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CONVERGING EVIDENCE FOR INFORMATION-PROCESSING STAGES: A COMPARATIVE-INFLUENCE STAGE-ANALYSIS METHOD *

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The isolation and identification of stages of information processing has been a goal of experimental psychologists for over 100 years. Several methodological procedures for pursuing this goal have been developed, but few attempts have been made to compare the results from the different methods. A new comparative-influence stage-analysis technique based on a combination of two earlier methods is proposed, and several experiments utilizing the new technique are reported. The overall results from the new stage-analysis method are quite consistent with those obtained from earlier methods and provide important converging evidence for the concept of stages of information processing. The new stage-analysis technique also provides a theoretical statement of the relationship between tachistoscopic and reaction time tasks, and illustrates the translatability of accuracy and speed as measures of human performance.

One of the earliest and most persistent issues in the field of experimental psychology concerns the analysis of mental processes into more elementary subprocesses or stages. It is therefore not surprising that many attempts have been made to discover suitable techniques for analyzing cognitive processes. Two of the most influential techniques for identifying mental stages or subprocesses are described below along with some of the major criticisms of each technique. Unfortunately, the two techniques have seldom been used to address the same processes, and thus most inferences about stages of processing have been based on a single methodological procedure with potentially limited generality. A new stage-analysis technique based on a combination of the previous techniques is proposed to provide converging evidence for the existence of information processing stages. The goal is to consider a

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technique that could possibly supplement, but not necessarily replace, the existing stage-analysis techniques. Several experiments utilizing the new technique are also reported and the conclusions of these experiments are examined in the context of the inferences derived from the previous methods of analyzing information processing stages.

Donder's subtractive technique

Over one-hundred years ago, Donders (1868) introduced a subtractive technique that he believed would not only allow a mental decomposition, but would also provide estimates of the duration of each component stage. Essentially Donders' method involves a comparison of the time required to perform two tasks that are presumed to differ in a single processing stage. The time difference between the two tasks is interpreted as the duration of the stage that is added to change one task into the other.

The subtractive technique for decomposing mental processes continued in use with slight modifications (see Boring 1950: 148–149, and Jastrow 1890) until about the turn of the century. At that time, reports from introspection experiments led to the conclusion that the nature of the entire task changed when an additional component was inserted into the processing sequence and consequently the technique was abandoned by many researchers (see Woodworth 1938: 302–309). It has recently been argued (*e.g.*, Taylor 1976) that there was (and still is) no persuasive objective evidence that insertion of an additional stage does in fact change the manner in which the task is performed, but the technique has nevertheless not been popular for many years. While Donders' technique is not explicitly accepted by many current researchers, his basic procedure has been utilized (without characterizing it as the subtractive method) in several recent studies (see Pachella (1974) for a brief review).

Sternberg's additive-factors technique

A technique introduced fairly recently by Sternberg (*e.g.*, 1969a, 1969b) was designed to be free of the difficulties perceived to be inherent in the subtractive procedure. Rather than attempting a comparison between two tasks that differ in the presence or absence of an entire stage, Sternberg's procedure attempts to compare two tasks differing only in the relative difficulty of a particular stage.

At least two assumptions seem to be involved in the application of this additive-factors technique to the investigation of stages of information processing. The first and most fundamental assumption is that information processing stages do exist and that the stage durations are independent such that the total time to perform a task is the sum of the durations of the component stages. (This assumption, of course, is also necessarily implicit in the Donders' technique.) The second assumption is that each stage is responsible for a different aspect of processing and hence each is selectively influenced by a different set of experimental factors. Two implications are immediately derivable from these assumptions. The first is that because stage durations are independent, factors that influence different stages will have independent (*i.e.*, additive) effects. The second implication is the converse of the first, namely that factors influencing the same stage will have dependent (*i.e.*, interactive) effects.

Given these assumptions, the procedure is fairly simple. An experiment is conducted in which two (or more) factors are simultaneously manipulated, and the pattern of reaction time results is used to make inferences about the organization of processing stages. If the two factors produce a statistical interaction, one concludes that both factors influence the same stage of processing. On the other hand, if the two factors do not interact and produce additive (independent) effects, one concludes that the two factors influence separate stages of processing.

This technique has been successfully employed with generally consistent results in a sizeable number of experiments (*e.g.*, Sanders 1977, 1980; Sternberg 1969a, 1969b, 1975), but it is subject to several criticisms. For example, Sternberg (1969a) and Taylor (1976) have pointed out that additive effects could be produced by factors influencing a single stage, *i.e.*, merely because two factors exert their influence on a common stage does not entail that their joint effect will be interactive rather than additive. It has also been argued (*e.g.*, Pachella 1974; Pachella *et al.* 1978; Wickelgren 1977) that because of uncontrolled error rates, reaction time cannot be considered as a meaningful constant-interval metric and thus may be inappropriate for evaluating the magnitude of differences as is required in the statistical tests of interactions in the additive factors technique.

A new technique of stage analysis

The proposed new method for investigating the organization of stages of information processing combines aspects of both the Donders and Sternberg techniques. The number of component stages is varied across tasks, and the relative difficulty of a particular stage is manipulated across conditions within each task. Comparisons in this technique consist of contrasting the magnitude of a factor's influence in two tasks that are presumed to differ in one or more stages of processing.

The manner in which inferences are drawn from these comparisons is portrayed in table 1. The entries in the left column represent possible outcomes when the same experimental factor is introduced in both tasks, and the entries in the middle and right columns indicate conclusions that may be drawn about the locus of the factor's effect. For example, the third row indicates that if a factor has an influence only in task 2, one can conclude that its effect was on stage (c) because that is the stage that differs between tasks 1 and 2.

