed across the display with the peripheral elements representing high discriminability levels and, correspondingly, the central stimuli were relatively low in discriminability. The important point to note here, however, is that when compatibility was lowered there was very little change in the RT to peripheral elements while there was a significant increase in the response latencies to the more central stimuli. Hence, there was an interaction between the factors of discriminability and S-R compatibility. This interaction may not be discrepant with the results obtained by Sternberg (1968) since it would seem that the definition of discriminability given by Garvey and Knowles falls closer to that applied by Chase and Posner (1965), a change in stimulus similarity, than to the manner in which Sternberg varied discriminability: by adding random noise. Therefore, it might be expected that two such
variables (discriminability as varied by changing similarity and compatibility) both of which have been separately found to affect the central processing stage may also statistically interact when employed in the same task.

In the present study an attempt was made to further differentiate the component processes contained in Stage 2 of the Smith model of human information processing in order to isolate a mechanism directly responsible for the effect of S-R compatibility. Furthermore, it was felt that additional clarification was needed with respect to the processes underlying or sensitive to stimulus discriminability. Therefore, S-R compatibility, stimulus discriminability, the number of alternatives, and practice were factorially combined in a CRT task.

**Method**

**Subjects.** Thirty-six male and female undergraduate students at The Ohio State University served as Ss. Each S participated in four consecutive daily sessions of 40 min. each and was paid at the rate of $1.25 per session.

**Stimuli and Responses.** The stimuli consisted of figures depicting a horizontal row of four, six, or eight vertical lines. All lines had a common base and were a standard 1/16 in. wide and 1 in. in length except for the line serving as the signal for that particular stimulus figure. Three levels of discriminability (low, medium, and high) were employed, and this was accomplished by increasing the "signal" lines to 1.1 in., 1.15 in., and 1.3 in. in length, respectively. The stimulus figures were then photographed, mounted into slides, and projected via a rear-projection technique onto a ground-glass screen located
18 in. in front of S. Directly beneath and in front of this screen was a panel containing a horizontal row of response buttons. The number of response buttons on the panel also could be changed from four to six to eight in order to correspond to the number of lines on the stimulus figures. The center-to-center distance between response buttons was 1 in. and the stimulus lines were always projected directly centered above this set of buttons.

Under the four-alternatives condition (four lines on the stimulus figure), S was instructed to use the index and middle fingers of each hand for the four possible responses. The fourth and fifth fingers of each hand were then added for the six-and eight-alternative conditions, respectively. The Ss were told to respond to the signal line in one of the three following manners, depending upon which compatibility group into which they were placed. Under the most compatible condition (direct mapping), the correct response consisted of merely depressing the button directly beneath the signal line on the stimulus figure. A displaced mapping was utilized for the intermediate level of compatibility, and here Ss were told to press the response button to the immediate right of the signal line (except, of course, if the signal appeared in the far right location of the stimulus figure, in which case they were to employ the left-most response button). For the low level of compatibility, a mixed assignment of stimuli to responses was used. This can best be understood if one considers the positions of stimulus lines as being numbered from 1 to n from left to right (where \( n \) = the number of alternatives). The left hand was then used to respond to signals occurring in the odd-numbered positions starting with
the index finger's response to Position 1 and continuing toward the fifth finger in a systematic order. The right hand likewise responded to signals in the even-numbered positions with the index finger being used for signals in Position 2. A schematic of the mapping for the mixed conditions is shown in Fig. 3.

Apparatus. The S was seated approximately 18 in. in front of the opaque screen on which the stimulus figures were back-projected, and he rested the appropriate fingers on the buttons located on the response panel situated immediately below and in front of the screen. The slides were presented via a Sawyer projector whose cycle was controlled by a Tektronics timer. The stimulus onset was produced by a Tektronics pulse generator operating a selanoid-driven shutter placed between the projector lens and the screen. The operation of this shutter also started a Berkley timer which accumulated time in units of 10,000ths of a sec. until terminated by the closing of one of the microswitches located under each response button. The shutter was also closed by this microswitch contact, thus causing the termination of the stimulus. After a delay of 2 sec., the next slide was presented. The experimenter recorded the time between stimulus onset and response (RT) as well as the accuracy of each response.

