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THE EFFECT OF ERRORS ON REACTION TIME IN A SERIAL REACTION TASK

by

John Thomas Burns

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CHAPTER I

INTRODUCTION

In recent years, the study of skilled performance has involved concentrated efforts to order its many phenomena within a comprehensive conceptual framework. A good example of this aim can be found in choice reaction time (RT) studies where great use has been made of the mathematical model of information which was concerned originally with communication problems in the engineering sciences. The psychological relevancy of this model has been tested by manipulating certain equated independent behavioral variables such as stimulus and response uncertainty and sequential probabilities. Efforts have also been made to point out the similarities between the known principles of skilled performance and those of the most intensively investigated branches of psychology such as learning and perception (Broadbent, 1958; Fitts, 1964).

In the recent past and continuing into the present, then, a major substantive theme in studying skilled performance has involved evaluating the suitability of certain appropriated concepts. Throughout these investigations, the dependent variables have been generally representations of over-all performance utilizing such measures as averaged latencies, transmitted information and the rate of transmitted information. However, the great interest, of late, in studying skilled performance has not been extended with equal vigor to what Welford (1960) has called, the micro-behavior of information processing. The study of micro-behavior here refers to a more fine

grained analysis of the organization of the behavioral and physiological units entering into complex perceptual-motor behavior. A pervasive problem in psychology has been to account for serial behavior (Lashley, 1951): certainly, this problem has rich contextual meaning in the study of skilled tasks. Despite the acknowledged importance of serial behavior, little detail work has been carried out exploring the principles relating the micro-behavioral units involved in the kind of tasks exemplified by typing or playing a piano. The present research is an effort directed toward elucidating certain inter-relationships existing between functional units which are felt to be representative of many kinds of discrete tasks.

In almost all examples of serial behavior there exist apparent criteria, either intrinsic or extrinsic to the task, which divide responses into two classes: correct responses and errors. However, we have little information in this kind of behavior about inter-dependencies between errors and correct responses. The present research is concerned with evaluating two independent variables which are directly related to two questions about a relationship between errors and correct responses during serial performance. The first question with which we will be concerned is whether or not an <u>error</u> is followed by an alteration in the time needed to process subsequent information inputs in a serial choice RT task. A second and related question is the influence on succeeding responses of the <u>correction procedure</u> available to the subject (S) when he does make an error: Do temporal measures of processing information after an error differ when the <u>S</u> is and when he is not required to correct

his mistake before continuing with the normal sequence of the task? Two other, more traditional, independent variables will be incorporated into the present study: Stimulus-response (S-R) compatibility and the duration of the response-stimulus interval. The reasons for selecting these last two variables will be discussed in detail later in this chapter.

The present research originated from certain incidental observations made during the analysis of data from unrelated experiments. It was noted that the response following an error, i.e., pressing the wrong key, in a serial choice reaction time task, when no provision was made for allowing a correction response, tended to be much longer than the error response itself and conversely, when the subject was required to correct his mistakes, it was found that the correction response was much faster than the error response. These initial observations were corroborated in subsequent pilot experiments for the present work.

Next we will go on to a review of literature which has been instrumental in structuring the present research project. The central interest in this thesis is the empirical determination of an error's influence on subsequent behavioral units in a serial task. As has been pointed out earlier the basis for this interest, other than its obvious possibility, was suggestive empirical findings. The body of literature directly relateable to posterror effects such as we are concerned with here is sparse. Consequently, a review of literature will, perforce, place relatively greater emphasis on studies which underly the selection of the two subsidiary

independent variables: S-R compatibility and the response-stimulus interval. Following the literature review in the next section, the statement of the problem will elaborate the reasons for selecting the particular independent variables and the general research design.

Repetition Effect. In some recent studies Bertelson has been investigating what he has designated the "repetition effect." These choice RT studies by Bertelson bear directly on our preliminary findings of faster RTs when the response is one of correction. In the first study Bertelson (1961) compared the effects on RT of repeating a stimulus versus alternating stimuli, when the number of choices was kept constant. He used three experimental conditions: a) in the repetition condition the probability of a stimulus repeating was .75 while the probability of a different stimulus was .25, b) in the alternation condition the probabilities were reversed--the stimulus alternation probability was .75 and repetition was .25, c) in the random condition the probabilities of repeated and alternated stimuli were equal at .50. Each of these three conditions was run under both a 50 msec. and 500 msec. response-stimulus interval. In the short response-stimulus interval, Bertelson found that the repeated stimuli in the repetition condition elicited faster RTs than did the alternated stimuli in the alternation condition (the alternated RTs were faster than the repeated RTs within the alternation group). Thus the availability of information about the likelihood of subsequent stimuli was not utilized equally well in these two conditions.

When the repeated and alternated RTs were compared in each condition it was found that the repeated responses were significantly faster in the repetition and random conditions when a short time intervened between successive trials, but that there was no difference between the repeated and alternated responses in the random group when a longer time (500 msec.) intervened. The findings of greatest relevance to the present study were that repeated responses had shorter reaction times than responses to different stimuli and that this tendency became less strong as the response-stimulus interval became longer.

A second study by Bertelson (1963) on the repetition effect investigated the effects of S-R compatibility and number of choice alternatives. A repetition effect was clearly evidenced at all levels of compatibility, i.e., direct correspondence, mirror image, and a vertical display; it was also present in a four-choice task. The faster RTs to the repeated stimuli did not differ greatly among the different compatibility levels in the two-choice situation, but where four choices were required the repetition RTs were significantly longer in the mirror image condition than in the direct correspondence condition. However, the major effects of compatibility and number of alternatives were on the RTs to nonrepeated stimuli; here the less compatible arrangements and greater input uncertainty tasks resulted in markedly longer reaction times.

Bertelson accounts for the faster reaction times and smaller effects of compatibility with repeated stimuli than nonrepeated

stimuli by hypothesizing a serial classification procedure where the first question asked is always whether the new stimulus is identical to the preceding one. Consequently, if the stimulus is not repeated it is assumed that more questions must be asked before a decision is made about the identity of the stimulus; such added questions result in longer reaction times. However, this explanation is insufficient, at best, in that the repeated responses in the less compatible condition in the four-choice task were significantly longer than in the more compatible condition. Bertelson realizes this problem but in attempting to answer it simply begs the question. In explaining the much longer RTs of the nonrepeated stimuli in the less compatible tasks, Bertelson accepts Fitts's (1959) hypothesis that performance differences among compatibility conditions are due to the fact that less compatible stimulus-response relationships require more recoding steps during internal processing.

Some findings by Hyman (1953) are relevant to the notion of a repetition effect. This author was studying the equivalence of different ways of varying input uncertainty, i.e., stimulus ensemble size, probability of a stimulus, and sequential probability. Hyman found longer average RTs in conditions where no repetition of a stimulus was allowed than in conditions where there were varying probabilities of a stimulus repeating itself. This finding was unexpected from an information theory point of view since the restriction against repetitions reduced the uncertainty about the succeeding input. Also, Hyman found that a RT to a stimulus when it repeated itself was much faster than when one or more different stimuli intervened. This was the case for four- and eight-choice tasks, but no

difference was found in the two-choice task. The lack of a repetition effect in the two-choice task does not contradict Bertelson's findings since Hyman's response-stimulus interval was well beyond that which Bertelson found sufficient for the repetition effect to wash-out.

At this point we want to mention the only observed reference in the RT literature to the possible inhibitory effect of an error on subsequent reaction times; it can also be found in a paper by Bertelson (1963). He was interested in "blockings" in a choice RT task where this term designated the occasional occurrence of very long RTs. It was observed that about 25% of these blockings followed an error. However, because Bertelson felt that these error-associated long RTs were something different from the blocking phenomenon, he did not include them in his analysis or in any further discussion.

Stimulus-Response Compatibility. It is commonly appreciated that perceptual-motor performance can be markedly affected by rather small changes in the kinds and ways of matching stimuli and responses in a behavioral task. As an example, Broadbent (see Ch. 11, 1958) cites that the direction of the on and off positions of a light switch differs in America and Britain; he notes that there is inordinate difficulty and frustration involved in adjusting to the opposite association although the distal stimulus and response elements are identical. One approach to the general problem of "preferred control-display relationships" has been the study of "stimulus-response (S-R) compatibility" by Fitts (1953,1954,1959) and his associates.

The basic notion of S-R compatibility is that interactions occur among various pairings of sets of stimuli and responses. These interactions are reflected in marked changes in performance time and error scores as particular stimulus displays and response formats are paired. The alteration due to stimulus and response pairings extends beyond different stimulus displays and response topographies. The rules relating stimuli and responses can also be variables affecting S-R compatibility; thus, it is found that a direct spatial correspondence between stimuli and responses results in much superior performance to the same stimuli and responses associated in a spatial mirror image correspondence. This finding was one demonstrated in a series of studies on S-R compatibility by Fitts's group. These results will be reviewed here.

In an early experiment Fitts and Seeger (1953) were concerned with the question of whether performance was appreciably influenced by variations in S-R pairings--an influence which could not be ascribed to either stimulus or response factors alone, these being kept constant. Each of three stimulus displays was paired with each of three response panels. The task involved moving from a center position on the response board to the position specified by the light(s) on the stimulus display. Reaction time and errors were dependent variables. It was found that each stimulus display when paired with a response panel with a isomorphic configuration gave much better performance than when paired with one of the two less similar response panels. This finding was reflected in both reaction time and error measures. It was also shown that a stimulus

display which resulted in superior performance over any other when optimally paired with a response panel could be degraded into the worst S-R combination by replacing the optimal response panel with one of the less similar panels.

In a second experiment in this same study, three different stimulus displays were paired with the same response panel. There were marked differences in performance and these differences persisted over a period of training lasting over two months. This finding was used to argue for the permanency of compatibility effects. Toward the end of the experiment, several sessions were conducted with the addition of a distracting task, i.e., mental arithmetic. It was hypothesized that the less compatible S-R combinations would be more disrupted by this added information processing requirement. Fitts maintains that the data were inconclusive in answering this question. However, combination of the error scores and RT scores, estimated from the data tables and graphs, indicates that the rate of information transmission was reduced more for the least compatible S-R arrangement under disruptive conditions.

In a subsequent study (Fitts & Deininger, 1954) it was shown that nonspatial characteristics of the S-R relationship exerted strong effects on compatibility. Spatial, pictorial (numbers), and words made up the visual stimulus displays; a common response panel was used throughout with all stimulus displays. Another independent variable consisted of relating the stimulus sets to the response panel in three different ways: maximum--as close to a spatial direct correspondence as possible, mirrored, and random.

A major finding of this study was a monotonic decrease in the rate of information transmission for the maximum, mirrored, and random relations, respectively, for all forms of stimulus display. Furthermore, there was an interaction between the stimulus displays and the form of S-R relation: The stimulus displays which showed the greatest compatibility when paired with a response board were most disrupted by the less compatible S-R relationship.

Recent studies have shown that S-R compatibility effects become more pronounced when the number of choice alternatives or uncertainty of a task increases. For example Fitts (1964) cites a slope constant of 0.017 sec/bit for a highly compatible task, i.e., pointing at a light, and a similar constant of 0.040 sec/bit when the task was made less compatible. These values are both considerably less than Hick's (1952) finding of a slope constant of 0.115 sec/bit in a button-light task. Other forms of information processing have also been found to be sensitive to S-R compatibility. Fitts and Biederman (1965) investigated the relation between S-R compatibility and several forms of "perceptual-demands" which were utilized during information processing. The conditions included 1) information conserving--the number of stimulus and response categories are the same, 2) information filtering--one or more stimulus dimensions are irrelevant, and 3) information condensation--all the stimulus information is relevant, but the stimulus categories are mapped into fewer response categories. The results of this study supported the hypothesis that greatest S-R compatibility effects were found in the task requiring the use of greatest number of response alternatives, i.e., the information conserving task.

A concept which Fitts feels is very important in understanding compatibility effects is that of population stereotype. A population stereotype is an indicator of the relative preference of responses to stimuli when no constraint is placed on what response may or should be made. The development of population stereotypes is influenced by both innate preferences, e.g., certain forms of movement, and well-learned habits. The closer an S-R relationship comes to the population stereotype the more likely it is to be a highly compatible relationship.

In discussing these results on S-R compatibility Fitts (1959) emphasizes notions of coding efficiency. Coding appears to be used in two senses: 1) The physical arrangement of the stimulus and response ensembles as well as the rules relating stimuli and responses. Coding in this sense refers to states of the independent variable manipulations at an operational level. 2) Coding is also conceived as an intervening construct referring to the internal operations mediating the S-R relationship. Compatibility effects are a function of the efficiency of intervening coding operations. It is with this latter usage that we will be most concerned here.

Formal models of psychological coding do not exist, at least in the sense that they have been developed for use in electrical communication systems (Peterson, 1961; Wozencraft, 1961), and Fitts's speculations about such coding processes seem to be based largely on generalizations from compatibility results. It is generally found that compatibility alterations in a task result in alterations of performance which demonstrate a positive correlation between

reaction times and error. For example, in the Fitts and Seeger article (1953) a correlation of .93 was obtained between time and error scores for the different S-R combinations. Fitts speculates that the degree of compatibility is negatively correlated with the number of internal recoding steps involved. Each step involved in transacting the S-R unit increases the time taken and the probability of errors. These empirical expectations would follow if the error rate varied as a function of the joint probability of error for each transformation step. The reaction times are assumed to summate over the number of recoding steps. At the risk of a spurious imputation, one might conjecture that Fitts's preference for a number-of-components analysis of the coding operation is necessitated by an apparent restriction in formal mathematical theories of coding: All one-to-one mapping situations are seen as equivalent and in order to account for compatibility effects one would have to resort to a strategy of positing several coding steps rather than an initially different coding operation.

The concept of coding has become increasing popular in recent years in neurophysiology (Brazier, 1963) and psychology. Lawrence (1963) has cogently argued the necessity of distinguishing between the proximal stimulus and the stimulus-as-coded. The latter is conceived of as a central resultant of an internal response operation independent of the proximal stimulus itself. It is the stimulus-as-coded which is associated with the response. The stimulus-response contingency is seen as a two-phase operation: 1) The selection of a coding operation which selects the appropriate parameters of a stimulus and

2) The development of an association with a response. The complexity of the coding operation is seen as variable and permanent even after the asymptotic stage of stimulus-as-coded and response association has been attained. Lawrence believes that the concept of a stimulus-coding-response is a general requirement for handling the problem of a stimulus having multiple cue functions, which is manifest in the study of such problems as set, compound stimuli, transposition, and one might add, S-R compatibility.