Inspection of table 1 indicates that the proposed comparative-influence method relies on the assumption of stage insertion to account for the difference between tasks 1 and 2. To the extent that the operation of early stages (*e.g.*, stages (a) and (b)) is affected by the presence or absence of a later stage (*e.g.*, stage (c)), the present method will lead to incorrect inferences. However, if the stages are sequentially independent and capable of functional insertion and deletion, one would expect the conclusions from this method to be consistent with the conclusions from the additive-factors method. A comparison of the conclusions from the additive-factor and comparative-influence methods can

Table 1
Stage inferences from factor effects.

	Outcomes	Stages (a) + (b)	Stage (c)
(1)	$T1 = 0, T2 = T1$	No influence	No influence
(2)	$T1 > 0, T2 = T1$	Positive influence	No influence
(3)	$T1 = 0, T2 > T1$	No influence	Positive influence
(4)	$T1 > 0, T2 > T1$	Positive influence	Positive influence

Note: T1 is the time difference between two conditions in task 1, and T2 is the time difference between the same two conditions in task 2.

therefore be considered as a partial, *i.e.*, weak, test of the validity of the stage insertion assumption.

It should perhaps be noted that in one respect the new comparative-influence method can be considered to be a special case of Sternberg's additive-factors method. As in the additive-factors method, statistical interactions are used as the basis for making inferences about the organization of processing stages. The major difference between the two methods is that the present method incorporates a change in task as one 'factor' and an independent variable manipulation as the other 'factor', whereas the additive-factors method utilizes independent variable manipulations for all 'factors'.

Implementing the comparative-influence method is straightforward when the two tasks to be compared involve the same dependent variable. However, if different dependent variables are typically employed in the two tasks, comparisons become difficult or impossible. This represents a potentially serious problem with a contrast between a tachistoscopic task and a reaction time task since the former tasks typically are described with accuracy measures while the latter tasks generally involve results expressed in terms of a time variable.

One solution to the problem of providing a common scale of measurement in tachistoscopic and reaction time tasks is to obtain complete relationships between time and accuracy in both tasks and then make comparisons of time at a specific value of accuracy, or accuracy at a particular value of time. Because the stage-analysis methods are described in units of time, the preferred comparisons in the present context are time measures at some particular value of accuracy. (Note that this procedure, by controlling accuracy when making time contrasts, should also overcome the objection that reaction time is often not an interval variable capable of allowing interaction contrasts. A new objection, that comparisons at less-than-perfect accuracy may differ qualitatively, as well as quantitatively, from those made at perfect levels of accuracy, cannot be evaluated until systematic data from the proposed method are available.)

Because of a desire to integrate research findings from two distinct paradigms, the two tasks utilized in the current experiments were modified versions of a tachistoscopic discrimination task and a choice reaction time task. Both tasks were designed to yield a range of time and accuracy values such that the complete relationship between time and accuracy could be determined. The reaction time task was termed a response-limited task since the stimuli were presented until the subject made his response and it was the occurrence of the response that limited the information processing. This is essentially a speed-accuracy tradeoff experiment (*e.g.*, Pachella 1974; Wickelgren 1977; Wood and Jennings 1976) as desired reaction times were varied across trial blocks with the subject instructed to attempt to produce all of his responses within the specific time boundaries. The tachistoscopic task was termed a stimulus-limited task since the subject's processing was presumably controlled by the duration of the stimulus, and the subject had an unlimited time to respond. Stimulus duration was controlled by surrounding the stimulus by visual masking stimuli to minimize iconic persistence and limit processing time to the duration that the stimulus was exposed.

Not much is known about the relationship between tachistoscopic discrimination and choice reaction time, but intuitively it seems reasonable to suggest that a choice reaction time task involves all of the processes or stages required in a tachistoscopic discrimination task plus at least one additional stage concerned with the rapid selection and execution of a response. A response is still necessary to communicate the decision in the tachistoscopic discrimination task, but its latency is not a critical component as in the choice reaction time task. Because the selection and execution of the response necessarily follows the encoding and identification of the stimulus, the tachistoscopic and reaction time tasks reflect the activity of stages that are relatively early, or relatively late, in the processing sequence.

The feasibility of this new stage analysis technique was explored in a series of experiments manipulating a variety of factors presumed to exert their influence on several different stages of processing (*e.g.*, number of stimulus alternatives, stimulus-response compatibility, stimulus degradation, and stimulus discriminability). The method will be judged successful to the extent that it is able to localize the effects of these manipulations in an early information processing stage (involved in both stimulus-limited and response-limited tasks), or in a later information processing stage (occurring only in the response-limited task).

General method

Subjects

Three males and one female between the ages of 20 and 30 served as *S*s in experiments 1, 2, 4, 5, and 6. Forty naive college students served as *Ss* in experiment 2. The sequence of experiments varied across subjects with the exception that experiment 1 was the last experiment for all *S*s. Two sessions with 13 blocks of 20 trials each were administered prior to the first experiment for each *S* to reduce general practice effects.

Apparatus

A PDP 11/34 computer interfaced with a Minibee typewriter keyboard and a Tektronix 606 display monitor was used to present stimuli, monitor responses, and measure latencies. Responses were made by pressing the lower left ('Z') and lower right ('/') keys on the keyboard with the index fingers of the left and right hand, respectively.