Procedure. The 36 Ss were randomly placed into the three experimental groups corresponding to the three levels of compatibility, direct (D), displaced (Dp), and mixed (M), with each group containing 12 Ss. Therefore, each S always used the same mapping between stimulus and response. On the first day, a practice session, the response assignments were thoroughly explained to S, who was then instructed that
### 4 Alternatives

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### 6 Alternatives

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### 8 Alternatives

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<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 3.** S-R mapping for the mixed condition. The Os represent response buttons and the digits indicate the proper responses to the various signal positions.
he was to respond as quickly as possible without making errors. The instructions were followed by 270 practice trials in which S responded to nine blocks of 30 stimulus figures—each block corresponding to a different combination of one of the three levels of discriminability and one of the three levels of the number of alternatives.

On Days 2 through 4 each S responded to six blocks of 40 stimulus figures each. Again, each block was a unique combination of alternatives and discriminability levels. The first 10 responses within each block were considered as practice trials and were not entered as data in the analysis. Within each daily session S viewed only two of the three alternative levels (one during Blocks 1-3 and the second in Blocks 4-6). However, all levels of discriminability were employed in each half of the daily session. The order in which Ss were presented alternative and discriminability levels was counterbalanced by a Latin square design across groups and days. Hence, each S actually performed a complete replication of the factorial design of number of alternatives x discriminability level, and therefore comparisons could be made between the two factorials in order to assess practice effects. Since the S-R mappings purposively confounded the number of alternatives with the fingers used to respond, only the RTs made by the fingers common to all alternative levels (the index and middle fingers of each hand) were entered into the data analysis.

Results

The error levels were observed to be quite low. This indicates that Ss did follow instructions. The percentage of errors for each condition is listed in Table 1, and as can be seen, the highest error
Table 1
Percentage of Errors for Each Condition

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Discriminability Level</th>
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<tr>
<td></td>
<td>High</td>
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<tr>
<td>Direct</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.4</td>
</tr>
<tr>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>8</td>
<td>2.4</td>
</tr>
<tr>
<td>Displaced</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>8</td>
<td>2.5</td>
</tr>
<tr>
<td>Mixed</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>6</td>
<td>2.2</td>
</tr>
<tr>
<td>8</td>
<td>1.9</td>
</tr>
</tbody>
</table>
rate was 3.0% and the range was narrow extending only from 1.3% to 3.0%. Median RTs were calculated for the correct responses made by each subject in each of the 54 cells in the design. These times are listed in Table 4 of the Appendix. The medians were then subjected to an analysis of variance. All main effects (compatibility, discriminability, number of alternatives, and practice) were significant at the \( p < .01 \) level as were all two-way interactions except for that of Compatibility x Discriminability, which had an \( F \) of less than one. The analysis of variance table and \( F \) ratios are shown in Table 2.

The basic results are shown in Fig. 4 where mean RT is plotted as a function of the number of alternatives for the three compatibility levels with discriminability as a parameter. The best-fit equations and their correlations are shown in Table 3. Four points should be noted from this figure. First, the compatibility factor interacts with the number of alternatives to produce changes in the slope of the function relating RT to the degree of choice. This was an expected result and is quite consistent with previous studies such as that by Broadbent and Gregory (1965). This interaction is shown more clearly in Fig. 5. Secondly, the discriminability factor also produces slope changes because of its interaction with the number of alternatives. The Discriminability x Number of Alternatives interaction is also shown in Fig. 6. This finding lends support to the suggestion made by Smith (1968) that when stimulus discriminability is varied by increasing the similarity among stimulus alternatives, the result should be a change in the rate of information transmission. The third point is that even though compatibility and discriminability separately produce slope
Table 2