While Lawrence's statement about coding mechanisms seems quite similar to that of Fitts's, it is addressed to a broader set of problems and doesn't explicitly make assumptions concerning the number of coding operations involved or the form of the relation of codes to error and time scores. However, Lawrence does talk about the complexity of coding in terms of the number of aspects of the stimulus situation which are relevant to an appropriate discrimination. This idea would seem to be relevant to the marked changes in performances induced by relatively simple rearrangement of the members of a set of stimuli: More aspects of the stimulus situation would have to be considered in one stimulus situation than in another.

There is considerable evidence in the experimental literature that complex behaviors are more sensitive to disruption than simpler and better established behaviors. Evidence has been advanced for this in learning situations (Spence, 1956); skilled performance (Duffy, 1962; Horvath, 1959); and perceptual processes (Easterbrook, 1959). It is not surprising, then, that a similar expectation of the greater sensitivity of less compatible S-R ensembles has been

advanced. This hypothesis was tested explicitly by Fitts (1953) in an earlier study, as was mentioned previously, and stated as part of a formal hypothesis in his theoretical paper (Fitts, 1959). This particular hypothesis relating S-R compatibility and the effects of disruption is an important consideration in the design of the present experiment.

We will next review a series of experiments which have been instrumental in the decision to select the response-stimulus interval as an independent variable.

Advance Information. It was mentioned earlier that our pilot work disclosed that Ss can correct an error response much faster than the average RT of the series. This finding was related to Bertelson's work on the repetition effect and it was implied in that review that the repetition effect would have to be taken into account if the correction response was to be advanced as a unique response. It may be the case that the faster correction RTs are due to a reduction in the uncertainty about the next stimulus based on definite knowledge about the succeeding event. In this section we shall review several papers by Leonard dealing with effects of advance information on subsequent performance.

Studies on the utilization of advance information have been included in general discussions on what has been called anticipation or prediction in skilled movements. It involves the class of variables which supply information that enables the individual to reduce the receptor-effector lag, and also allows his performance to be smoother and more adaptive. Both continuous and discrete behaviors have been

investigated for the effects of advance information. Poulton (1957) has classified these forms of anticipation in terms of the receptor and effector mechanisms utilized.

Leonard's series of articles are concerned with the effects of advance information in discrete choice situations. This problem is closely related to the general phenomena of receptor-effector anticipation in many tasks, e.g., reading aloud and typing, where there is a lag between the response and some processing of sensory input. Thus a subject may have just vocalized a word or two behind what he could report if the text were withdrawn immediately after any given response point. The basic question in an early study by Leonard (1953) was whether advance information would expedite the execution of a succeeding response and, if so, in what components of the task would such savings be manifest.

The task in this study by Leonard involved moving a stylus along a path from a center position to one of five endpoints arranged in a pentagon. In a control condition the subject would return from an endpoint to the center whereupon the next endpoint would be indicated. In the experimental group, upon reaching an endpoint one of the other endpoint lights would come on indicating where the experimental Ss should go next after they had returned to the center. Thus the experimental group had complete information about the next stimulus before reaching the center while the control group received their information upon reaching the center.

A time analysis of the various components, e.g., time spent at center and movement time spent to and from endpoints, involved in this task was undertaken. The average over-all times disclosed a

clear superiority for the experimental group (890 msec. vs. 720 msec.) which had advance information. Most of this superiority was due to less time spent at the center by the experimental group ($p<.001$); there was a suggestion that the experimental group took a longer time moving to and from the endpoints. It was concluded from these data that the experimental group was able to organize part of its subsequent response during the movement time from the goal.

A second part of this study essentially replicated the above procedure using a different apparatus. A joystick was moved to three points of an equilateral triangle arrangement. The major procedural alteration consisted of the experimental group receiving the primary information and the advance information simultaneously. The control group was informed of the next move upon reaching an endpoint. The results indicated more clearly the difference between the two groups in the time spent at an endpoint before initiating the next move: the experimental group spent significantly less time at the endpoint. Also, although not significant, the movement times were longer for the experimental group. However, in both parts of this study the tendency for longer movement times by the experimental group did <u>not</u> balance the time gained at the "decision" (center) point by the experimental group which resulted in its superior performance. Leonard notes, in addition, that one of the most striking features of performance of the experimental group was its smoothness compared to the ragged actions of the control group.

A second study by Leonard (1954) pursued further the modes of utilizing advance information. The experiment utilized the same stylus and pentagon apparatus as had been used in the previous experiment. The major difference was the inclusion of a condition in which the advance information was sometimes changed after the S returned to the center piece, i.e., the unreliable advance information condition. In this latter condition the S could not be completely sure that the advance information received at an endpoint would be confirmed at the center point.

The results again showed that the reliable advance information condition resulted in appreciably less time spent in the center portion when compared with the condition where the new information was first received at the center disc. However, the condition where there was occasional false advance information had over-all performance (RTs) which was inferior to both the control group and the group with completely reliable advance information. A breakdown of time scores of the unreliable advance information condition into those trials which were confirmed and those which were disconfirmed at the center showed very different results. The former trials resulted in time scores at the center point which were slightly less than those of the control group but still much longer than in the reliable advance information condition. On the disconfirmed trials there were very long latencies at the center; the presentation of a new signal at the center could not be reacted to as fast following prior advance information as when advance information had not been given.

Leonard comments that occasional misinformation did not dispose the Ss to wait until reaching the center before deciding on the subsequent response. The results were interpreted by Leonard as supporting a notion that subjects in the unreliable feedback condition were attempting to achieve the smoothness and continuity of their performance characteristic of the reliable advance information condition. However, the increased uncertainty of the unreliable condition resulted in a more careful observation of the display and, consequently, longer time scores.

A later experiment (Leonard, 1958) investigated the effects of partial advance information in a discrete choice reaction time experiment. The experiment involved three conditions: a six-choice task, a three-choice task, and a two-choice task which preceded a three-choice task by different time intervals. The experiment was suggested, in part, by Hick's work on the rate of gain of information; one hypothesis advanced by Hick (1952) was a process of sequential binary classification of the stimulus information with each step requiring a fixed amount of time. The question was whether the partial advance information could serve as one of the binary classification steps.

In the two control conditions the three lights (always either the left hand three or right hand three) or six lights would come on and 0.1 sec. later one would go off serving as the signal. In the experimental situation either one of the two groups of three lights would come on and following a variable time period one light would go off; the range of foreperiods was .050 to .500 seconds in .50 second steps.

It was found that the experimental three-choice task had rates of information transmission equivalent to the control three-choice RTs after a 300 msec. interval following the initial presentation of three stimuli. Actually, the information transmission scores improved through the .500 sec. foreperiod at which point they were slightly superior to the control three-choice scores.

There are several general points to be drawn from this series of studies. It is clear that preprocessing of information concerning a second event can overlap with movement. However, this concurrence is not completely independent; there was evidence that the groups in the first study given advanced information did slow down during movements. Nevertheless, the utilization of the advance information more than compensated for the slowing of the response so the over-all latencies of the advance information group were faster than the control group. Another effect of advance information that was brought out in the first study was a marked increase in the smoothness and continuity of movement during performance. Smooth and nonragged behavior seems to be a strong preference on the part of Ss and is brought out again in the second study where occasional false information was given. Here Ss preferred to take advantage of the advance information rather than wait until arriving at the center even though this resulted in over-all inferior performance in the control group.

All of the studies reviewed here have used external information as a source of advance information. Thus either the source of the next endpoint was shown or a subset from which a crucial stimulus

would be selected was indicated a brief time before the stimulus itself. Advance information is not always so overt; for example, Poulton (1957) has defined perceptual anticipation as involving complex expectations based on prior experiences which are elicited by certain cues in a situation. For example, a tennis player goes through a sequence of movements which allow him to be in a position to return the ball; these movements clearly are not governed by the moment-to-moment stimuli from the ball's trajectory. Rather a sampling of stimuli at discontinuous moments seems to initiate behavioral sequences which are expectations based on past experience. However, here again the eliciting stimuli are external events. An extension of the basis of advance information to that implied by interoceptive cues has not been explored to our knowledge.

Finally, these studies on the utilization of advance information have not systematically explored the effects of varying S-R compatibility. It may well be that the ease of profiting from advance information is related to the difficulty of the processing the advance information involved. If this is so, then, one might be less able to utilize advance information in less compatible tasks.

Statement of the Problem. Bertelson's finding of a shorter RT to sequentially repeated stimuli is obviously related to our observation of a faster correction response. The question arises whether the correction response is anything more than an example of a repetition effect. The major difference between Bertelson's repetition response and the correction response is in the former case the response preceding the repeated stimulus was generally

correct while in the latter case it was invariably incorrect. It seems quite plausible that a correction response is different in kind from a repetition response if one assumes that a S detects, in a significant percentage of instances, that he has made a mistake and the conditions are such that the S is aware that a mistake will necessitate an immediate correction response; under these conditions he will have available complete advance information about the next stimulus. If the repetition effect still involves a decision-time component in making a RT to the repeated stimulus, the correction response should be faster than a repetition response because of the advance information. In fact, a differential prediction can be made regarding these two examples of responding to a repeated stimulus. Bertelson found that with a longer response-stimulus interval the repetition effect washed out in a two-choice situation. Just the opposite effect would be expected in the case of a correction response where advance information is the crucial feature: the longer interval permits a fuller utilization of the advance information concerning a subsequent stimulus. This statement assumes that the S working under a correction procedure has sufficient time to make some use of the advance information. Thus in any attempt to demonstrate the uniqueness of the faster RTs of correction responses, it will be necessary to compare them with matched controls of repeated responses preceded by a correct response.

The importance of S-R compatibility to the correction effect derives from the presumed negative correlation between coding efficiency of an S-R relationship and decision time. It is assumed

that the more incompatible an S-R relationship the longer the time to process the input information. It is further posited that this implication would be true in a choice RT task using a correction procedure where complete information about a subsequent stimulus is obtained through the S detecting his error and knowing the correct response, i.e., the advance information gained from detecting an error will require relatively more processing when a task has low S-R compatibility. If this last inference is correct, some further predictions can be made about the RT of the correction response: It would be expected that the correction response should be faster for a highly compatible task than a less compatible task because less time would be required to process the advance information. If any interactions occur between the response-stimulus interval and S-R compatibility, one would expect the fastest correction RTs for a relatively long response-stimulus interval and more compatible S-R relationship, while the least effect, if any, should be noted for the combination of a shorter response-stimulus interval and a low S-R compatibility.

In the case of the noncorrection procedure, i.e., a nonpredictable stimulus follows an error rather than repeating the error stimulus, our preliminary observations disclosed a longer than normal RT to the first stimulus following an error. In determining whether this inhibition perseverates for any appreciable period of time the response-stimulus interval is considered an important variable in the present study. As we have seen above, the length of this interval also has important implications for the correction effect in terms of testing certain notions about advance information; however, in the

case of a noncorrection procedure we are interested in different response-stimulus spans to test the perseveration of an inhibition of RTs following an error. It is predicted that the degree of posterror lengthening will become less with a longer interval between the error and the next stimulus.

Also, in the case of the noncorrection condition, certain interrelations are presumed to exist between S-R compatibility and response-stimulus interval. In light of the pilot work, if it is reasonable to advance the notion that a detected error engenders some sort of process which detracts from one's ability to process efficiently the next S-R unit in the sequence, then the magnitude of this inhibition might be seen as a indication of the disruptibility or stress sensitivity of the task. We have cited evidence that complex tasks are more sensitive to disruptive events than simpler and better learned tasks. Consequently, it seems likely that greater disruption following an error would be found in the noncorrection procedure for the less compatible than a relatively compatible task. These differences between S-R compatibility conditions may well be exaggerated for the short response-stimulus intervals if the disruptive effect decays over time. In order for these differential predictions to be tested validly, it is necessary that the proportion of error detections be comparable in both the high and low compatibility groups, i.e., a potentially greater posterror disruption in a low compatibility task could be offset if few errors were detected for any reason.

Although the major explorations in this research will be concerned with the effects of errors on closely following responses, a more general question emerges in light of our tentative findings relating the posterror effects to the kind of correction procedure used in a serial task. We will evaluate the effects of the correction procedures on over-all performance. These analyses will involve responses not in close proximity to errors and will use some of the classic measures of information processing taken over the performance as a whole.

Empirical Predictions. In summary, this research, building on the results of pilot studies and certain preliminary interpretations of these results, will attempt a testing of the following empirical hypotheses.

1. The first correct response following an error (and perhaps later ones also) in a serial choice RT experiment, performed under a task-condition which does not require a correction of the error, i.e., a noncorrection procedure, will be significantly longer than its matched control.
   a) The lengthening of the noncorrection posterror RTs will become less as the response-stimulus interval becomes longer.
   b) The lengthening of the posterror RTs will be greater as the task compatibility becomes less.
2. If the response following an error is a correction response and the S is aware of a contingency requiring a correction response following an error, i.e., a correction procedure, the correction response will have a shorter RT than its

matched control (i.e. a repetition response).

a) The magnitude of this effect will be positively correlated with the length of the response-stimulus interval for time intervals less than that required for maximum information processing.

b) The magnitude of the correction effect will be directly related to the S-R compatibility of the task.

3. For correct responses not in close proximity to an error, no differences will be found in terms of speed or accuracy between the correction and noncorrection conditions.

CHAPTER II

METHODS

Subjects. Forty-eight male students at the University of Michigan served as subjects in this experiment. They were volunteers recruited from the Mental Health Research Institute's subject pool and were paid at the rate of $1.25 per hour. None had obvious visual or motor impairments which might have interfered with their performance. Subjects who normally wore glasses as aids in distance vision were requested to wear them during the experiment.

Apparatus. The visual display consisted of a series of eight small neon indicator lamps (NE51) arranged in a row on a 2 ft. x 2 ft. backboard painted flat black. The light bulbs were grouped into two blocks of four each, adjacent bulbs measured 1 3/4 in. apart from center to center and a distance of 4 in. separated the block of lights on the left from the block of lights on the right. The asymptotic rise time of the lamps was three msecs. The display board was at eye level and rested on a table eight feet in front of the subject. On the table directly before the subject were ten response keys, eight active keys which accommodated each of the eight fingers and two immobile keys which served as thumb rests. Each active key had a travel distance of 1/16 in. and required a pressure of 2.75 ounces. The serial presentation of single lights served as the stimuli in a self-paced choice reaction time task. An invariant one-to-one correspondence between each button and only one light was maintained during the entire experiment. However, it was possible to alter the mapping, i.e., stimulus-response compatibility

(COMP), existing between the button-light pairs by means of a patch-board on the back of the stimulus display. Two button-light mappings were used in the experiment, in which either the relation between the lights and buttons was one of spatial direct correspondence (DC), or the inverse of this, a mirror image (MI) relation.

The subject worked in a room adjacent to the one which contained the control and recording components of the apparatus system. The experimental room was lighted dimly by a 25 watt bulb placed in a hooded floor lamp.