Procedure

The stimuli varied across experiments, but all were constructed from a 10 by 14 dot matrix subtending a visual angle of approximately 30′ by 40′. Stimuli were randomly selected with equal probability in each experiment. In the response-limited task the stimuli were presented until a response was detected by the computer, and in the stimulus-limited task the stimulus duration was controlled by the experimenter via the computer. The pre- and post-stimulus masks in the stimulus-limited tasks consisted of a 10 by 14 matrix of dots presented for 500 msec immediately before and after the stimulus.

Following the response in each task the stimulus was presented again for 500 msec to provide accuracy feedback for the *S*'s response. Time feedback was also provided in the response-limited task by displaying a horizontal time line with two vertical lines indicating the fastest and slowest desired reaction times, and a vertical arrow representing the actual time taken to produce a response on that trial.

Experiments 2 through 6 involved one practice block of 20 response-limited trials, six experimental blocks of 20 response-limited trials, and six experimental blocks of 20 stimulus-limited trials. The sequence of tasks was varied across subjects, but all sequences were counterbalanced in the following manner: three blocks of one task with decreasing times (*i.e.*, stimulus exposure durations or desired reaction times), six blocks of the other task with three in decreasing and three in increasing times, and finally three blocks of the first task with increasing times. The stimulus durations in the stimulus-limited task were: 140, 120, 100, 80, 60, and 40 msec. The desired reaction times in the response-limited task were: 550 to 600, 500 to 550, 450 to 500, 400 to 450, 350 to 400, and 300 to 350 msec.

Experiment 2 involved five sessions per condition per *S*, and experiments 4 through 6 involved four sessions per condition per *S*. Experiment 3 had only one session per condition with different *S*s in each condition. The order of conditions in experiments 2, 4, 5, and 6 was balanced across sessions for each *S*.

Experiment 1

The first experiment was conducted to resolve some methodological problems associated with the determination of response-limited time-accuracy operating characteristics. The manner in which the response-limited time-accuracy operating characteristics are most conveniently characterized involves computing the least-squares linear regression equation between reaction time and accuracy and then using the slope and intercept values from this equation to predict a value of time corresponding to a particular level of accuracy. However, the identification of the slope and intercept parameters from linear equations involves several issues that should be considered before accepting the parameters at face value. One such issue is that at the present time there is no general agreement as to which measure of accuracy is the most appropriate (*e.g.*, Kantowitz 1978). A variety of accuracy measures have been employed (*e.g.*, d', $(d')^2$. Ht, log odds correct to incorrect), although Wood and Jennings (1976) conclude that "... to date no single transformation has been shown to provide consistently better fits to the empirical data than various alternatives" (1976: 94).

A second problem associated with the computation of slope and intercept parameters is that the least-squares linear regression procedures typically used to estimate these parameters are actually inappropriate when both the accuracy and the time variables are random and subject to error. The difficulty lies in determining along which axis the squared deviations are to be minimized when neither variable is fixed. Fortunately, this problem is not a serious one when the correlation between the x (time) and y (accuracy) variables is large because the regression of x on y is nearly the same as that of y on x and thus the amount of error in either direction is slight.

A third issue that raises potenttial problems with the computation of slope and intercept parameters is that the function is expected to have at least three segments with increasing reaction time first producing chance accuracy, then monotonically increasing accuracy, and finally perfect accuracy. Inclusion of observations from the lower (chance accuracy) and upper (perfect accuracy) horizontal segments in the linear equation will result in the underestimation of both the slope and the intercept parameters relative to the true values of the middle segment of the function. Two solutions have been proposed for this problem. One solution, suggested by Lappin and Disch (1972), employs Bogartz' (1968) technique for determining the point of intersection of two line segments to distinguish the middle segment from each horizontal segment. Unfortunately, this solution uses a least-squares regression procedure and assumes that the values of one variable are fixed and not subject to error. Therefore unless the x-on-y and the y-on-x regression lines are nearly identical for each segment of the function, the parameter estimates may be in error. A much simpler solution has been suggested by Wood and Jennings (1976) who advise that observations "... with accuracies very near chance or perfect performance ... be omitted from the process of fitting the data with linear (or alternative) equations" (1976: 102). In practice, most of the results from speed-accuracy experiments seem to lie within the range of 55% to 95% and thus the problem of including observations from the horizontal segments of the function in the computation of the tradeoff parameters typically has not presented any serious difficulties.

Four highly practiced *S*s attempted to produce response-limited time-accuracy operating characteristics by varying the speed and accuracy of their responses. The three issues discussed above were examined by determining: (a) the distribution of accuracy values; (b) the correlations between speed and accuracy; and (c) the appropriateness with which different accuracy measures described the data in the linear regression equations.

Method

Subjects

All *S*s had over 35 sessions, *i.e.*, approximately 4200 trials, of experience with variable-accuracy reaction time tasks as they participated in the experiments described later in this report before participating in this experiment.

Procedure

An experimental sessions consisted of seven blocks of trials with a practice block of 20 trials followed by six experimental blocks of 40 trials each. The stimuli in all blocks were the digits 0 and 1. Deadlines, indicating the fastest and slowest desired reaction times, were: 400 to 450 msec, 300 to 350 msec, 200 to 250 msec, 150 to 200 msec, 250 to 300 msec, and 350 to 400 msec across the six experimental blocks. *S*s were instructed to attempt to produce responses within the desired time periods regardless of the accuracy of the response. Eight sessions were completed within a two-week period.