Analysis of Variance for Median Reaction Times

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
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<td>Practice (P)</td>
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<td>1.048</td>
<td>86.6</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Alternatives (A)</td>
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<td>5.023</td>
<td>140.9</td>
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<tr>
<td>Discriminability (D)</td>
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<td>1.326</td>
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<td>Ss(C)</td>
<td>33</td>
<td>.166</td>
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<td>C x P</td>
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<td>.158</td>
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</tr>
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<td>C x A</td>
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<td>.136</td>
<td>3.8</td>
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<td>P x A</td>
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<td>.111</td>
<td>10.4</td>
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<tr>
<td>C x D</td>
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<td>.012</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>.022</td>
<td>4.1</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>A x D</td>
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<td>.012</td>
<td></td>
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<td>C x P x A</td>
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<td>1.8</td>
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<td>C x A x D</td>
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<td>1.2</td>
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<tr>
<td>P x A x Ss(C)</td>
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<td>.011</td>
<td></td>
<td></td>
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<tr>
<td>P x D x Ss(C)</td>
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<td>.005</td>
<td></td>
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<tr>
<td>A x D x Ss(C)</td>
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<td>.007</td>
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<td></td>
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<tr>
<td>C x P x A x D</td>
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<td>.002</td>
<td></td>
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</tr>
<tr>
<td>P x A x D x Ss(C)</td>
<td>132</td>
<td>.005</td>
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</table>
Fig. 4. The relationship between RT and number of alternatives for each experimental condition.
Table 3
Best-Fit Equations and Their Correlation Coefficients

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<tr>
<th>Group</th>
<th>Discriminability</th>
<th>Equation</th>
<th>r</th>
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<tbody>
<tr>
<td>Direct</td>
<td>High</td>
<td>( RT = 0.25 + 0.050(N-1) )</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>( RT = 0.27 + 0.059(N-1) )</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>( RT = 0.24 + 0.083(N-1) )</td>
<td>0.68</td>
</tr>
<tr>
<td>Displaced</td>
<td>High</td>
<td>( RT = 0.32 + 0.056(N-1) )</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>( RT = 0.32 + 0.064(N-1) )</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>( RT = 0.29 + 0.092(N-1) )</td>
<td>0.64</td>
</tr>
<tr>
<td>Mixed</td>
<td>High</td>
<td>( RT = 0.39 + 0.073(N-1) )</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>( RT = 0.34 + 0.099(N-1) )</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>( RT = 0.37 + 0.114(N-1) )</td>
<td>0.63</td>
</tr>
</tbody>
</table>
Mean Reaction Time (sec.)

Compatibility
- Mixed
- Displaced
- Direct

Number of Alternatives

Fig. 5. Compatibility x Number of Alternatives interaction.
Fig. 6. Discriminability x Number of Alternatives interaction.
changes, there is no interaction between these two variables. This is shown clearly in Fig. 7 which depicts the interaction plot between these two variables. Thus, it can be seen that the increase in RT due to a lowering of discriminability is almost constant regardless of the compatibility level. Finally, the basic relationship between RT and the degree of choice is not logarithmic as predicted by Hick's law; rather it is linear. This discrepancy appears to be a function of the task employed. It was noted previously that Neisser (1967) has consistently found a linear relationship when a visual search task is employed and it can be argued that the present task basically involves a visual search procedure since S was always presented with several stimulus lines from which he had to find the longest—the signal.

Seemingly, another conflict with Hick's law is that the intercept appears to be best placed at the point where the number of alternatives equals one rather than zero. That is, the intercept is more interpretable at this point. However, this placement is justified since RT is typically plotted against the log₂ of the number of alternatives and the intercept occurs at a log value of zero which corresponds to a value of one on a linear scale. Also the discriminability factor loses meaning when there is only one alternative since it was defined as the difference in length between the signal and the other stimulus lines. If a one-alternative level had been employed, no differences in RT would have been expected under the various discriminability levels since only the signal line would have been presented and due to its absolute length was quite detectable.