The presentation of the stimuli was programmed by punched paper tape which was processed through a Friden reader (Model No. 2). Two serial orders, varying in stimulus uncertainty, were used in this experiment. The stimulus order used in the major part of the experiment was constructed from the set of eight light-stimuli. This series was random with two constraints: each stimulus appeared 120 times and the first order transition frequencies were equal, i.e., each of the possible sequential stimulus pairs occurred 15 times in the series; repeated stimuli were included in the series, however, stimuli were not repeated more than three times in a row. When the MI compatibility relation was used the stimuli were reversed and the responses called for remained the same as those in the DC condition. The other stimulus order consisted of blocks of trials on the same stimulus for a simple RT condition.

Following each response the stimulus light went out and a blank interval (I) of either 150 msec. or 820 msec. intervened before the next stimulus appeared. This blank interval (or response-stimulus

interval) was controlled by a one-shot timing circuit activated by closing the response key microswitch. Because a logic circuit controlled the advance of the reader to the next stimulus in the sequence, a number of operations could be made contingent on an error response. When the correction procedure (COR) mode was used, the concurrence of a signal that the response had been made and that the response was correct was necessary for the stimulus reader to advance. If an error response was made, a new stimulus was not presented, instead the same stimulus was repeated, following the blank interval, until the correct response was made. However, when the noncorrection procedure (NCOR) was used, any key response, error or correct, was sufficient to bring about an advance to the next stimulus in the sequence. With both modes of correction procedures, error-feedback information could be given to the S by means of a 500 cps tone of 50 msec. duration presented immediately after an error response was made. This tone was given through sound-dampening earphones.

The onset of each stimulus opened a gate which connected a 1000 cycle/sec. tuning fork (±.002%) to four decade counters. Closing the response microswitch stopped the value on the counters and this information was punched out on the paper tape as a single reaction time. Thus, a RT was measured from the stimulus onset to the tripping of the response key microswitch. The decade counters were set to zero upon each new stimulus. Each RT, the stimulus, and whether the response was correct or not was punched in coded form on paper tape by a 60 characters per/sec. punch (Tally Model

No. 420PR). These three items of data punched on the paper tape were subsequently analyzed on a IBM 7090 computer. Another recording device used in the experiment was an Esterline-Angus event recorder. Each response was identified by the deflection of one of the pens and another pen indicated whether or not the response was an error. These latter data were not punched on the paper tape.

Procedure. A 2 x 2 x 2 complete factorial design formed the basic structure of the experiment. The independent variables representing the classifications of this factorial were: a) The S performed either under an error COR procedure or NCOR procedure; b) The S was assigned to either a spatial DC or a MI stimulus-response compatibility condition; c) The S received both the short and a long response-stimulus Is which were 150 msec. and 820 msecs., respectively. The first two factors of the design represent independent classifications with the two levels of each being assigned to different individuals, while the response-stimulus interval factor was a correlated dimension with each S receiving both levels. In addition to these independent variables, several partitions of the obtained RT data led to the formation of two more variables which were crucial for testing the experimental hypotheses and entered into the basic statistical analyses. These partitions of the data will be described in detail later in the section of this chapter devoted to computer programs.

Forty-eight Ss were assigned randomly to one of the four correction procedure-compatibility combinations, i.e., COR-DC,

NCOR-DC, COR-MI and NCOR-MI. Consequently, each cell of the four-fold correction x compatibility table was filled by 12 Ss.

Each subject was run on two consecutive days. Day one was a training session and the protocol followed was: each S received 2080 stimuli--1040 stimuli were given under each response-stimulus interval. The order of presentation of the two response-stimulus intervals (short and long) was balanced over the other conditions of the design and over the two days; each S was given either an SLLS or LSSL order. The first 80 stimuli of each 1040 sequence called for a series of ten responses to be made to each stimulus-light progressing stepwise from left to right. The major purpose of this condition was to get an estimate of the S's reaction time to each stimulus in what approximated a simple reaction time (SRT) situation. The remaining 960 stimuli of a particular interval condition were presented in two blocks of 480 stimuli. During the first block of 480 stimuli each error was immediately followed by a 500 cps tone heard over the pair of sound attenuating earphones, which in order to reduce background noises, were worn throughout the experiment. The major purpose of this tone was to aid the MI group to learn and maintain an initially difficult S-R relationship. The error feedback tone was given only during the first blocks of 480 stimuli on day one.

Subjects were told the compatibility relationship that existed between the lights and buttons, so that no element of discovery was necessary. They were also instructed about the nature of the correction procedure condition and compatibility condition under

which they would work throughout the entire experiment. The same speed-accuracy instructional set was given to all Ss. It established, as a guide, an upper limit of 10% errors and a lower limit of 1 or 2% errors (see appendix A for the complete instructions). The second block of 480 stimuli was presented without the tone feedback. A break of two to three minutes intervened between the two 480 stimuli segments and a longer break of about five minutes intervened between the two interval conditions.

On the second day (experimental sessions) the S experienced what was essentially a replication of the conditions on day one. However, there were two major differences: the error feedback tone was never used and the order of the intervals was reversed.

Computer Programs. The experimental design called for a minimum of 199,680 individual responses to be recorded; the actual total increased this figure by the total number of correction responses made in the COR condition. Not only the absolute amount of the data, but also the elaborate manner in which the research design required the data to be partitioned, necessitated the use of automated data reduction procedures. For this, a program was written for the IBM 7090 computer which printed a list of the individual RTs, partitioned the data, and printed them in a summary form which facilitated subsequent statistical analysis.

The two additional variables derived from the RT data which were alluded to earlier will now be described. The data of fundamental interest in this study are RTs following an error. The analysis of such data was concerned with the first three correct

responses immediately following an error. These posterror responses were matched by appropriate controls which were correct responses not in close proximity to an error. The posterror (PE) responses and their matched control (MC) responses constituted the two conditions making up what is referred to subsequently as the reaction time (RT) factor. The ordinal position of the responses, embracing both the PE and MC responses, has been designated the trial (T) factor with levels "plus-one," "plus-two," and "plus-three." Table 1 presents the basic structure for the analysis.

Table 1. Summary of Design of Analysis Showing Correction Variables (COR and NCOR), Interval (Short and Long), Compatibility (Direct Correspondence and Mirror Image), Reaction Time (Post-error and Matched Control) and Trials (Plus-one, Plus-two, Plus-three). n = number of data points in each cell.

COMP	Reaction Times	Correction						Noncorrection					
		Short			Long			Short			Long		
		+1	+2	+3	+1	+2	+3	+1	+2	+3	+1	+2	+3
DC	PE	n=12	12	12	12	12	12	12	12	12	12	12	12
	MC	12	12	12	12	12	12	12	12	12	12	12	12
MI	PE	12	12	12	12	12	12	12	12	12	12	12	12
	MC	12	12	12	12	12	12	12	12	12	12	12	12

A basic feature of the computer program was the segregation of errors and certain associated correct responses which met a specified criterion from each S's series of 960 stimulus presentations. The plus-one, plus-two and plus-three responses of the PE level of the reaction time factor came from a sextet of sampled responses where the defining characteristic of each sextet was an error response.

All errors were sampled which were followed by three correct responses and preceded by two correct responses, with the restriction that none of these adjacent correct responses could be within two responses of another error. All such acceptable sextets were listed and the printed output showed the RT and stimulus of each member. Each PE member of a sextet was matched with an MC based on the data of correct responses removed from errors by the distance criterion mentioned above. Data which did not meet the sextet criteria or were not sufficiently removed from the errors were relegated to a separate category of RTs.

The MC for each PE reaction time in a particular sextet was arrived at as follows: The MC reaction time for a plus-one PE response came from an eight x eight matrix in which the columns represented the first stimulus and the rows the second stimulus of stimulus pairs, and the cells of this matrix represented all possible stimulus pairs from a set of eight stimuli; such a matrix will include repeated stimuli. For example, if the stimulus to which an error had been made were a three and the next stimulus in the sequence were a five, the MC latency score for this particular plus-one PE response was the median of all the entries in the 3-5 cell of the plus-one MC matrix. Similarly, for the PE plus-two and plus-three responses the MC matrices represented stimulus pairs where the second member was separated from the first by one or two intervening stimuli, respectively. It should be noted that in the COR condition the PE plus-one response will always be a correction response and its control the MC plus-one response will always be a repetition response. In the NCOR condition, the PE and MC plus-one responses will involve repeated stimuli only as a chance occurrence;

there was no constraint which forced a repeated stimulus at the plus-one level as was the case in the COR. This latter situation holds for the plus-two and plus-three responses in both the COR and NCOR.

Certain descriptive statistics were computed by the computer on these PE latencies and MC reaction times. For each S under both the short and long interval condition the median was separately calculated from all the individual RTs at each of the three PE trials; the central tendency measure calculated at each of the three MC trial levels was the mean of individual MC median scores used to match the individual PE reaction times. In summary, the computer program extracted from all the data the analyzable errors and their associated PE responses; matched these PE responses with appropriate control scores; then supplied central tendency measures on these data.

CHAPTER III

RESULTS

The analyses of the results are based on day two data. The RT scores analyzed in both the COR and NCOR were the medians of each S's individual RTs at each of the three trial levels for the PE responses, and, for the equivalent MC responses, the means of these matches whose individual items were median values (see p. 33). Since these medians and means-of-medians showed a typically positively skewed RT distribution, each S's scores were transformed to a common logarithm; this transformation visibly normalized the distribution of the scores. Analyses of variance (AOV) were carried out using these transforms. The factors of the AOVs were compatibility (DC and MI), trials (plus-one, plus-two, and plus-three), reaction time (PE and MC), and interval (short and long). The majority of the summary tables of the several AOVs have been placed in the appendix with the exception of the Tables which contain the overall AOVs for the COR and NCOR.

Correction Procedure. The first hypothesis tested was that the correction response is faster than a repetition response. Figures 1 and 2 clearly show that the correction responses (the PE plus-one RTs) were faster than the repetition responses (the MC plus-one RTs). This is also reflected in Table 2 by the significant main effect of the reaction time factor ($F=39.92$, $p<.01$) and in the significant T x RT interaction ($F=76.52$, $p<.01$). The percentage of the total T x RT interaction sum of squares accounted for by the contrast $2(PE_1 - MC_1) - (PE_{23} - MC_{23})$ was calculated

TABLE 2

Analysis of Variance of Transformed
Reaction Times of the Correction Procedure

Source	df	MS	F
Between subjects	23		
C (compatibility)	1	185,999	7.38*
Subj. w. groups	22	25,174	
Within subjects	264		
T (trials)	2	877,099	234.20**
CxT	2	6,711	2.05
T x subj. w. groups	44	3,745	
RT (reaction time)	1	81,171	39.92**
CxRT	1	6,451	3.17
RT x subj. w. groups	22	2,033	
I (interval)	1	51,440	8.13**
CxI	1	22,596	3.17
I x subj. w. groups	22	6,321	
TxRT	2	123,658	76.52**
CxTxRT	2	5,404	3.35*
TxRT x subj. w. groups	44	1,616	
TxI	2	1,958	
CxTxI	2	5,526	1.73
TxI x subj. w. groups	44	3,176	
RTxI	1	67,498	49.66**
CxRTxI	1	892	
RTxI x subj. w. groups	22	1,359	
TxRTxI	2	31,687	15.22**
CxTxRTxI	2	628	
TxRTxI x subj. w. groups	44	2,081	

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

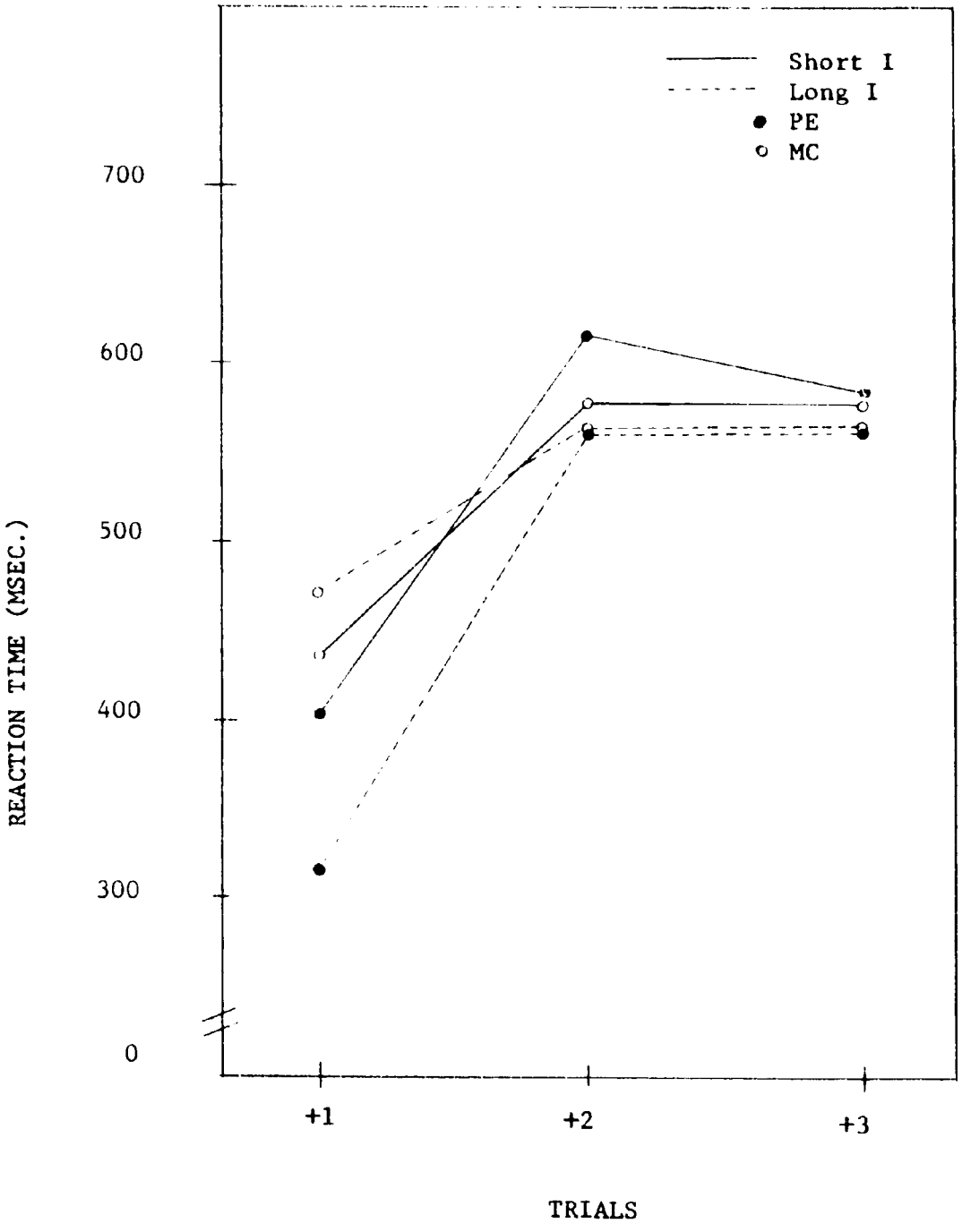


Fig. 1 Raw Score RTs of Correction Procedure Averaged Over Compatibility

(see p. 355, Walker and Lev, 1953). This particular component of the interaction was found to account for 99.7% of the total interaction effect, and the residual sum of squares, when tested with the same error term, was not significant. This finding confirms the impression gained from Table 3 that the greatest differences between the PE responses and the MC responses occurs on the first trial following the error, i.e., the difference between the correction response and repetition response. The direction of the relationship between the PE and MC reaction times changes on the plus-two trial, the PE time score being longer than its MC in the short interval, and about equal in the long interval; the plus-three trial shows no appreciable differences between the PE and MC latencies, with the possible exception of the short DC condition. These latter results characterize both the DC and MI conditions.