Results and discussion

The empirical relationships between reaction time and accuracy for the four *S*s are portrayed in fig. 1. Each data point represents the mean reaction time and percentage correct for a single block of 40 trials. It can be seen that the majority of the data points for each *S* are within the accuracy range of 55% to 95% and that the data appear to fall along reasonably straight lines. Only one of the *S*s (No. 4) complied with the instructions to produce relatively slow reaction times; the other *S*s apparently preferred to perform at the minimum time consistent with reasonably high accuracy.

Regression functions based on all of the data were determined with several alternative accuracy measures. The correlation coefficients, indicating the precision of the fit of each function to the data, are listed in table 2. All correlations are fairly high, with approximately 50% to 80% of the reaction time variance predicted by knowledge of the accuracy level. Moreover, no accuracy measure seems to be

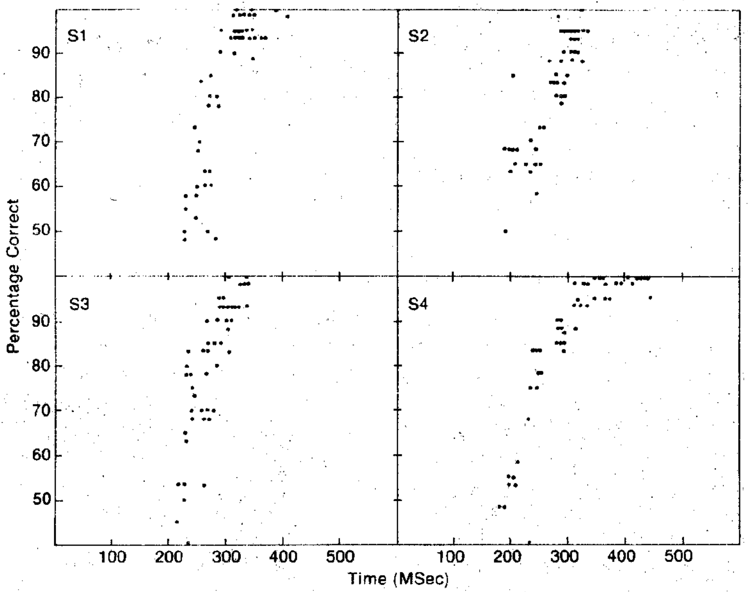

Fig. 1. Response-limited time-accuracy operating characteristics for the four subjects in experiment 1.

markedly superior to any other accuracy measure. This latter fact suggests that the choice of an accuracy measure depends more on convenience or theoretical bias than descriptive power.

The results of this experiment lead to the following conclusions: (a) empirical data largely fall within the middle monotonically increasing segment of the reaction

Table 2
Reaction time – accuracy correlations with five measures of accuracy.

Subject	Accuracy measure				
	Pc	d'	$(d')^2$	log odds	Ht
1	0.835	0.861	0.832	0.864	0.874
2	0.844	0.781	0.706	0.780	0.794
3	0.816	0.843	0.795	0.846	0.858
4	0.856	0.917	0.891	0.917	0.924

Note: Pc is percentage correct, d', is the signal detection theory measure of sensitivity, log odds is the logarithm of the ratio of correct to incorrect responses, and Ht is the information theory measure of information transmitted.

time-accuracy function; (b) the relationships between reaction time and accuracy are reasonably linear with moderate correlations in the 0.7 to 0.9 range; and (c) no single accuracy measure is clearly favored over any other measure, with the familiar measure of percentage correct serving to describe the data about as well as most of the more theory-dependent measures. In the remaining experiments, therefore, time-accuracy operating characteristics will be derived from the linear regression equation relating time and percentage correct responses.

Experiment 2

One of the most well-documented effects in the reaction time literature is that reaction time increases with an increase in the number of stimulus or stimulus-response alternatives. Additive-factor experiments (*e.g.*, Sternberg 1969b) have led to the conclusion that this manipulation influences both an early stage concerned with stimulus encoding and a later stage concerned with response selection and/or execution. This inference is based on the discovery that the number-of-alternatives factor interacts with a factor presumed to influence stimulus encoding (*i.e.*, stimulus degradation) and with a factor presumed to influence response selection (*i.e.*, stimulus-response compatibility).

If the stimulus-limited and response-limited tasks in the present series of experiments are distinguished by the presence of an additional stage concerned with response selection and/or execution in the response-limited task, the additive-factor results lead to an expectation of an outcome like that represented in row 4 of table 1. That is, both tasks should exhibit an effect of number of stimulus alternatives, but the size of the effect should be greater in the response-limited task than in the stimulus-limited task.

Method

Procedure

In this and all succeeding experiments 'condition' refers to the experimental manipulations being investigated, 'task' refers to the stimulus-limited or response-limited tasks, and 'time' refers to the specific time values (*i.e.*, stimulus exposure durations or desired reaction times) utilized in a block of trials. The present experiment therefore involves a two-alternative condition and a ten-alternative condition, each administered across six time values in two tasks. The stimuli in the ten-alternative condition were the digits 0 through 9, while those in the two-alternative condition were adjacent pairs of digits with different pairs presented on different sessions. This arrangement led to the 10 digits being equally probable across the five sessions with each condition.

In both conditions the odd digits (*i.e.*, 1, 3, 4, 7, and 9) were to be responded to with the right index finger (*i.e.*, the '/') key and the even digits (*i.e.*, 0, 2, 4, 6, and 8) were to be responded to with the left index finger (*i.e.*, the 'Z' key). Notice that this arrangement of conditions involves the manipulation of the number of stimulus alternatives while holding constant the number of response alternatives, *i.e.*, there were only two possible responses in both conditions.