Another observation that should be made from both Fig. 4 and 5 is
Fig. 7. Compatibility x Discriminability interaction summed over alternatives.
that there is a systematic increase in the intercept of the linear function relating RT to the number of alternatives as the compatibility level is decreased from direct to mixed mapping. This result has not been previously reported; however, no prior experiment has paired the number of alternatives with S-R compatibility and manipulated compatibility by varying only the mappings between constant stimulus and response sets. The implications of this finding will be considered more fully in the discussion section of this paper.

The other major variable, practice, was analyzed by comparing the data from the first half of the experiment with those collected during the second half. This was possible since all Ss completely replicated the factorial combination of Discriminability Level x Number of Alternatives. The interactions Practice x Compatibility and Practice x Discriminability are shown in Fig. 8 and 9, respectively. The important point to note in Fig. 8 is that the decrease in RT over practice is greater for the mixed group than for either the direct or displaced groups. This finding is in close agreement with Garvey and Knowles (1954) and Broadbent and Gregory (1965). In fact, Broadbent and Gregory even suggested that compatibility represents the degree of pre-experimental practice S has received on a given task. Therefore, it would be expected that the initial differences observed between compatibility levels would dissipate as the amount of practice was increased.

Likewise, it can be observed in Fig. 9 that the original increment in RT due to a lowering of the discriminability level also decreases over practice. Initially, the time difference between the highest and
Fig. 8. Practice x Compatibility interaction.
Fig. 9. Practice x Discriminability interaction.
lowest levels of discriminability amounted to 190 msec. However, by the latter half of the experiment this difference had decreased to only 130 msec—a reduction of approximately 32%.

Discussion

By the application of Sternberg's (1968) additive factor analysis, two components can be identified within the central stage of processing, Stage 2 of the Smith (1968) model. This follows from the fact that discriminability and compatibility were found to have additive effects on RT and both factors affected the central processing stage as indicated by the change in transmission rate across levels of these two variables. It is suggested, therefore, that the first component, which is sensitive to the discriminability factor, has the function of serially searching through and comparing the stimulus lines in order to identify the signal. Hence, as discriminability is lowered, this process becomes more difficult since the lines being compared become more similar. The second component can be identified as a translator, as suggested by Welford (1968), and serves to connect the identified signal to its appropriate response. If compatibility is lowered, then a more involved translation must take place between stimulus and response and the time consumed by the second component increases correspondingly. The next step is to gain an estimate of the processing rates of these two components.

Crossman (1955) and Vickers (1967) have reported that RT is a linear function of stimulus discriminability when discriminability is defined in units of 1/(log₂ s₂ - log₂ s₁), where s₂ and s₁ represent the greater and lesser stimulus, respectively. This suggests the
possibility that the slope constant, $B$, in the general equation $RT = A + B(N)$ can be systematically decomposed by showing that $B$ is a linear function of discriminability, as defined by Crossman. The relationship between $B$ and discriminability is shown in Fig. 10 and can be written:

$$B = E + F(D) \quad \text{(Eq. 5)}$$

where $D$ is discriminability units, and $F$, representing the processing rate of the search component, is the change in $RT$ per alternative per discriminability unit. The intercept, $E$, of Eq. 5 then represents the central processing time per alternative which is not attributable to the search component.

If the assumption is allowed that the compatibility levels presently employed could be expressed in terms of the number of translations occurring between stimulus and response, as suggested by Fitts (1959), then the constant $E$ could be expressed as a function of the number of translation steps, and hence a processing rate could be obtained for the second component—the translator. While inferring the number of translation steps is of necessity tenuous, it is suggested that the following schema can be reasonably employed. Under the highest compatibility level, where direct mapping existed, $S$ needed to perform only one translation on the average—a spatial transform from the signal on the display to the response button immediately below it. With the displaced mapping an extra translation was necessary to select the button to the right of the signal. Hence, the displaced condition contained two translation steps. However, $S$s in the mixed condition, in addition to the spatial transform had to (1) identify the signal's position as odd or even, (2) select either the left or right hand
Fig. 10. Relationship between $B$ and discriminability.