A second hypothesis tested stated that the difference between a correction RT and its appropriate repetition RT would be less for a relatively short response-stimulus interval. This expectation is substantiated by the significant T x RT x I interaction ($F=15.22$, $p<.01$) and is shown in Fig. 1. Here the form of the T x RT interaction was the same for both the short and long intervals but differs in magnitude. For this interaction effect the differences between the plus-one PE and MC (correction response and repeated response, respectively) for both the short and long intervals were compared with the same contrast averaged over the plus-two and plus-three trials, i.e., $2[(SPE_1 - SMC_1) - (LPE_1 - LMC_1)] - [(SPE_{23} - SMC_{23}) - (LPE_{23} - LMC_{23})]$. This comparison accounted for 97.5% of the total interaction sum of squares with the residual sum of squares not being significant. The interaction was due

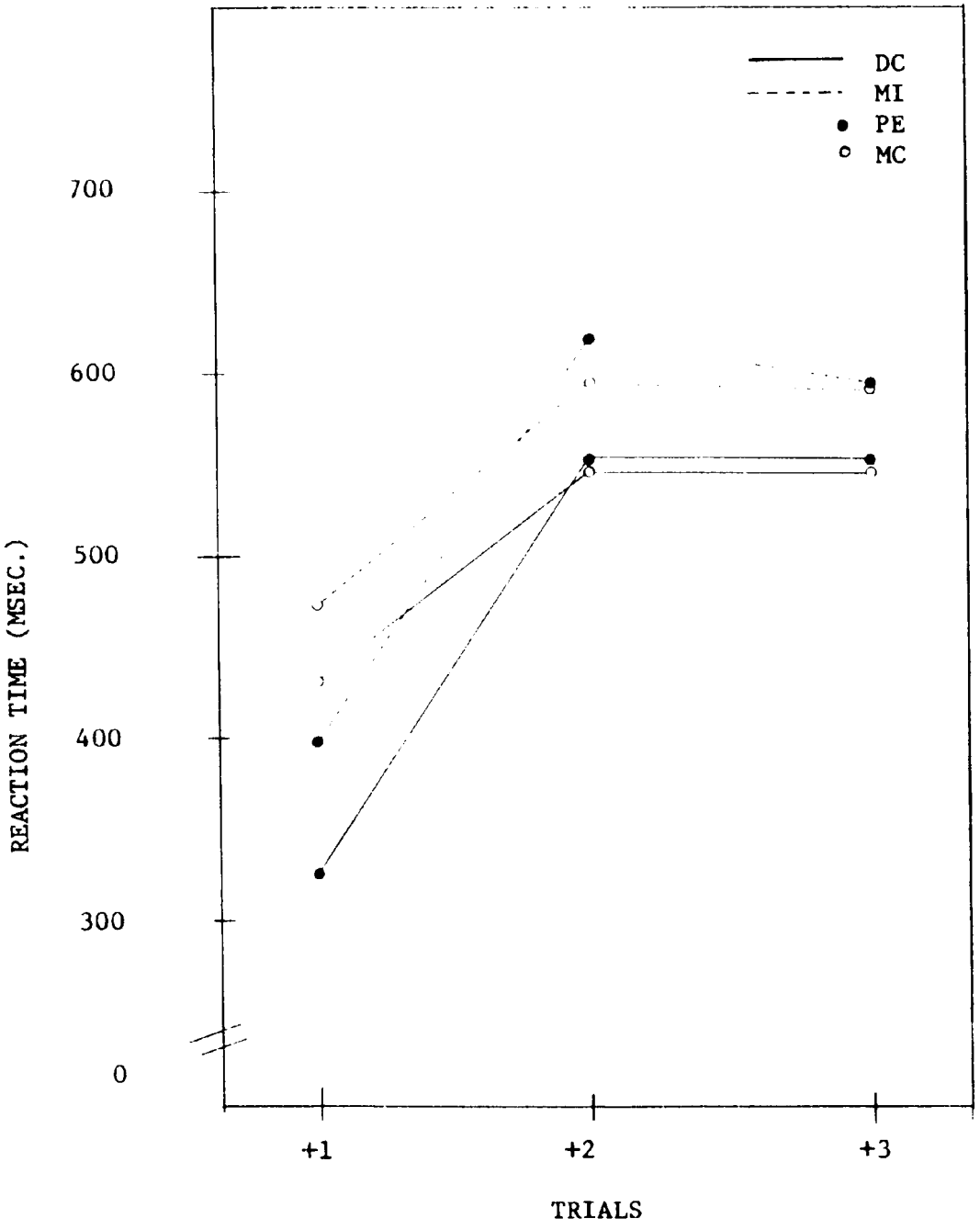


Fig. 2 Raw Score RTs of Correction Procedure Averaged Over Intervals

TABLE 3

Raw Score Reaction Times and Standard Deviations of Posterror (median), Matched Control (mean-of-medians), and Simple Reaction Time (means-of-medians) of Correction Procedure Conditions

	Direct								Mirror Image						
	SRT		Trials						SRT		Trials				
			+1		+2		+3				+1		+2		+3	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Short Interval																
Posterror	287	80	340	83	573	85	564	96	322	88	467	120	660	81	619	42
Match Control			403	85	550	70	546	63			470	107	608	49	611	35
Long Interval																
Posterror	278	93	296	85	536	80	545	68	274	82	331	91	583	45	576	52
Match Control			461	39	541	72	545	69			478	51	583	50	580	43

TABLE 4

Number of Ss (Total=12) Whose
Average PE Reaction Time Was Faster
Than the MC at the Plus-One Level and the
Number of Ss Whose PE Reaction Times Were Slower
Than the MC at the Plus-Two and Plus-Three Level

	Trials		
Direct Correspondence	+1	+2	+3
Short I	9	8	8
Long I	12	6	5
Mirror Image			
Short I	5	10	7
Long I	11	5	6

to the greater difference between the correction response and its repeated-response control in the long interval condition than the same difference in the short interval condition. It should be noted that the repeated response RTs are directly related to the interval lengths while the correction response RTs are inversely related to the response-stimulus intervals (see Fig. 1 and Table 3). The results of this interaction are in agreement with the expectation of a difference in the directional effect of intertrial times on the repetition response and correction response.

It was predicted that there would be a smaller difference between the correction response and the repetition response in the less compatible task (MI) than in the more compatible task (DC). An important test of this hypothesis is the T x RT x COMP second order interaction; this interaction was significant ($F=3.35$, $p<.05$). The form of the relationship between the PE responses and the MC responses is similar to the preceding interaction (see Fig. 2). On the first trial, there is a greater difference between the correction response and repeated response for the DC group than for the MI group than there is between these two groups averaged over the last two trials. This contrast accounted for 92.2% of the total sum of squares for this interaction with the remainder again being nonsignificant. This result is in agreement with the notion that it is more difficult for the MI group to take advantage of the advance information in making the correction response than it is for the DC group. This statement is supported by a closer

examination of the plus-one RTs of the DC and MI groups for the short and long intervals: The smallest difference seen in Table 3 between the correction condition and the repetition condition is after the short interval for the MI group (3 msec.). Similar differences are much greater for the more compatible DC condition and for the MI group after the longer response-stimulus interval.

Another feature which is clearly discernable in examining the compatibility groups separately (see Table 3) is that the plus-two RT of the MI group following the short interval appears considerably longer than its MC, and more so than the equivalent difference for the DC group. However statistical tests of the simple effects which compared the several differences between the PE plus-two and plus-three responses with their respective MC were not significant. For these latter tests, the error terms were based on data which included the plus-one trial.

An AOV (Table B-I, appendix) was performed with the plus-one level of the trial factor excluded. The resulting error terms into which trial factor entered were appreciably smaller than the equivalent error terms in Table 2, indicating a heterogeneity of variance over trials. Separate AOVs compared the PE scores at the plus-two and plus-three trials with their MC for each compatibility and interval combination (Table B-VI-IX, appendix). These analyses led to the determination that after the short interval the second posterror response was significantly longer than its matched control in both the DC and MI condition, while this difference was not significant for either compatibility condition at the plus-three

level. None of the comparisons were significant in the long interval condition.

Table 4 presents the number of Ss who displayed an average PE reaction time faster than its MC at the plus-one trial and the number of Ss who had a longer PE than MC for trials plus-two and plus-three. The percent of each S's PE reaction times which were less than his MC reaction times was calculated at the plus-one trial. These values averaged over Ss were: DC-S-64%, DC-L-85%, MI-S-47%, and MI-L-82%.

It was desired to compare the correction RTs and repetition RTs with the scores of the simple reaction time (SRT). This was done primarily to determine whether the correction RTs were as fast as the SRTs. The latter condition represents the case where the S enters into the situation with complete advance information about the stimuli. In the case of the correction response, advance information was dependent on a momentary detection of an event. An AOV (Table B-X, appendix) was performed only on the plus-one trial scores in which the scores of simple reaction time (SRT) were included. Each S had a median score of his SRT for each key--this score was transformed to a common logarithm. These SRT medians were used to match the PE plus-one responses. Thus the distributions of key responses for the PE plus-one, the MC plus-one and the SRT were identical. The F test of this "repeated" factor consisting of the correction response, repetition response, and SRT, was significant ($p<.01$). Because of the significant compatibility x repeated interaction and repeated x interval interaction,

the individual comparisons among three conditions of the repeated factor were carried out at the separate levels of compatibility and interval. The SRTs were found to be significantly faster than both the correction responses and repetition responses in the S-DC, S-MI, and L-MI ($p<.05$); in the L-DC the SRT was significantly faster than the repetition response ($p<.01$) but not the correction response. The SRTs were significantly faster than the correction RTs in all cases except when the task compatibility is high and the response-stimulus interval is long. The correction responses were significantly faster than the repetition responses ($p<.01$) in all conditions except the S-MI; this condition involved the most complex task and shortest interval. Table 3 includes the raw score means-of-medians of the SRT.

Finally, it was desired to determine whether a repetition effect could be found for the NCOR. The mean of the medians of the repeated stimuli cells from the plus-one matching matrix were obtained for each S. Similarly, the means of the medians for the nonrepeating stimuli cells were obtained. The millisecond values averaged over Ss of these respective scores were: DC-S (392 vs. 539), DC-L (399 vs. 506), MI-S (414 vs. 712), and MI-L (453 vs. 626). A clear repetition effect was demonstrated for the NCOR.

Noncorrection Procedure. The structure of the over-all analysis of variance for the NCOR was the same as that for the COR (see Table 1). Table 5 summarizes the findings of the AOV performed on these logarithmic RT data. Figures 3 and 4 depict some of the most important relationships existing among the different treatment conditions and Table 6

TABLE 5

Analysis of Variance of Transformed
Reaction Times of the Noncorrection Procedure

Source	df	MS	F
Between subjects	23		
C (compatibility)	1	907,990	43.27**
subj. w. groups	22	20,984	
Within subjects	264		
T (trials)	2	30,144	53.26**
CxT	2	3,673	6.49**
T x subj. w. groups	44	566	
RT (reaction times)	1	79,036	128.74**
CxRT	1	4,925	8.02**
RT x subj. w. groups	22	614	
I (interval)	1	244,475	59.08**
CxI	1	14,154	3.46
I x subj. w. groups	22	4,088	
TxRT	2	44,095	133.60**
CxTxRT	2	3,267	9.90**
TxRT x subj. w. groups	44	330	
TxI	2	14,315	27.74**
CxTxI	2	297	
TxI x subj. w. groups	44	516	
RTxI	1	17,656	27.42**
CxRTxI	1	5	
RTxI x subj. w. groups	22	644	
TxRTxI	2	13,108	37.34**
CxTxRTxI	2	363	1.03
TxRTxI x subj. w. groups	44	351	

**$p < .01$

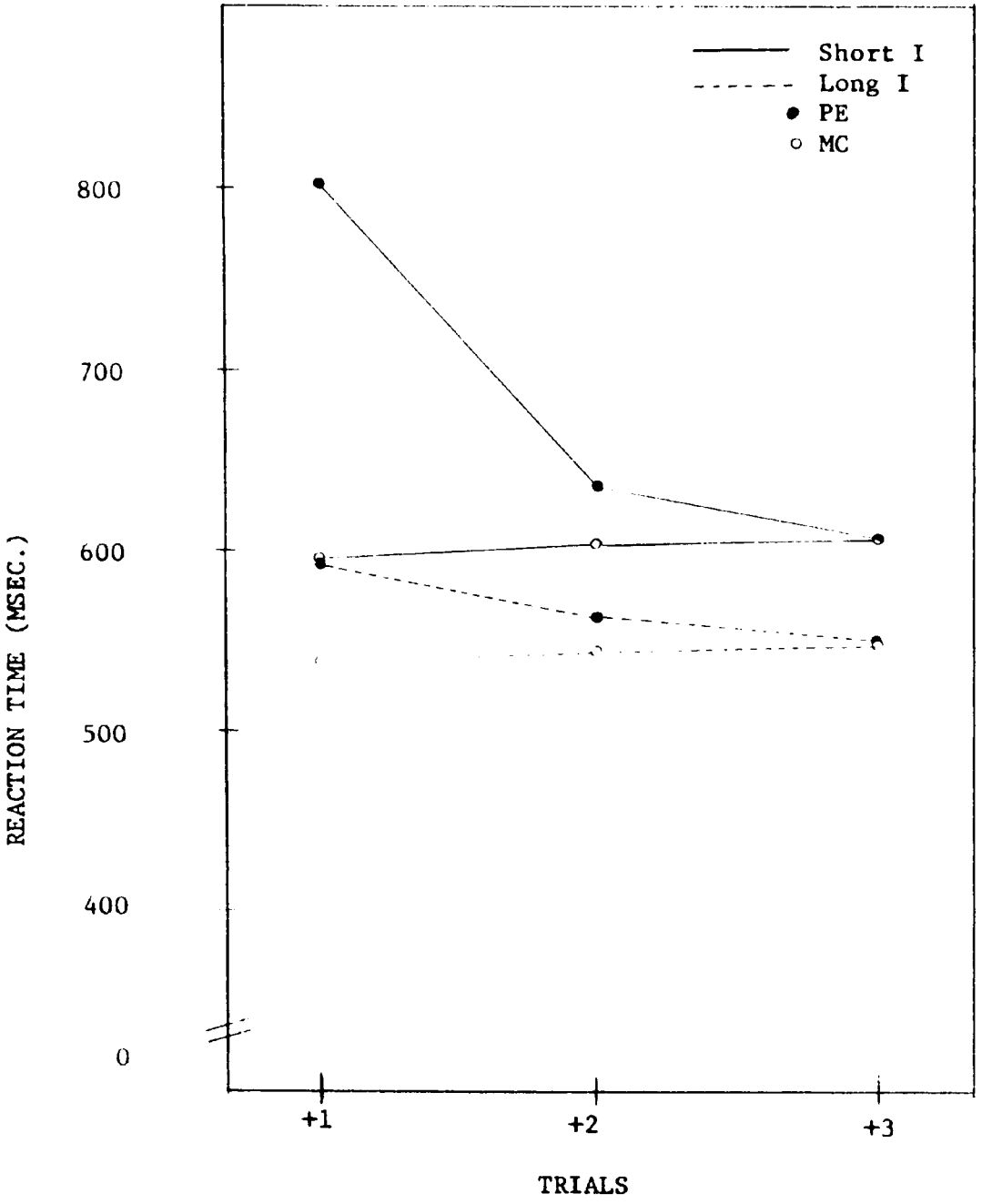


Fig. 3 Raw Score RTs of Noncorrection Procedure Averaged Over Compatibility

presents the averaged scores of the NCOR results.