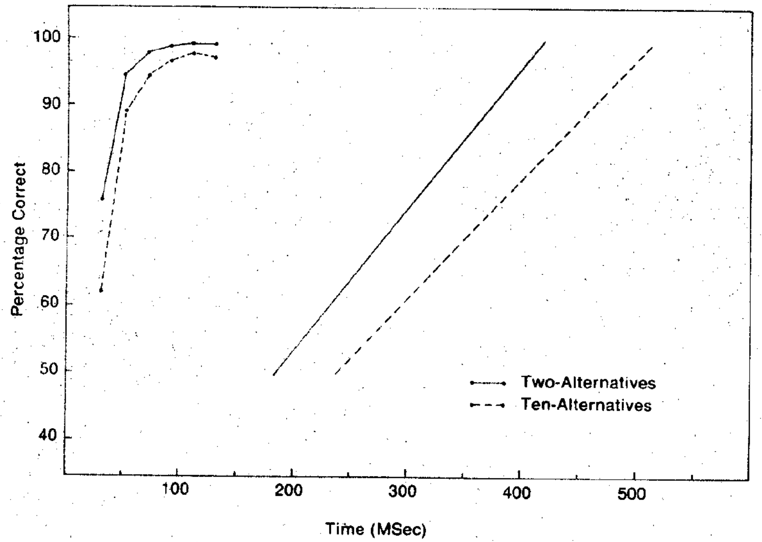

Fig. 2. Time-accuracy relationships in experiment 2. The stimulus-limited functions are on the left, and the response-limited functions are on the right.

Results and discussion

The primary data from this experiment consisted of mean percentage correct values for the stimulus-limited task and regression parameters for the response-limited task. The means of the percentage correct values and the regression lines for the four *S*s are portrayed in fig. 2.

Tests of the predictions from table 1 were conducted in the following manner. First, regression parameters were determined for each *S* in each task and condition and then used to predict the time that corresponded to 90% accuracy. (This particular accuracy value was somewhat arbitrary, but it had the desirable characteristic of falling within the range of actual accuracy values in both tasks.) Next, these predicted times were subjected to an analysis of variance to test the task X condition interaction (*i.e.*, T1 *vs.* T2). And finally, the time differences in the stimulus-limited task were evaluated in a *t*-test to determine if they were greater than 0 (*i.e.*, T1 *vs.* 0).

Regression parameters were computed in both tasks by using accuracy values to predict time. Since the functions in the stimulus-limited task asymptoted very early, only the first two (for three of the *S*s) or the first three (for the remaining *S*) exposure durations were included in the regression computations. Correlation coefficients, indicating the fit of the regression equations to the data, averaged 0.78 and 0.92 for the two-alternative and ten-alternative conditions in the stimulus-limited task, and 0.78 and 0.78 for these conditions in the response-limited task.

A repeated-measures analysis of variance on the predicted times at 90% accuracy revealed a significant task × condition interaction ($F(1,3) = 22.67$, $p < 0.05$). A *t*-test conducted on the data from the stimulus-limited task indicated that the predicted times from the ten-alternative condition were significantly greater than those from the two-alternative condition ($t(3) = 4.98, p < 0.05$).

The mean predicted times at 90% accuracy were 53 and 60 msec for the two- and ten-alternative conditions in the stimulus-limited task, and 355 and 414 msec for these conditions in the response-limited task.

These results indicate the $T1 > 0$, and $T2 > T1$. This corresponds to outcome (4) of table 1 and thus leads to the inference that the number-of-stimulus-alternatives factor influences both an early and a late information processing stage. An early stage is implicated because there is an effect of number-of-stimulus-alternatives in the stimulus-limited task, and a later stage is implicated because the factor effect is larger in the response-limited task than in the stimulus-limited task. The present technique and the additive-factor technique therefore are in agreement in concluding that two different stages are susceptible to manipulation of this factor. As Sternberg (1969a) mentioned, this conclusion is also consistent with the conclusions reached by Jastrow (1890) on the basis of his review and summary of the early work with the Donders' subtractive technique.

Experiment 3

Because the previous experiment employed a small number of highly practiced *S*s, there exists the possibility that the results do not generalize to naive *S*s. It is also possible that the entire method is limited to well-trained *S*s, and thus might have very restricted applications. The present experiment investigated these issues by repeating the previous experiment with naive *S*s tested for only a single session each.

Method

Subjects

Forty college students participated in a single experimental session to fulfill a course requirement in introductory psychology.

Procedure

The procedure was similar to experiment 2 with the exceptions that each *S* participated in only one condition, and the different two-alternative pairs were balanced across subjects with four *S*s receiving each digit pair.

Results and discussion

The major results are summarized in fig. 3. Regression lines were not computed from the response-limited data because of extreme variability probably attributable

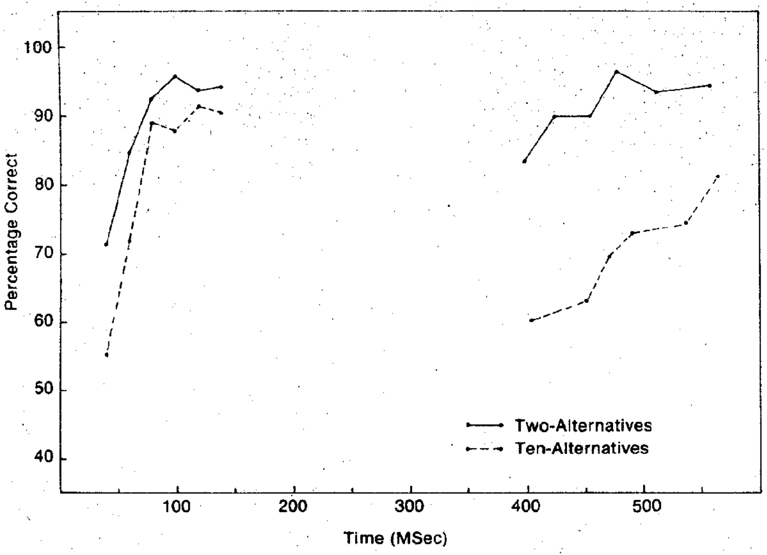

Fig. 3. Time-accuracy relationships in experiment 3. The stimulus-limited functions are on the left, and the response-limited functions are on the right.

to lack of practice. Instead the reaction times and percentage correct values were averaged for each experimental block, and these bivariate averages ordered from the fastest to the slowest reaction times.