Discriminability $= \log_2 S_g - \log_2 S_i$

- Direct
- Displaced
- Mixed
depending on whether the signal was odd or even, and then (3) select the correct finger on this hand. In summary, it is suggested that the three compatibility levels be viewed as sequences of one, two, or four translation steps between stimulus and response. The intercept, $E$, from Eq. 5 is now shown as a function of the number of translations in Fig. 11. The basic relationship is:

$$E = G + H(T)$$  \hspace{1cm} (Eq. 6)

where $T$ is the number of translations; $H$, the processing rate of the translator, is the time per alternative per translation; and $G$ is an estimate of central processing time not attributable to either the search or translator components. Substituting Eq. 5 and 6 back into the general Hick relationship yields the expansion of the additivity principle:

$$RT = A + G(N) + H(T \times N) + F(D \times N)$$  \hspace{1cm} (Eq. 7)

$$= .31 + .020(N) + .007(T \times N) + .008(D \times N)$$

The best-fit estimates of the cycle times $E$ and $H$, for the search and translator components were 8 and 7 msec., respectively. The 95% confidence interval for $E$ extended from 5 to 11 msec., while this same interval for $H$ was bounded by 5 and 9 msec. It should be noted that the search or comparison component identified in the present study is theoretically similar to the central comparison operation isolated by Briggs and Blaha (1969) by varying display load. They reported that the cycle time for this component approached an asymptote at about 14 msec. per comparison which is slightly higher than the 8 msec. per alternative found in the present study. However, Briggs and Blaha employed far more complex stimuli (Vanderplas figures) than the simple
Fig. 11. Relationship between $E$ and the number of translation steps.

$E = 0.20 + 0.007(T)$

$r = 0.989$
lines used here and therefore it is not too surprising that they obtained a slower processing rate for central comparisons.

It was noted previously that the intercept $A$ showed a systematic increase as the compatibility level was lowered. This intercept constant is typically considered an estimate of the time consumed by all events other than those involved in the central processing stage. In other words, the intercept $A$ represents stimulus encoding and response decoding times or Stages 1 and 3, respectively, of the Smith (1968) model. It is not too surprising, therefore, that the compatibility factor would influence the intercept because of its effect on the response decoding or response "selection" process. As a matter of fact, Welford (1968, p. 77) has offered an explanation of this result in his discussion of the response selection process in terms of excitatory and inhibitory neurological mechanisms. Welford, basing his argument upon physiological evidence provided by von Bekesy (1967), has suggested that due to either an expectancy or preliminary processing of the stimulus a "build-up" of neural activity occurs in the motor cortex. This build-up has its peak at those cells innervating the motor response associated with the expected or partially processed stimulus. Furthermore, this neural activity is assumed to spread in such a manner that adjacent cells in the motor cortex also receive a somewhat lesser excitatory potential while cells farther removed are actually inhibited.

Translating Welford's argument into terms of the present study yields the conclusion that only in the case of the direct mapping condition was the initial neural build-up associated with the exactly appropriate response. This conclusion, of course, requires the assumption
that initial neural activity is associated with the most likely, natural, or compatible response that could be made to the partially processed stimulus. However, this assumption is not unreasonable. Extending the logic suggests that the displaced mapping condition should require more time than the direct mapping since the peak of initial neural activity is associated with an inappropriate response. However, since the correct response was always the button to the immediate right of the signal, it would be expected that due to the spread of excitation the cells innervating the correct response had received some excitatory potential. Therefore, in order to emit the correct response, S had to merely increase to some absolute level the neural activity in the already excited cells associated with the response. Since under mixed mappings the correct response was farther removed spatially from the signal than under the other two conditions, it can be assumed that the task of increasing the potential of the correct response cells and decreasing the potential in the inappropriate cells was relatively more difficult and hence consumed more time.