The major empirical prediction made concerning the NCOR was that the PE plus-one RT would be significantly longer than its plus-one MC. (In the NCOR the plus-one trial no longer refers to a correction response and a repetition response; the posterror stimuli are a random sample from all eight of the possible stimuli).

The expected longer PE reaction times are seen both in the graphs of Figures 3 and 4 and in the results of Table 5. The over-all RT main effect is highly significant ($F=128.74$, $p<.01$) but is qualified by several interactions. Again the two second order interactions which were significant were the T x RT x I and COMP x T x RT. In both of these effects (see Figures 3 and 4) it appears that the differences between the first PE responses and their MCs account for most of the second order interactions. Also, most of the RT main effect seems to result from longer PE reaction times on the first response. The contrast $2[(SPE_1 - SM_1) - (LPE_1 - LM_1)] - [(SPE_{23} - SM_{23}) - (LE_{23} - LM_{23})]$ was made to check this impression for the T x RT x Interaction effects. This contrast accounted for 99.2% of the total interaction sum of squares; the residual sum of squares was not significant when tested by the error term for this interaction effect. This finding supports the hypothesis that a PE lengthening would be more pronounced when relatively little time intervened between an error response and the presentation of a new stimulus input. There was a much greater difference between the first PE response and its MC following the short interval than following the long interval; this large difference is not

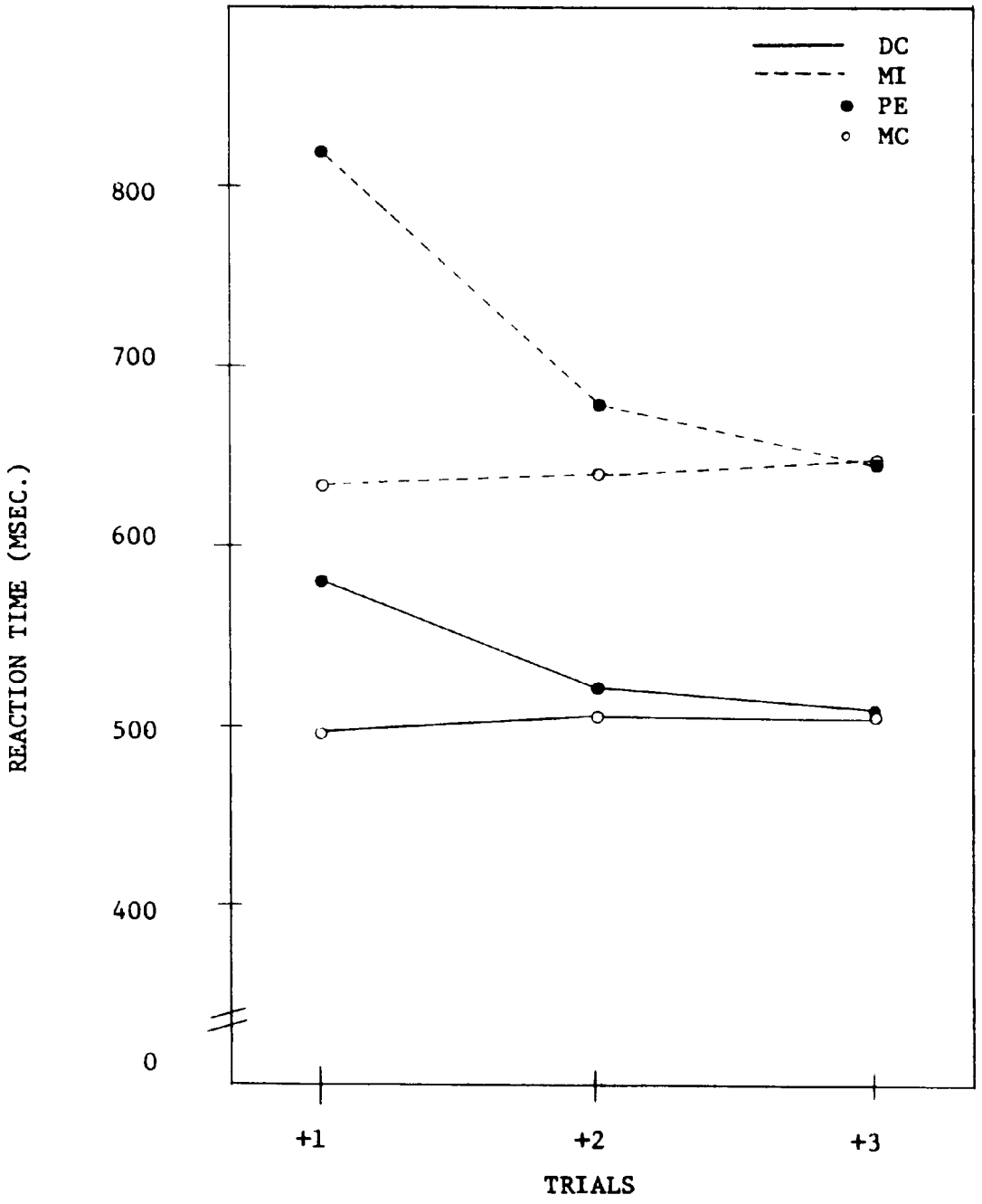


Fig. 4 Raw Score RTs of Noncorrection Procedure Averaged Over Intervals

TABLE 6

Raw Score Reaction Times and Standard Deviations of Posterror (median) and Matched Control (mean-of-medians) of Noncorrection Procedure Condition

	Direct Correspondence						Mirror Image					
	Trials						Trials					
	+1		+2		+3		+1		+2		+3	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Short Interval												
Post Error	654	86	541	62	532	57	960	155	735	104	683	91
Match Control	515	50	524	54	523	52	680	78	684	81	692	95
Long Interval												
Post Error	505	55	500	43	489	53	683	92	624	80	610	61
Match Control	481	38	489	41	491	42	594	60	600	63	606	62

TABLE 7

Number of Ss (Total=12) Whose Average PE Reaction Time Was Longer Than the MC Reaction Time

	Trials		
Direct Correspondence	+1	+2	+3
Short I	12	8	7
Long I	9	8	4
Mirror Image			
Short I	11	8	5
Long I	12	7	8

maintained on the second and third trials. These relationships are clearly seen in Fig. 3.

The COMP x T x RT interaction was due to the greater difference between the plus-one PE latency and its MC for the MI group than the same comparison for the DC group. This is reflected in the contrast $2[(DPE_1 - DMC_1) - (MPE_1 - MMC_1)] - [(DPE_{23} - DMC_{23}) - (MPE_{23} - MMC_{23})]$ which accounted for 89% of the interaction sum of squares. This result confirms the prediction that the less compatible task (MI) is more sensitive to the effects of an error than a task involving a highly compatible S-R relationship (DC).

A more detailed analysis involving individual comparisons showed that the PE plus-one RT was significantly longer than the MC for all combinations of response-stimulus interval and S-R compatibility ($p<.01$). The MS error term used to test these differences came from four 2 x 2 AOVs (Tables B-XII to XV, appendix) in which the main effects are T and RT. Each AOV analyzed a different combination of compatibility and interval; all three levels of the trial variable were used. Another set of similar AOVs compared the PE latencies with the MCs (Tables B-XVI to XIX, appendix) for only trials plus-two and plus-three. The findings of these latter AOVs replicated those of similar analyses in the COR. The second response following an error was significantly longer than the matched control following the short interval ($p<.05$) for both the DC and MI groups, while there were no significant differences between

the PE and MC at the plus-three trial. There were no significant main effects for the reaction time factor following the long interval. An indication of the consistency of the posterror lengthening effects can be gained from Table 7 which shows the number of Ss whose PE scores were longer than their MC scores. The percentage of PE reaction times which were greater than the MC latencies was calculated for each S at the plus-one trial. The values averaged over Ss were: DC-S-87%, DC-L-62%, MI-S-92%, and MI-L-77%.

Correction Procedure vs. Noncorrection Procedure. The results to be described in this section are not directly connected with the influence of errors on subsequent RTs, which is the principle concern of this research. However, several analyses were performed in order to assess the some possible general effects of the two correction procedures on information measures and on nonerror associated RTs. The first analysis was an attempt to find out if the correction procedures affected the RTs which were relatively removed from the errors. A score was obtained from each S, for the short and long intervals separately, which was the mean RT of the correct responses in the plus-one MC matrix, including repetition responses. These scores were obtained for both the COR and NCOR. Each response in these plus-one matrices was removed from an error by at least two intervening correct responses. These RT scores were transformed to a common logarithm and an AOV was carried out (Table B-XX, appendix).

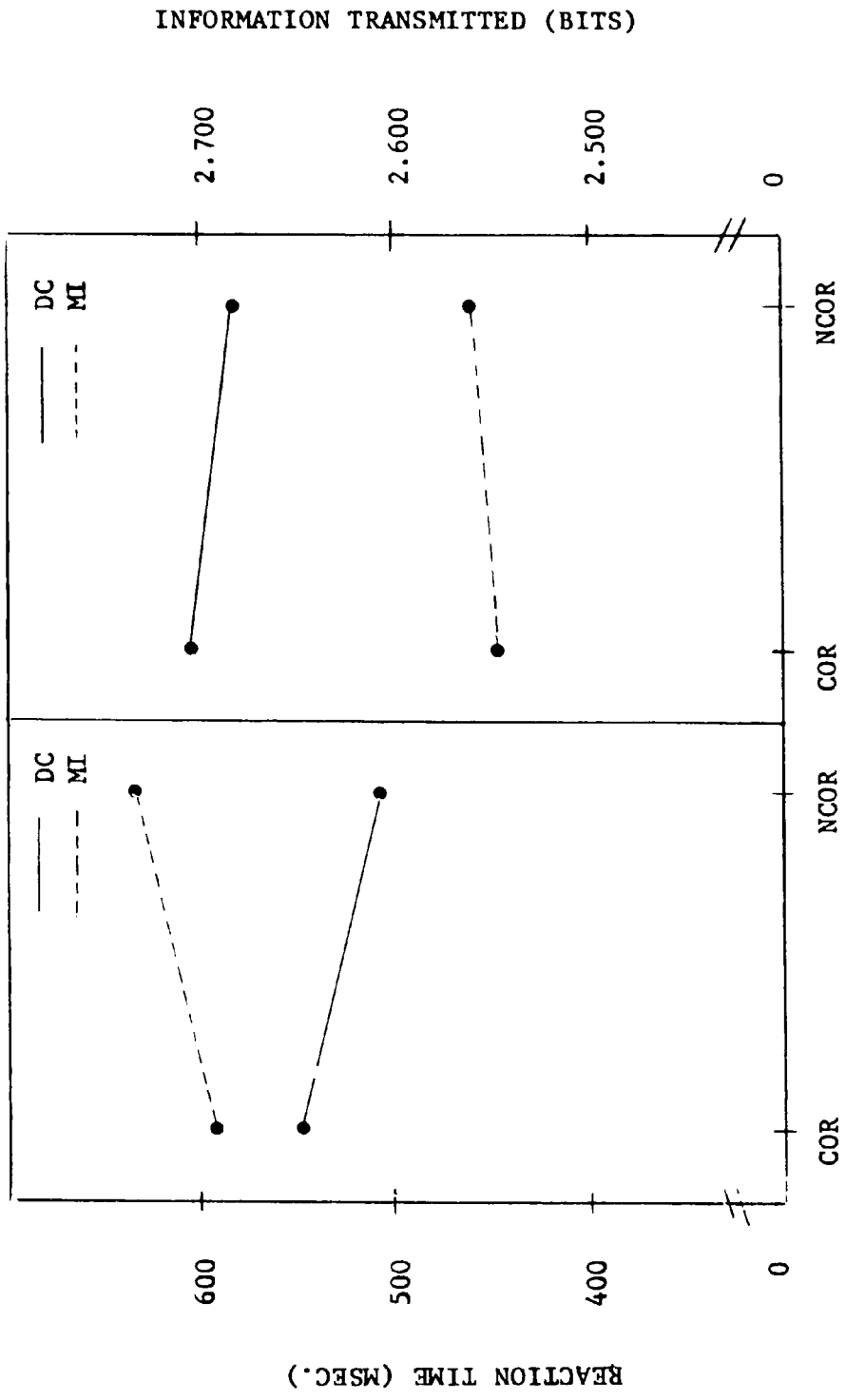


Fig. 5 Reaction Times of MC Matrix and Transmitted Information Averaged Over Intervals

TABLE 8

Means and Standard Deviations of Raw Score
MC Reaction Times, Information Transmitted,
Rate of Transmitted Information, and Per Cent Errors.