No statistical tests were conducted on these data, but the results illustrated in fig. 3 suggest that the findings were qualitatively very similar to those of the previous experiment. Evidently neither the methodological procedure nor the general pattern of results is restricted to situations in which only very experienced *S*s are employed.

Experiment 4

Variations in the compatibility of the relationship between stimuli and responses have frequently been demonstrated to influence reaction time (*e.g.*, Smith 1968), and several additive-factor studies (*e.g.*, Biederman and Kaplan 1970; Broadbent and Gregory 1965; Sternberg 1969a) have led to the conclusion that this factor affects a relatively late information-processing stage concerned with response selection and/or execution. It is therefore expected that manipulation of this factor will lead to an outcome like that portrayed in row 3 of table 1. There should be no effect of stimulus-response compatibility in the stimulus-limited task, but a sizeable effect should be evident in the response-limited task.

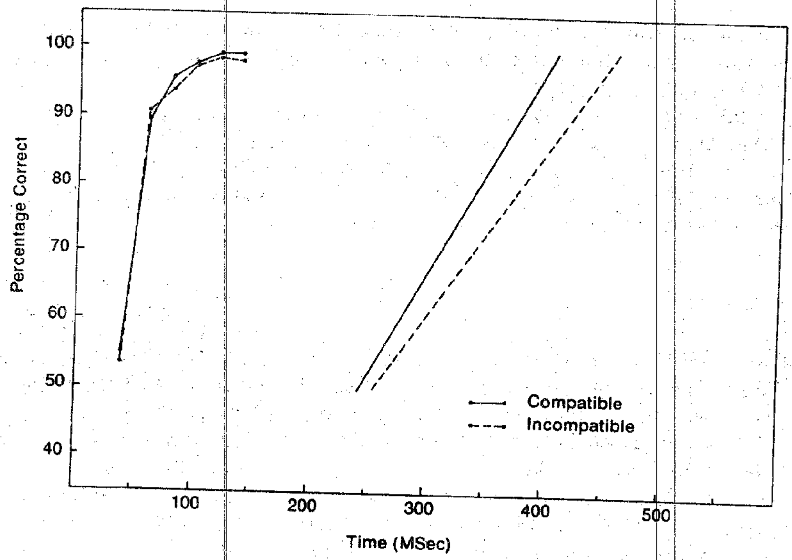

Fig. 4. Time-accuracy relationships in experiment 4. The stimulus-limited functions are on the left, and the response-limited functions are on the right.

Method

Procedure

The stimuli in this experiment consisted of diagonal arrows pointing to the lower left or the lower right. In the compatible condition the *Ss* were instructed to press the key in the location indicated by the arrow, but in the incompatible condition the opposite key was to be pressed. Thus, the left ('Z') key was to be pressed when an arrow pointing to the lower left appeared in the compatible condition, but the right ('/') key was to be pressed on the occurrence of this arrow in the incompatible condition.

Results and discussion

The empirical time-accuracy functions from the stimulus-limited task and the regression lines from the response-limited task are illustrated in fig. 4.

Correlation coefficients between the time and accuracy averaged 0.89 and 0.86 for the compatible and incompatible conditions in the stimulus-limited task, and 0.82 and 0.80 for these conditions in the response-limited task.

Analyses of the predicted times at 90% accuracy revealed a significant task X condition interaction ($F(1,3) = 62.63$, $p < 0.005$), and no significant difference between the compatible and incompatible conditions in the stimulus-limited task ($t(3) < 1.0$).

The mean predicted times at 90% accuracy were 60 and 61 msec for the compatible conditions in the stimulus-limited task, and 362 and 387 msec for these conditions in the response-limited task.

According to the terminology of table 1, these results indicate that T1 = 0 and T2 > T1. The results of this experiment therefore correspond to outcome (4) of table 1 and thus are consistent with the additive-factor conclusion that the stimulus-response compatibility manipulation affects a relatively late information processing stage concerned with response selection and/or execution.

Experiment 5

Several additive-factor experiments (*e.g.*, Meyer *et al.* 1975; Sanders 1980; Schwartz *et al.* 1977; Sternberg 1967) have yielded apparently inconsistent results when the factor of stimulus degradation (*i.e.*, irrelevant stimulation superimposed on the target stimulus) have been manipulated. For example, Sanders and Schwartz *et al.* found that the degradation factor does not interact with the factor of stimulus intensity, implying that the two factors influence separate stages. Moreover, Sternberg (1967) found that degradation interacted with a factor presumed to influence the comparison stage when *S*s were unpracticed, but after a session of practice it exhibited an additive effect. And finally, Meyer *et al.* reported that stimulus degradation interacts with associative priming, a factor presumed to be related to a relatively late stage of semantic analysis. The precise locus of this manipulation is therefore not yet established, and the current technique may prove helpful in determining which stage is primarily influenced by stimulus degradation. If it is an early stage such as encoding, then both the stimulus-limited and response-limited tasks should exhibit an approximately equal effect of stimulus degradation. However, if a later stage such as comparison or decision is the locus of the effect, and if this stage is not involved in the stimulus-limited task, then the manipulation should have an influence only in the response-limited task.