The major disadvantage of this hypothetical response selection process, as Welford admits, is its lack of quantification. In order to quantify the predictions from this model, assumptions are required concerning the actual gradients across the motor cortex as well as the distances between cells associated with the different responses. The latter assumption can possibly be replaced by an estimate of the separation between signal and response in terms of the ordinal positions on the display and control panels. Using this metric, the direct condition had a median separation of 0 positions (the correct response was always
right below the signal), while the displaced and mixed levels had median separations of 1.0 and 1.8 positions, respectively. These separations are roughly proportional to the differences observed between the intercept \( A \) values of .253, .310, and .367 sec. for the three compatibility levels. Therefore, the influence of compatibility upon the intercept of the basic relationship between RT and degree of choice can be interpreted as the effect exerted on the response selection process via the neurological mechanisms mentioned above. A more exact quantification of this effect, however, would require the scaling of compatibility along dimensions more commensurate with the physiological knowledge of the motor cortex.

In reviewing, then, Stage 2 of Smith's model has been successfully subdivided into two components via Sternberg's additive factor analysis. The first of these components, the search or comparison mechanism, was found to be sensitive to the discriminability level and the number of alternatives. Therefore, it was suggested that the function of this mechanism was to serially compare the stimulus lines until the longest line, the signal, was identified. A serial comparison process was indicated by the linear relationship between the slope constant \( B \) (time per item) and discriminability level. However, the present design does not allow a conclusion on whether this comparison process is exhaustive (all lines are compared) or self-terminating (lines are compared only until a longer one is found). Such a distinction would further clarify the nature of the comparison stage and would also permit a more accurate estimate of its processing rate, which presently is estimated as 8 msec. per comparison.
The second component, the translator, was affected by the compatibility level and the number of alternatives. It was proposed that the translator starts with the identified signal and then performs a series of transformation steps in order to arrive at the appropriate response. The operation time of the translator was tentatively estimated at 7 msec. per transformation step. However, the most important conclusion here is merely that a stage within central processing has finally been identified which can account for S-R compatibility effects without assuming that compatibility somehow determines stimulus categorization time. Obviously, more effort needs to be applied to the scaling of stimulus-response compatibility in order to arrive at a more accurate estimate of the processing rate of the translator component of central processing.

From the above results, it can also be concluded that the manner in which discriminability is experimentally varied is rather important. The present study changed discriminability by controlling the similarity (length) between the stimulus alternatives and found that this type of manipulation affects a central stage of processing, the comparison stage. Similar results were obtained by Chase and Posner (1965). On the other hand, Sternberg (1964, 1968), who varied discriminability by adding random visual noise to the stimuli, has reported that discriminability produces systematic changes in the initial encoding stage of processing—Stage 1. Therefore, it is suggested that discriminability needs to be operationally redefined in terms of either stimulus similarity or of stimulus degradation in order to ensure separation of its two divergent effects on human processing.
In conclusion, the results from the present study reconfirm the additivity principle and offer an expansion of the model of human information processing set forth by Smith (1968). Swanson and Briggs (1969) showed that the intercept constant in Hick's law could be meaningfully analyzed into two components: initial encoding plus decoding time and sampling plus preprocessing time; and Briggs and Blaha (1969) were able to decompose the central processing constant into: memory retrieval time and comparison time. The present results allow two additional stages to be identified within central processing: a search or comparison component which is a function of stimulus similarity and a translator responding to S-R compatibility. Hence, the concepts of additivity and sequential processing proposed by Donders over a century ago are still quite viable, and subprocesses within this sequential chain can be identified and measured by implementing Sternberg's suggestion that independent variables be selected which differentially load the various sequential stages—thus producing quantitative rather than qualitative changes in the vehicle choice-reaction time task.
### APPENDIX

#### Table 4

<table>
<thead>
<tr>
<th>Compatibility</th>
<th>Alternatives</th>
<th>Discriminability Level</th>
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<tbody>
<tr>
<td></td>
<td>First Half</td>
<td>Second Half</td>
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<tr>
<td></td>
<td>High Medium</td>
<td>Low</td>
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<tr>
<td>Direct</td>
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<td>6</td>
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<tr>
<td>Displaced</td>
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<td></td>
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<td>Mixed</td>
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<td>1.0336 .9534 .8478 .8478</td>
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