	MC Reaction Times		Information/Second		Information Transmitted		Per Cent Errors	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Short								
Direct Correspondence								
Correction	551	70	4.737	.507	2.668	.112	7.1	2.7
Noncorrection	522	51	4.982	.520	2.693	.074	5.4	1.6
Mirror Image								
Correction	609	40	3.914	.342	2.527	.100	9.7	3.1
Noncorrection	670	78	3.543	.520	2.577	.219	7.6	4.4
Long								
Direct Correspondence								
Correction	544	64	4.945	.479	2.743	.112	4.8	2.4
Noncorrection	492	42	5.347	.447	2.675	.106	5.8	2.2
Mirror Image								
Correction	577	44	4.252	.403	2.568	.128	8.2	3.1
Noncorrection	600	60	4.020	.502	2.543	.230	8.2	4.6

Figure 5 shows a surprising result of this analysis depicting graphically the significant interaction ($F=5.93$, $p<.05$) between the compatibility conditions and the correction procedures. The DC group's NCOR latencies were significantly faster than their COR latencies ($p<.01$); the MI group showed just the opposite relation, the NCOR latencies being significantly slower than the COR latencies ($p<.01$). A significant COMP x I interaction ($F=7.42$, $p<.01$) detects the relatively greater difference between the short and long intervals for the MI group than for the DC group, although both differences are in the same direction. And the significant COR x I interaction ($F=8.37$, $p<.01$) results from the smaller difference between the two response-stimulus intervals for the COR procedure group than the NCOR procedure group. The average RTs for the various condition can be found in column one of Table 8.

A general measure of accuracy was obtained by calculating the amount of information transmitted by each S in each condition; an information measure was obtained on each series of 960 stimuli and responses. The COR and NCOR conditions were made comparable by not including the correction responses from the COR in the information analysis. The AOV evaluated the effects of the correction procedures, compatibility, and intervals (see Table B-XXI, appendix). Table 8 presents the mean values of transmitted information in column two. The DC group transmitted significantly more information than the MI group ($F=11.34$, $p<.01$). While the main effect for the COR factor was not significant, there was a significant COR x I interaction ($F=10.49$, $p<.01$). Individual comparisons were

made among all possible pairs of means entering into this interaction (S-COR, L-COR, S-NCOR, and L-NCOR) by the Newman-Keuls multiple range test.[1] The only significant difference among these pairs was between S-COR and L-COR ($p<.01$); the L-COR condition was more accurate than the S-COR condition (2.655 vs. 2.597 bits). The percent of errors made was also calculated for each S and these values averaged over Ss are presented in the fourth column of Table 8. The pattern of these error scores was the same as the information measure; separate analysis was not undertaken on the error percentages.

Finally, the rate of information transmitted in bits/sec. was calculated for each subject. The time score which entered into this composite score was the mean latency taken over all responses which entered into determining the amount of information transmitted. An analysis of these time scores resulted in the same picture as was found in the analysis of the nonerror association correct RTs in Table B-XX, appendix. An AOV of the rate scores is presented in Table B-XXII, appendix. The rate measure

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[1] In applying the Newman-Keuls test to these means two MS errors were used to estimate the $S\bar{x}$: MS within and MS within-between. One of these was used to test each comparison and was determined by whether the particular contrast was based only on within effects or both within and between effects.

reflected the same interaction between COMP and COR ($F=5.27$, $p< .01$) that was seen for the nonerror associated reaction times. For the DC group the rate measure was significantly higher under the NCOR, while the MI group showed a significantly higher rate under the COR.

CHAPTER IV

DISCUSSION

The Correction Procedure. A correction RT was faster than a repetition RT in all combinations of conditions in the COR; these results imply that an error can supply information about a subsequent event, i.e., the next stimulus. Several studies (see p. 14) have been mentioned earlier purporting that advance information derived from external sources can be used to enhance the processing of subsequent information; the present findings extend this capacity to information supplied by internal cues. These cues are derived from S's ability to detect through self-monitoring when he has made a mistake. The greatest profit from these findings can be gained by a careful examination of the correction and repetition RTs at the various levels of S-R compatibility and response-stimulus interval.

Advance information can be more efficiently acted on if the S-R relation is simple and/or the processing time available before the arrival of the next signal is relatively long (Table 3). This is manifest in both the RTs of the plus-one PEs and the differences between these PEs and their MCs. These findings are consonant with a model relating the complexity of S-R compatibility to coding efficiency and the latter, in turn, to the required processing time of the message. Less compatible tasks are seen to involve less economical codes or perhaps more coding steps. Lawrence (1963) could advance the notion of a more complex coding operation being required to code the stimulus of a less compatible task.

The notion of S-R compatibility effects being a direct function of the number of internal recoding steps or transformations is due to Fitts (1959). This kind of reasoning finds further support in the present experiment where the smallest difference between the RTs of a correction response and its repetition response control was for the MI group following a short interval, while the greatest superiority of a correction RT over a repetition RT was for the DC after the long interval (see Table 3).

A comment is in order on the finding that the RTs of the MI group offer no appreciable evidence of an ability to preprocess information following the short interval. It is unlikely that this is due to a pervasive difficulty of the MI group in detecting errors, since following the long interval the MI group detected an average of 82% of their errors (using PE<MC as the criterion). The problem for the MI group following the short interval may have been insufficient time for the operation of either or both error detection and preparation for the expected stimulus; the root difficulty in both of these possibilities might be contingent on the complexity of the coding operations involved in MI relationships.

These experimental results seem consonant with a notion of coding uncertainty; unfortunately, while popular, this kind of concept is currently limited in accounting for some of our results. We cannot find in either Fitts's (1959) or Lawrence's (1963) theoretical papers explicit statements leading one to expect differential susceptibility of S-R codes to perturbations in the human communication system. This latter requirement presents itself when considering

the interactions between compatibility and the reaction time factors found in both the COR and NCOR. Since sophisticated and testable models of central coding processes are not yet available, the validation and extension of the coding concept in human information processing will depend on prima facie evidence exemplified by the kind of results discussed here. In summary, the three major hypotheses concerned with the COR found strong support in the findings of this experiment. The correction responses were faster than the repetition responses, and this advantage was greater when more time intervened between the error and the next stimulus, and for the more compatible task.

The repetition effect was confirmed in both the DC and MI conditions in an eight-choice task, and extends the boundary of this phenomenon. A major exception to Bertelson's findings was noted: a repetition effect was clearly discernable following the long intertrial interval (see plus-one MCs in Table 3). Bertelson (1961) found in the random condition of a two-choice task that the repetition effect washed out after 500 msec. The prolongation of the repetition effect in the COR cannot be attributed to a greater expectancy of repeated stimuli based on an increased probability of a stimulus being repeated because of the correction contingency. There is clear-cut evidence of a repetition effect in the NCOR following the long interval (see p. 44). Unfortunately, the available literature on the repetition effect doesn't allow a determination, based on well-controlled experimental evidence, of whether the duration of the repetition effect increases with the

number of choice alternatives in serial tasks. There is some relevant evidence in Hyman's study (1953); he found faster RTs to repeated stimuli in four- and eight-choice tasks but not in a two-choice task. The interval between stimuli appeared to be about 10 seconds, thus this repetition-like effect persisted over a much longer response stimulus interval than was used in the present study.

Again the differences in the persistence of the repetition effect may arise from differences in coding complexity, perhaps because a set to respond repetitively is maintained as a function of the degree to which the system (the S) is involved with monitoring the feedback of the response. It would take more time to compare the feedback to the long code of a less compatible task than to the shorter code of a more compatible task. It follows that the perseveration of a repetition effect should increase as a function of any operation which is assumed to increase the coding complexity of a task, e.g., input uncertainty, compatibility, etc. In the present study, there was evidence that the DC condition showed a lessening of the repetition effect over time while this was not observed in MI condition (see Table 3).

The picture of a PE response when it is a correction response looks very different from a response at the same PE level of the trial variable in the NCOR. Does an error occasion a similar process in both correction conditions? We believe it does. The argument that there is a general PE effect in both correction procedures will be developed now as we discuss the NCOR results below, and the relevant findings from the COR will be brought up there.

The Noncorrection Procedure. The data of this investigation adduced to demonstrate that Ss have the capacity to discriminate an error by relying on internal cues and that errors occasion alterations in information processing beyond their simple occurrence are most vividly displayed in the NCOR posterror effects. In the NCOR there was unequivocal support for the prediction of a PE lengthening; significantly longer RTs were seen in all cells at the plus-one trial and at the plus-two trial following the short interval (see Table 6). This phenomenon has not, to our knowledge, been dealt with in the literature. The patterning of these PE lengthening effects supports quite clearly our expectations related to the response-stimulus interval and compatibility. In both the DC and MI compatibility tasks, the difference between the PE and MC reaction times decreased over time; this was true between the short and long interval conditions and over trials within an interval condition. The fact that the PE lengthening lessens with time, even, when there were no intervening overt responses, i.e., between the two interval conditions, negates the argument that this temporal effect is an artifact of a response which "clears" the information processing mechanism and, presumably, ends involvement with the previous error. However, the execution of implicit responses, say correction responses, may be an important factor in the PE lengthening. A precise distinction between competing response and increase in "noise" explanations is definitionally and demonstrably difficult. Some of these problems will be elaborated in the course of the discussion.

The magnitude of the PE lengthening effect was negatively correlated with S-R compatibility as predicted, there was greater inhibition in the MI task following an error. Moreover, this compatibility effect interacts with the intertrial interval. In terms of the percentage increase of the PE latencies over the MCs, the order from greatest inhibition to least inhibition was S-MI, S-DC, L-MI, and L-DC (see Table 5). Here again we see the need for better models of coding which account for the widespread interactions between task complexity and other information processing variables.

In light of the marked differences between the RTs of the first response following an error response in the COR and NCOR, (the correction response and a random response, respectively) the question arises of the equivalence, in these two conditions, of the process presumably initiated by making an error. There are several lines of evidence which suggest that the general process is effectively inhibitory in both the COR and NCOR. Both the COR and NCOR showed the same pattern of longer PE reaction times at the plus-two level; so in the trials where one could observe a similar kind of response in both of the two correction conditions, evidence of lengthening was observed. The greatest difficulty arises in explaining the RTs of the correction responses which were very fast when compared with the NCOR plus-one PE.

This apparent contradiction is resolved when one compares the correction response RT with an appropriate control group. The SRT condition was similar to the correction response in that

complete advance information was available about the subsequent stimulus and the response-stimulus interval was the same. The differences consisted of the SRTs being presented in a block of trials, whereas the correction responses occurred intermittently, and that the correction responses were preceded by an error. In every instance, it was found that the correction RT was longer than the SRT (see Table 3), significantly so in all instances except the L-DC condition, it is in this latter condition that the correction response had the maximum opportunity to approach the SRT. This finding is again consonant with the notion that an error results in a subsequent limitation on information processing efficiency which is reflected in longer RTs. The magnitude of the PE lengthening is reduced in the correction response, presumably, because advantage can be taken of the available advance information.

An ambiguity exists in this argument for a lengthening of the correction response: in the COR the S's knowledge about the subsequent event was contingent on the detection of an error, while in the SRT condition the expectancy about subsequent events could be maintained over a series of events. This difference may have accounted for the advantage in the SRT reaction times. However, it was noted earlier that Leonard (1958) found that 300 msec. advance information was sufficient to reduce a six-choice RT to a three-choice RT; consequently, there should have been sufficient time in, at least, the long interval conditions of the present experiment to prepare for the next response; and yet, a lengthening

was demonstrable there also (see Table 3). On the basis of these findings it seems both plausible and parsimonious to discuss the PE effect as a unitary process manifesting itself in both correction procedure conditions.

Do the posterror effects imply that a detected error initiates the process leading to an inhibition of PE reaction times? Is it a reasonable alternative that the process which occasions the error itself is responsible for the PE effects? Unreported observations in the present study seem to indicate that the RTs of errors and the responses just preceding errors are different from their MCs. Also, there is evidence in the neurophysiological literature that definite alterations in the electrical activity of the brain can be detected which are associated with error behavior (Adey, 1963; John, 1963). However, several findings of the present study suggest that it is prudent to distinguish error phenomena and posterror phenomena. The RTs of errors and preerrors tended to be faster than MCs in the direct correspondence condition. Also, the frequency of PE effects under optimal conditions, are seen in a maximum of 80 or 90 percent of the responses--a finding more compatible with an error detection notion, than being based on a process beginning with or before an error and, then, inexorably pursuing its course.

The Comparison of the Correction and Noncorrection Conditions. The most noteworthy finding made in the analyses comparing the effects of the COR and NCOR on the serial performance was their differential effect on the nonerror correct RTs. The effect of these

correction procedures was interactive with the two compatibility conditions. Thus the Ss in a DC condition reacted significantly faster in the NCOR condition than another DC group that performed under the COR; this difference amounted to 40 msec. Just the opposite difference between the two correction procedures was found when the MI task was performed: The group run under the COR was significantly faster than the group run under the NCOR (by 42 msecs.). This interaction between compatibility and the correction procedures was not seen in the analysis of the transmitted information scores (see Table 5). In summary, a general level of accuracy was maintained within a compatibility condition at the expense of rapid processing, but the condition under which this trade-off was most necessary was contrary for the two kinds of compatibility used in this experiment.

No good explanations come to mind to explain these incidental observations. However, a speculation which momentarily seemed relevant to the findings in the DC condition will be put to rest. Welford (1952) has stated that in some well-learned tasks one may dispense with monitoring response-produced feedback. Dispensing with this feedback would free the information processing mechanisms earlier to deal more rapidly with subsequent inputs. It is reasonable to assume that in the DC condition one would not have to rely on feedback monitoring because it is a highly compatible task. However, the external feedback introduced by the correction requirement might have induced a general tendency to monitor response-produced feedback and, consequently make the RTs in the DC-COR longer

than in the DC-NCOR. Unfortunately, this argument is insufficient since it implies that the longer COR results are attributable solely to response feedback. If this were the case one would expect that the difference between the DC-COR and DC-NCOR would be minimal following the long response-stimulus interval because the time taken up by feedback monitoring could occur during the 800 msec. interval. It was not. The difference between the two correction conditions was considerably greater following the long interval than following the short interval (see Table 8).

Only a guess, based on experience with the task, can be offered as a clue to the reasons for the longer RTs under the NCOR for the Ss performing the MI task. The MI relationship is difficult and unstable and, perhaps, more conservative decision and error monitoring criteria are required in the NCOR where there are not any external indications of performance adequacy. In the COR the S could depend on external information to indicate to him any marked deterioration of performance, e.g., a retrogression to long-term DC responding. The availability of this information may have allowed the S to relax certain time consuming quality control operations and still be assured of a satisfactory level of accuracy.

Whether or not the above conjectures are germane, the correction procedure is a variable of considerable importance in serial performance. Because the correction procedure and S-R compatibility are strongly interactive, caution is advisable in accepting any general statements about the role of compatibility in serial performance from studies carried out under only one correction procedure.

Possible Mechanisms. Several mechanisms which might help account for the inhibitory effects of an error on subsequent RTs will be discussed in this section.