Method

Procedure

The stimuli in this experiment were either intact or degraded versions of the digits 0 and 1. The degraded versions were produced by superimposing 12 additional dots in the digit display as illustrated in fig. 5. *S*s were instructed to press the left ('Z') key when a 0 appeared and to press the right ('/') key when a 1 appeared.

Results and discussion

Fig. 6 illustrates the empirical time-accuracy functions for the stimulus-limited task and the regression lines for the response-limited task.

Correlation coefficients between time and accuracy averaged 0.46 and 0.67 for the intact and degraded conditions in the stimulus-limited task, and 0.77 and 0.79 for these conditions in the response-limited task. One probable reason for the low

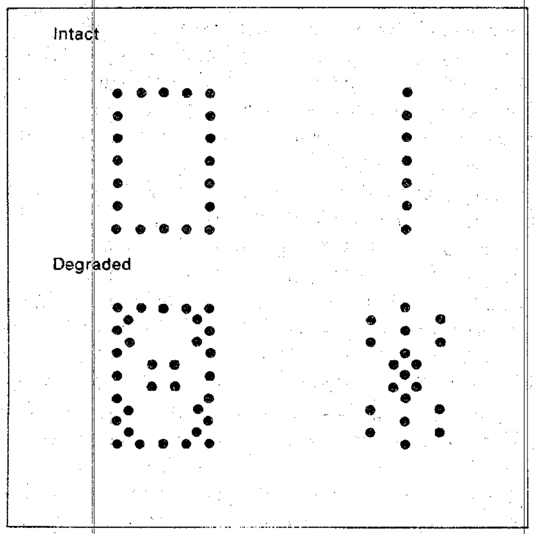

Fig. 5. Illustration of stimuli in the intact and degraded conditions in experiment 5.

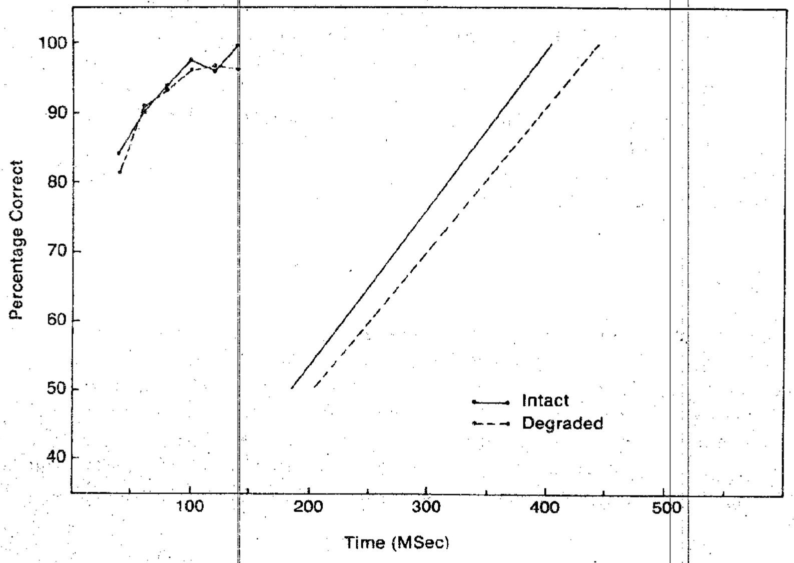

Fig. 6. Time-accuracy relationships in experiment 5. The stimulus limited functions are on the left, and the response-limited functions are on the right.

correlations in the stimulus-limited task is the restricted range of accuracy caused by the very high accuracy levels even in the shortest exposure durations (see fig. 6).

Statistical analyses of the predicted times corresponding to 90% accuracy indicated a significant task × condition interaction ($F(1,3) = 16.03$, $p < 0.05$) and no significant difference between the intact and degraded conditions in the stimulus-limited task ($t(3) = -2.91$, $p > 0.05$).

The means of the predicted times were 57 and 53 msec for the intact and degraded conditions in the stimulus-limited task, and 353 and 378 msec for the intact and degraded conditions in the response-limited task.

Expressed in the terms of table 1, these results indicate that $T1 = 0$, and $T2 > T1$. The present results therefore conform to outcome (3) of table 1 and lead to the conclusion that stimulus degradation does not influence the early stage of stimulus encoding. This conclusion is somewhat surprising, but a recent experiment (Salthouse and Somberg 1979) utilizing different target and mask stimuli replicated the result that a constant superimposed degradation pattern had no effect on tachistoscopic discrmination performance. Moreover, this inference is not inconsistent with some of the other additive-factors results. The Sanders (1980) and Schwartz *et al.* (1977) discovery that stimulus intensity and stimulus degradation produced additive effects can be interpreted as indicating that the intensity manipulation affected the encoding stage, while the degradation manipulation affected a later stage concerned with comparison or decision. The results of Johnsen and Briggs (1973) are also consistent with this interpretation as they found that the factors of stimulus degradation and response type, which is presumed to influence the decision stage, produced an interaction. However, it should be noted that Sternberg (1967) found an additive effect when these same two factors were simultaneously manipulated. An alternative interpretation of the lack of an interaction between stimulus intensity and stimulus degradation is that both of these factors influence separate perceptual stages. For example, Sanders (1980) has proposed three distinct perceptual stages corresponding to preprocessing (sensitive to stimulus intensity), feature extraction (sensitive to stimulus degradation), and identification (sensitive to stimulus discriminability).