1. Channel with Limited Capacity. A model which has gained wide popularity in recent years for explaining information processing in RT experiments has involved the concept of the human as a single-channel communication system. Variants of this model have been explicated by many writers (Broadbent, 1958; Welford, 1960), but they share a basis in a schema having a single central channel for information processing of limited capacity. The processing of sensory events is accomplished in a serial manner and the theory, classically, precludes simultaneous action by the central mechanism on two events (Broadbent, 1958). The sequential compartments of this information processing system include input mechanisms for receiving and transmitting sensory events, along with a capacity for short-term storage; a decision mechanism which would include a variety of functions: identification, response selection, and monitoring capabilities; and an effector mechanism which includes feedback loops.

The single channel model has been most widely employed in accounting for phenomena subsumed under the concept of refractoriness (Broadbent, 1958; Welford, 1952). This designation has been applied to the observations that stimuli acting on the channel within a certain time of one another result in a lengthening of the response(s) involved. The lengthening has been attributed to the processing of the second stimulus being delayed during the

period of time that the channel is concerned with making a response to the first. There is evidence that an overt response is not necessarily needed for refractoriness to be demonstrated (Davis, 1959).

The characteristic lengthening the PE effect, observed in this experiment may be viewed as a form of refractoriness. In a very large percentage of instances, the S is aware he has made an error (inferred from the percentage of PE reaction times greater or less than the appropriate MC and also from the S's self-reports). (The source of the error detections may be thought of as based on either peripheral response-produced feedback, or the error may be already detected at the level of the central decision mechanism, but too late to prevent its overt occurrence.) The detection of an error, then, would be envisioned as initiating central processes which effectively "capture" the channel for a period of time and make it refractory to any new input; whether this refractoriness is absolute or relative, in all of its forms, is currently open. As in other forms of refractoriness, the delays following an error become less with longer interstimulus intervals. The essential notion of the refractory period is that the limited capacity of the channel is "taken-up" by some event to the exclusion of other events. The event occasioned by an error cannot be shuttled-off to another independent channel. With time the perturbation of the channel abates and the former steady-state is achieved; inputs are then processed with normal facility. If we pursue an information theory analogy further, it seems reasonable that the simpler codes involved in the DC condition would be more robust in their reactions to bursts of "noise" in the channel than the MI codes.

This conjecture could serve as an explanation of the relatively longer RTs of PEs in the MI group. In the present experiment, the human system demonstrated marked PE refractoriness to new stimuli (NCOR) and a lesser but clear lengthening to expected stimuli (COR); however, advance information can be utilized in the COR. This diminution of refractoriness in the COR may have been a result of the to-be-repeated signals status as already registered and the presence of a well established set about an error's implication.

2. Orienting Reflex. A mechanism initiated by a detected error response may be the orienting reflex (OR). This concept would complement the notion of a single-channel with limited capacity rather than compete with it. Pavlov (1960) originally advanced the OR as an explanation of external inhibition--the finding that detection by the animal of a new stimulus in the environment could effectively inhibit a well-established conditioned reflex. The OR is a constellation of somatic, autonomic, electroencephalographic, and receptor alterations which occur when the nervous system has detected any significant change in a stimulus: the OR is peculiarly sensitive to the collative parameters of stimuli (Berlyne, 1960).

Sokolov's (1960, 1963a, 1963b) formulation of the OR involves a "neuronal model of the stimulus" which seems particularly relevant to our search for a specific mechanism underlying the PE effects. He has succinctly described this model:

> The orienting reflex as a complex functional system includes the integrative activities of different brain areas. Its distinguishing characteristic is that it arises in response to novelty. It depends upon elaboration of a nervous model of stimulus and the mismatch between the model and a new stimulus. The elaboration of the neuron model consists in fixation by the nervous system of stimulus traces. The origin of the orienting reflex apparently lies in a mismatch of extrapolatory impulses and afferent signals reaching common efferent neurons (1963a).

This conception holds that following repeated stimulation many parameters of the stimulus are stored in the form of a neuronal model [of the stimulus] in the cortex. If a situation occurs where the expected stimulus is altered in some significant sense, an OR will be elaborated. This elicitation is, presumably, mediated by a disinhibition of the effector mechanisms, which are thought to be housed in the reticular system, of the OR by the cortex. Investigations of the OR have generally involved environmental stimuli, however, there doesn't appear to be any reason why the comparator mechanism--examining for mismatch--could not be equally concerned with monitoring interoceptive and central stimuli.

It is assumed that the OR could interfere with the information processing capacity of the information processing channel. It is known, for example, from the Russian work that the elaboration of the OR is correlated with a delay of the motor component of a conditioned response (Sokolov, 1963b). If a S distinguishes an error from a correct response, one can reasonably bring to bear the OR. When the monitoring of the response process discloses a mismatch between the obtained and expected response-associated

stimuli, the conditions for the OR are satisfied. As the study of refractoriness phenomena has progressed over the years, the importance of stimulus events has come into greater prominence. That the time is ripe for relating the OR to refractoriness can be appreciated in a statement by Davis in a recent paper which summarizes his view of this problem:

> The writer suggests that these delays [refractoriness] will occur whenever a subject's attention is taken up for whatever reason, whether or not an instrumental response to the attention-provoking signal is made. In terms of the single-channel conception of the human operator, the channel becomes occupied (and hence refractory to other signals) by any ("novel," intense) signal or by any signal which requires some form of discrimination (Davis, 1959).

3. Conflict. Another explanatory approach involves the S-R theory of conflict. Brown and Farber (1951) have offered a theoretical sketch which is primarily a conceptual analysis of the relationships among several intervening variables. They argue that competition between two incompatible response tendencies results in a state of conflict with an attendant emotional response. The stronger the absolute value of these competing response tendencies and the more nearly equal their relative strengths, the greater will be the conflict and the emotional response. The resolution of the conflict in favor of a particular response tendency takes time which is reflected in behavioral response measures. Berlyne (1957) has advanced a similar theory of conflict, adding the total number of competing response tendencies as a determining variable.

There is a reasonable case to be made for the development of conflict after a S has made an incorrect response in the serial

task used in the present experiment. One could argue that following a detected error the S wished to correct his mistake. In the NCOR the instructional set proscribed an overt correction response, consequently, any persisting correction tendency would be a likely competitor with the tendency to respond to the next stimulus presented in the sequence. The time taken to resolve this conflict in favor of the correct response to the next stimulus would be added to the posterror RT and accounts for its unusual slowness. (The resolution of the conflict might be achieved by making covert correction responses). In the case of the COR, the presence of a response tendency to correct a detected error would be expected to work in concert with the available advance information. Both the conflict and information factors would tend to aid in bringing about a fast correction response. Postulating a tendency to correct one's errors may be challenged as making a fairly strong assumption about a motivational disposition in the subjects of this experiment. In support of attributing to them such a disposition we can cite the evidence that, over-all, male college students are characterized by high levels of need for achievement and the resulting strong motivation to persist and complete tasks which are seen as tests of one's excellence (Atkinson, 1964).

The major difficulty for a conflict hypothesis in explaining the present results is the finding of posterror RTs significantly longer than their MC on the second trial after an error (see Table 3).

If one of the competing members is a correction tendency, it should no longer be active following its execution in the COR. Nevertheless, the second posterror response in the COR was significantly longer than its control after the short interval. A possible way of accounting for this apparent inconsistency would invoke both features of the Brown and Farber theory. First of all there is the vying of the incompatible response tendencies (this might be designated the cognitive aspect of the theory). This feature has only taken us part of the way as a possible explanation of the posterror inhibition. The other major feature of the theory, the emotional response, may have properties sufficient to account for the anomalous findings on the second posterror response in the COR. A traditional feature of S-R theory is that drive states are accompanied by both an increase in energy and in drive-specific stimuli (Sd). The emotional response's influence may be mediated by an influx of such drive stimuli into the information processing channel. The mechanism by which the drive stimuli exert their disruptive influence could be developed in terms of an increased number of competing responses (associated with the drive stimuli) present in the information processing channel. Another possibility emphasizes the informational aspects of the drive stimuli and conceives of them as increasing the noise level of the channel and, consequently, resulting in a longer sampling time before a decision is reached about the posterror stimuli. (In terms of the currently popular decision theory models of RT (Edwards, 1964;

Stone, 1960), it is the writer's opinion that the posterror effects, found in the present study, will be more easily mapped into notions of longer sampling times due to noise bursts, than related to a change to a more conservative decision criterion). The crucial assumption underlying the relevancy of drive stimuli in explaining posterror inhibition following the correction response is that these stimuli or their effects persist for some time after one of the competing responses has been performed.

CHAPTER V

SUMMARY

An experimental investigation was undertaken to determine whether reaction time (RT) of human Ss following an error response (an inappropriate key-press) differed from RT following a correct response. A related question was whether the correction procedure available to the S upon making an error affected subsequent reaction times. The first posterror response, when it was correct, was of primary interest. One group of Ss had to correct their mistakes (the correction condition) while a second group of Ss had to go on to the next event in a serial reaction task without being allowed to correct mistakes (the noncorrection condition). Preliminary interpretation of data from pilot experiments led to the selection of two other independent variables: 1) S-R compatibility, and 2) response-stimulus interval.

Three major predictions were made about the RTs to posterror stimuli in a noncorrection condition: 1) When a S made an error the RT to the next stimulus in the task would be longer than a RT to a matched response which was preceded by a correct response. 2) As more time intervened between making an error and the next stimulus (the response-stimulus interval), the RT to the posterror stimulus would show less evidence of inhibition (lengthening). 3) Tasks of low S-R compatibility were expected to show greater posterror inhibition than tasks of high S-R compatibility.

By definition and experimental arrangement, a correct response to the first stimulus following an error was a correction response. A series of predictions were also made about posterror effects in a correction condition: 1) The RT of a correction response would be faster than the RT of a matched control response, i.e., a "repetition" response. 2) A longer response-stimulus interval would be followed by a relatively faster correction response (a greater "correction effect"). 3) The correction effect would be less salient in a task of low S-R compatibility.

An incidental exploration of the data was undertaken to evaluate the influence of the correction procedures on nonerror associated RTs and accuracy measures.

The Ss performed at an eight-choice serial RT task. The stimuli were single lights and the response was pressing a single key associated with a light. Either a direct correspondence (DC) or mirror image (MI) light-key relationship obtained; these relationships constituted the two S-R compatibility conditions. The duration of the two response-stimulus intervals were: short (150 msec.) and long (820 msec.). The independent variables (correction procedure, S-R compatibility, and response-stimulus interval) were incorporated into a factorial design. A total of 48 male college students served as subjects.

The primary experimental data analyzed were RT scores. The experimental RTs were from ordered trials of correct responses whose first member was preceded by an error. Another group of RTs were obtained to serve as matched controls for the posterror

data.

In the noncorrection condition the predicted longer posterror RTs were uniformly observed. The greatest inhibition occurred on the first response following an error; this difference was significant for all treatment conditions. A relatively greater inhibition was noted following the short interval. The MI task showed much more inhibition of the posterror RTs than the DC task. The correction condition yielded faster correction responses than repetition responses in all conditions. The correction effect was not as great after the short interval as after the long interval. The MI task did not show as great a correction effect as the DC task.

In the DC condition the RTs of the nonerror associated correct responses were significantly faster in the noncorrection condition than in the correction condition; just the opposite relation held true for the MI condition.

It was concluded: Subjects were able to detect a large proportion of their errors relying on internal cues and the detected errors occasioned marked changes in the latency characteristics of subsequent responses. An error response gave rise to an inhibitory process, i.e., the processing of a subsequent input was not done with normal facility. This inhibitory process decreases with time, and behavior presumed mediated by more complex internal coding operations is more sensitive to posterror inhibition. The detection of an error can serve as advance information about a subsequent event and it is this which accounts for the faster RTs of the correction response. However, the utilization of this

advance information is affected by the complexity of the coding necessary to transact an S-R event.

The pattern of results suggests that a unitary process is initiated by an error which is fundamentally inhibitory in both correction conditions. However, with a correction procedure the availability of advance information mitigates the posterror inhibition.

The major inference drawn from the finding of an interaction between the compatibility conditions and the correction procedures was a methodological one. Any generalizations made about the effect of compatibility on the rate of processing information are limited if they have not considered the correction procedure variable.

The final section of the paper was devoted to conjectures about possible mechanisms which could account for the inhibitory effects of an error on subsequent RTs. These were: 1) the single-channel concept and refractoriness, 2) the orienting reflex, and 3) response conflict.

APPENDIX A

INSTRUCTIONS

As you can see, the apparatus on the table consists of two parts. Notice 8 small lights on the backboard. Before you is a response panel which is made up of 8 buttons. These buttons will accommodate your fingers with the exception of your thumbs -- you will never use your thumbs to respond at anytime during performance on this apparatus. All eight lights and buttons will be used during the experiment. A relation exists between the lights and buttons such that when any particular light comes on only one button is the appropriate response. Any other button-response constitutes an error. As soon as you turn one light off another will appear, and so on, until the end of the run. [NONCORRECTION -- Any button will turn a light off, but remember only one button is appropriate; that is, only one response is correct. CORRECTION -- However, only the correct response will result in the next stimulus-light being presented. If you make an error the same light will always be repeated until you make the correct response. But there is one further distinction to keep in mind; you will find stimuli repeating themselves when you have not made an error. This is due to the random nature of generating the stimuli, such nonerror associated repetition can occur by chance. Remember then that repeated stimuli occur by chance and always following an error.] [DIRECT CORRESPONDENCE -- The relationship between the buttons and lights is one of spatial direct correspondence, i.e., the button which is directly before

APPENDIX A (Continued)

the light is the correct button. MIRROR IMAGE -- The relationship between buttons and lights is one of spatial mirror image, i.e., the correct response is the corresponding finger of the opposite hand to that over which the light is presented.]

As an aid, you will be given "feedback" during the first part of the run, i.e., every incorrect response will be accompanied with a "beep" over the earphones.

We are interested in precisely evaluating complex perceptual-motor performance over an extended period of time. Your task will be to respond to the appearance of a stimulus light by pressing the correct response button as quickly as possible. The only time you should respond is at the actual occurrence of each stimulus light. The strategy you should adopt is to respond correctly, as quickly as you can, to each stimulus light. This strategy is essentially a request for an individual to establish his optimal level of performance, i.e., his fastest speed of reacting compatible with maximally accurate responding. The "trade-off" between speed and accuracy is your judgment, but as an aid, I can give you an upper and lower bound. If you are making no errors -- you are going too slowly, if you are averaging more than one error out of 10 responses -- you are going too fast.

I now want to make some further specifications about the nature of the task. We are interested in discrete responses to stimuli,

APPENDIX A (Continued)

(i.e., button pushes to lights). There may be a tendency to push two buttons simultaneously. This type of responding contaminates the data and is to be avoided. Another important caution is to make sure you let up on a button before you make a subsequent response. Failure to do so results in two responses being made together and again constitutes a multiple response. Finally, it is very important for this study, that you maintain maximum motivation to perform at the task, with the instructions in mind, throughout the run. The runs are somewhat long and variability due to shifts in motivation and attention will confuse the issue with regard to the variables of interest in this study.

In summary:

1) NONCORRECTION -- Any response will turn off the stimulus light, but only one response is correct -- CORRECTION -- If you make an error, the same light will repeat until you respond correctly. A light may be repeated when you haven't made an error, but will always be repeated when you have made an error -- DIRECT CORRESPONDENCE -- The button directly before the light -- MIRROR IMAGE -- The corresponding button on the opposite hand from the light.

2) Individual. Discrete responses should be made and multiple responses avoided (2 buttons simultaneously or failing to lift a finger after a response).

3) You should strive to optimize your performance, i.e., responding correctly as rapidly as possible.

4) Your optimal level of performance should be maintained throughout the entire run.

Any questions?

APPENDIX A (Concluded)

To begin with, I will give a short series of trials on each button beginning with left hand most button. Remember, wait until each light appears and then respond as quickly as possible.

NONFEEDBACK. Throughout the rest of the run you will not be given any feedback over the earphones when you make an error. Therefore, you will have to constantly monitor your own performance in order to keep informed on the quality of your work.

Appendix B

TABLE B-I

Analysis of Variance of Transformed Reaction Times
of the Correction Procedure with the First Trial Excluded

Source	df	MS	F
Between subjects	23		
C (compatibility)	1	82,834	4.33*
Subj. w. groups	22	19,125	
Within subjects	164		
T (trials)	1	560	1.38
CxT	1	1,009	2.50
T x subj. w. groups	22	403	
RT (reaction time)	1	2,929	5.65*
CxRT	1	63	
RT x subj. w. groups	22	518	
I (interval)	1	23,763	13.41**
CxI	1	3,852	2.17
I x subj. w. groups	22	1,772	
TxRT	1	638	1.86
CxTxRT	1	841	2.46
TxRT x subj. w. groups	22	342	
TxI	1	1,027	1.77
CxTxI	1	10	
TxI x subj. w. groups	22	577	
RTxI	1	4,583	17.68**
CxRTxI	1	28	
RTxI x subj. w. groups	22	259	
TxRTxI	1	793	2.26
CxTxRTxI	1	166	
TxRTxI x subj. w. groups	22	350	

*p<.05
**p<.01

APPENDIX B (Continued)

TABLE B-II

Analysis of Variance of Transformed
Reaction Times of the Correction Procedure for the
Short Interval Direct Correspondence Condition

Source	df	MS	F
Between subjects	11	20,798	
Within subjects	60		
T (trials)	2	276,488	59.91**
T x subj. w. groups	22	4,615	
RT (reaction time)	1	4,576	2.86
RT x subj. w. groups	11	1,602	
TxRT	2	18,003	8.76**
TxRT x subj. w. groups	22	2,056	

**p < .01

APPENDIX B (Continued)

TABLE B-III

Analysis of Variance of Transformed
Reaction Times of the Correction Procedure for the
Long Interval Direct Correspondence Condition

Source	df	MS	F
Between subjects	11	22,883	
Within subjects	60		
T (trials)	2	239,781	130.46**
T x subj. w. groups	22	1,838	
RT (reaction time)	1	88,550	38.75**
RT x subj. w. groups	11	2,285	
TxRT	2	82,802	38.02**
TxRT x subj. w. groups	22	2,178	

**p < .01

APPENDIX B (Continued)

TABLE B-IV

Analysis of Variance of Transformed
Reaction Times of the Correction Procedure for
the Short Interval Mirror Image Condition

Source	df	MS	F
Between subjects	11	11,798	
Within subjects	60		
T (trials)	2	139,753	37.74**
T x subj. w. groups	22	3,703	
RT (reaction time)	1	1,810	1.31
RT x subj. w. groups	11	1,379	
TxRT	2	2,749	2.29
TxRT x subj. w. groups	22	1,199	

**$p < .01$

APPENDIX B (Continued)

TABLE B-V

Analysis of Variance of Transformed Reaction Times of the Correction Procedure for the Long Interval Mirror Image Condition

Source	df	MS	F
Between subjects	11	7,511	
Within subjects	60		
T (trials)	2	235,272	63.79**
T x subj. w. groups	22	3,688	
RT (reaction time)	1	61,075	40.23**
RT x subj. w. groups	11	1,518	
TxRT	2	3,688	1.84
TxRT x subj. w. groups	22	2,005	

**$p < .01$

APPENDIX B (Continued)

TABLE B-VI

Analysis of Variance of Transformed Reaction Times of the Correction Procedure for the Short Interval Direct Correspondence Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	13,691	
Within subjects	36		
T (trials)	1	184	
T x subj. w. groups	11	399	
RT (reaction time)	1	2,945	7.67*
RT x subj. w. groups	11	384	
TxRT	1	33	
TxRT x subj. w. groups	11	388	

*$p < .05$

APPENDIX B (Continued)

TABLE B-VII

Analysis of Variance of Transformed Reaction Times of the Correction Procedure for the Long Interval Direct Correspondence Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	13,584	
Within subjects	36		
T (trials)	1	469	
T x subj. w. groups	11	522	
RT (reaction time)	1	65	
RT x subj. w. groups	11	329	
TxRT	1	91	
TxRT x subj. w. groups	11	354	

APPENDIX B (Continued)

TABLE B-VIII

Analysis of Variance of Transformed Reaction Times of the Correction Procedure for the Short Interval Mirror Image Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	4,527	
Within subjects	36		
T (trials)	1	1,776	3.23
T x subj. w. groups	11	550	
RT (reaction time)	1	4,563	9.00*
RT x subj. w. groups	11	507	
TxRT	1	2,269	6.81*
TxRT x subj. w. groups	11	333	

*$p < .05$

APPENDIX B (Continued)

TABLE B-IX

Analysis of Variance of Transformed Reaction Times of the Correction Procedure for the Long Interval Mirror Image Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	4,200	
Within subjects	36		
T (trials)	1	176	
T x subj. w. groups	11	490	
RT (reaction time)	1	30	
RT x subj. w. groups	11	334	
TxRT	1	44	
TxRT x subj. w. groups	11	309	

APPENDIX B (Continued)

TABLE B-X

Analysis of Variance of Transformed Reaction Times to Repeated Stimuli (SRT, Correction Response, and Repetition Response)

Source	df	MS	F
Between subjects	23		
C (compatibility)	1	102,453	3.66
C x subj. w. groups	22	28,013	
Within subjects	120		
REP (repeated)	2	514,695	104.76**
CxREP	2	18,860	3.84*
REP x subj. w. groups	44	4,913	
I (interval)	1	54,406	3.09
CxI	1	39,896	2.09
I x subj. w. groups	22	17,614	
REPxI	2	63,622	8.81**
CxREPxI	2	1,503	
REPxI x subj. w. groups	44	7,222	

*p <.05
**p <.01

APPENDIX B (Continued)

TABLE B-XI

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure with the First Trial Excluded

Source	df	MS	F
Between subjects	23		
C (compatibility)	1	531,407	37.60**
Subj. w. groups	22	14,132	
Within subjects	164		
T (trials)	1	1,663	
CxT	1	128	
T x subj. w. groups	22	571	
RT (reaction time)	1	3,754	8.26**
CxRT	1	171	
RT x subj. w groups	22	454	
I (interval)	1	94,031	41.10**
CxI	1	8,229	3.59
I x subj. w. groups	22	2,289	
TxRT	1	3,242	10.70**
CxTxRT	1	664	2.19
TxRT x subj. w. groups	22	303	
TxI	1	366	
CxTxI	1	472	1.12
TxI x subj. w. groups	22	418	
RTxI	1	236	
CxRTxI	1	60	
RTxI x subj. w. groups	22	531	
TxRTxI	1	202	
CxTxRTxI	1	620	2.01
TxRTxI x subj. w. groups	22	307	

**$p < .01$

APPENDIX B (Continued)

TABLE B-XII

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure for the Short Interval Direct Correspondence Condition

Source	df	MS	F
Between subjects	11	11,742	
Within subjects	60		
T (trials)	2	12,428	21.96**
T x subj. w. groups	22	566	
RT (reaction time)	1	29,931	110.04**
RT x subj. w. groups	11	272	
TxRT	2	16,782	45.48**
TxRT x subj. w. groups	22	369	

**$p < .01$

APPENDIX B (continued)

TABLE B-XIII

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure for the Long Interval Direct Correspondence Condition

Source	df	MS	F
Between subjects	11	8,637	
Within subjects	60		
T (trials)	2	128	
T x subj. w. groups	22	392	
RT (reaction time)	1	1,440	5.49*
RT x subj. w. groups	11	262	
TxRT	2	728	4.31*
TxRTx subj. w. groups	22	169	

*p <.05

APPENDIX B (Continued)

TABLE B-XIV

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure for the Short Interval Mirror Image Condition

Source	df	MS	F
Between subjects	11	17,052	
Within subjects	60		
T (trials)	2	33,127	36.97**
T x subj. w. groups	22	896	
RT (reaction time)	1	58,084	39.92**
RT x subj. w. groups	11	1,455	
TxRT	2	38,260	67.72**
TxRT x subj. w. groups	22	565	

**p < .01

APPENDIX B (Continued)

TABLE B-XV

Analysis of Variance of Transformed
Reaction Times of the Noncorrection Procedure for the
Long Interval Mirror Image Condition

Source	df	MS	F
Between subjects	11	12,711	
Within subjects	60		
T (trials)	2	2,748	8.89**
T x subj. w. groups	22	309	
RT (reaction time)	1	12,168	23.08**
RT x subj. w. groups	11	527	
TxRT	2	5,064	19.10**
TxRTx subj. w. groups	22	265	

**p < .01

APPENDIX B (Continued)

TABLE B-XVI

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure Short Interval Direct Correspondence Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	7,925	
Within subjects	36		
T (trials)	1	180	
T x subj. w. groups	11	507	
RT (reaction time)	1	1,271	13.10**
RT x subj. w. groups	11	97	
TxRT	1	105	
TxRT x subj. w. groups	11	313	

**p<.01

APPENDIX B (Continued)

TABLE B-XVII

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure Long Interval Direct Correspondence Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	5,722	
Within subjects	36		
T (trials)	1	257	
T x subj. w. groups	11	279	
RT (reaction time)	1	158	1.26
RT x subj. w. groups	11	125	
TxRT	1	438	4.13
TxRT x subj. w. groups	11	106	

APPENDIX B (Continued)

TABLE B-XVIII

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure Short Interval Mirror Image Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	11,013	
Within subjects	36		
T (trials)	1	2,160	2.25
T x subj. w. groups	11	958	1.28
RT (reaction time)	1	1,680	
RT x subj. w. groups	11	1,316	
TxRT	1	3,710	5.87*
TxRT x subj. w. groups	11	632	

*$p < .05$

APPENDIX B (Continued)

TABLE B-XIX

Analysis of Variance of Transformed Reaction Times of the Noncorrection Procedure Long Interval Mirror Image Condition with the First Trial Excluded

Source	df	MS	F
Between subjects	11	8,180	
Within subjects	36		
T (trials)	1	32	
T x subj. w. groups	11	235	
RT (reaction time)	1	1,112	2.57
RT x subj. w. groups	11	432	
TxRT	1	475	2.81
TxRT x subj. w. groups	11	169	

APPENDIX B (Continued)

TABLE B-XX

Analysis of Variance of
Transformed Reaction Times From MC Matrix

Source	df	MS	F
Between subjects	47		
COR (correction)	1	98	
COMP (compatibility)	1	106,733	29.32**
CORxCOMP	1	21,570	5.93*
Subj. w. groups	44	3,640	
Within subjects	48		
I (intervals)	1	15,327	47.44**
CORxI	1	2,763	8.37**
COMPxI	1	2,450	7.42**
CORxCOMPxI	1	19	
I x subj. w. groups	44	330	

*p <.05
**p <.01

APPENDIX B (Continued)

TABLE B-XXI

Analysis of Variance of
Information Transmitted Scores

Source	df	MS	F
Between subjects	47		
COR (correction)	1	575	
COMP (compatibility)	1	477,567	11.34**
CORxCOMP	1	6,953	
Subj. w. groups	44	42,096	
Within subjects	48		
I (intervals)	1	6,224	
CORxCOMP	1	42,294	10.49**
COMPxCOR	1	3,788	
CORxCOMPxI	1	473	
I x subj. w. groups	44	4,033	

**p <.01

APPENDIX B (Concluded)

TABLE B-XXII

Analysis of Variance of
Rate of Information Transmitted Scores

Source	df	MS	F
Between subjects	47		
COR (correction)	1	24	
COMP (compatibility)	1	275,204	62.60**
CORxCOMP	1	23,188	5.27*
Subj. w. groups	44	4,396	
Within subjects	48		
I (intervals)	1	29,051	6.61*
CORxI	1	1,305	3.22
COMPxI	1	925	2.28
CORxCOMPxI	1	3	
I x subj. w. groups	44	405	

*p < .05
**p < .01

APPENDIX C

TABLE C-I

Common Log. Transforms and Standard Deviations of Posterrors (median), Matched Control (mean-of-medians), and Simple Reaction Time (means-of-medians) of Correction Procedure Condition. The Constant 2.200 has been subtracted from the means in the Table.

	Direct								Mirror Image							
	SRT		Trials						SRT		Trials					
			+1		+2		+3				+1		+2		+3	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Short Interval																
Posterror	.242	.113	.318	.111	.554	.063	.548	.067	.289	.132	.457	.102	.616	.052	.590	.030
Match Control			.397	.083	.536	.053	.534	.048			.466	.073	.583	.030	.585	.030
Long Interval																
Posterror	.223	.126	.254	.124	.524	.065	.533	.054	.220	.124	.305	.109	.564	.034	.559	.038
Match Control			.460	.039	.529	.058	.533	.055			.477	.045	.564	.037	.562	.031

APPENDIX C (Continued)

TABLE C-II

Common Log. Transforms and Standard Deviations of Posterrors (median) and Match Controls (means-of-medians) of Noncorrection Procedure Condition. The Constant 2.6050 has been Subtracted from the Means in the Table.

	Direct Trials						Mirror Image Trials					
	+1		+2		+3		+1		+2		+3	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Short Interval												
Posterror	.207	.055	.125	.049	.118	.047	.372	.066	.256	.065	.226	.055
Match Control	.105	.040	.112	.044	.111	.043	.225	.048	.227	.049	.231	.057
Long Interval												
Posterror	.095	.049	.093	.032	.082	.046	.226	.055	.186	.053	.179	.040
Match Control	.076	.034	.083	.035	.084	.038	.167	.041	.171	.041	.175	.044

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