Experiment 6

The failure to find an effect of stimulus degradation in the stimulus-limited task was surprising, and raises the possibility that no factor can be identified that exerts its influence only in an early stage of processing involved in both the stimulus-limited and response-limited tasks. An attempt was therefore made to manipulate a factor that would lead to an outcome like that of row 2 in table 1, implicating only an early information-processing stage. The factor selected was stimulus discriminability, the extent to which two stimuli could be distinguished from one another.

Method

Procedure

The stimuli consisted of a single vertical line located either to the left or right of a center dot. The task was to press the left ('Z') key when the line was to the left of the dot, and to press the right ('/') key when the line was to the right of the dot. In the low discriminability condition the distance of the vertical line from the center dot was approximately 3′, while in the high discriminability condition the distance was approximately 9′.

Results and discussion

The major results consisting of the empirical and regression-derived time-accuracy functions for the stimulus-limited and response-limited tasks, respectively, are summarized in fig. 7.

Mean correlations between time and accuracy were 0.80 and 0.79 for the high and low discriminability conditions in the stimulus-limited task, and 0.84 and 0.87 for these conditions in the response-limited task.

An analysis of variance on the predicted times at 90% accuracy revealed that the task × condition interaction was significant ($F(1,3) = 15.03$, $p < 0.05$). The t-test assessing the difference between the high and low discriminability conditions in the stimulus-limited task was also significant ($t(3) = 4.18, p < 0.05$).

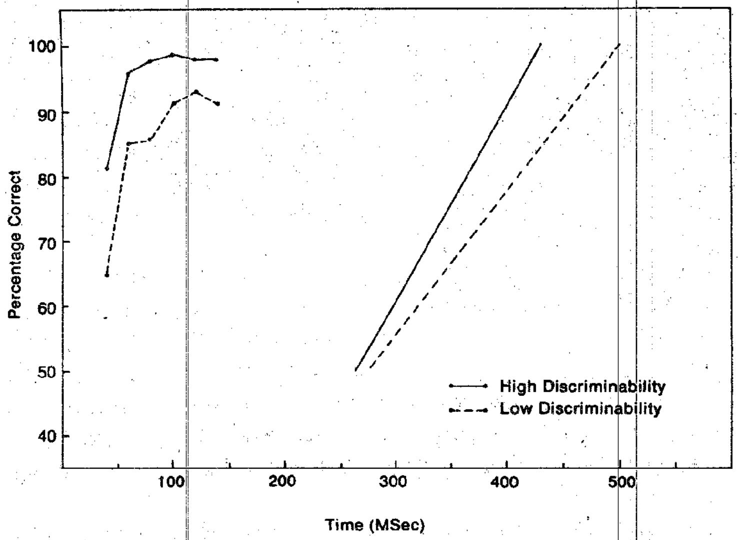

Fig. 7. Time-accuracy relationships in experiment 6. The stimulus-limited functions are on the left, and the response-limited functions are on the right.

The mean predicted times at 90% accuracy were 52 and 60 msec for the high and low discriminability conditions in the stimulus-limited task, and 380 and 416 msec for these conditions in the response-limited task. In the terminology of table 1, these results can be expressed as T1 > 0, T2 > T1. This corresponds to outcome (4) of table 1 and leads to the inference that stimulus discriminability has an influence both on an early stage present in both the stimulus-limited task and the response-limited task, and on a late stage present only in the response-limited task.

The inability to demonstrate an equal magnitude effect in both the stimulus-limited and response-limited tasks leaves open the possibility that no factor can be identified that exerts its influence only in an early stage of processing. If future studies are also unsuccessful in identifying such a factor, one might be tempted to question the validity of the stage insertion assumption. At the present time, however, it seems reasonable to accept, at least tentatively, the inference that the factor of stimulus discriminability does indeed influence at least two distinct processing stages.

General discussion

The major inferences from these experiments can be easily summarized. The factors of stimulus-response compatibility and stimulus degradation affect a late stage present only in the response-limited task, and the factors of stimulus discriminability and number-of-stimulus-alternatives have an influence on both an early and a late stage of processing. In most respects this assignment of factors to stages is consistent with the interpretations from additive-factor experiments (*e.g.*, Sanders 1977; 1980; Sternberg 1969b). The only discrepancy seems to concern the factor of stimulus degradation, and inconsistencies in earlier experiments (*e.g.*, Johnsen and Briggs 1973; Meyer *et al.* 1975; Sanders 1980; Schwartz *et al.* 1977; Sternberg 1967) make its localization uncertain in the additive-factor framework.

The similar outcomes from the additive-factor method and the current comparative-influence method provide impressive converging evidence for the concept of processing stages. This is not a trivial finding since problems associated with each method by itself have the potential to invalidate the findings from a single technique. Determining that the same general pattern of results is obtained with independent procedures therefore increases one's confidence in the reality of stages of processing.

The confirmation of the earlier conclusions from additive factor experiments also indicates that the criticism of the stage insertion assumption is not fully justified. The present results suggest that, at least under some circumstances, it can be assumed that an additional stage inserted late in the processing sequence does not affect the processing carried out in stages earlier in the sequence. The results from experiments 4 and 5 in which the factors of stimulus-response compatibility and stimulus degradation had no effects in the stimulus-limited task but sizeable effects in the response-limited task support this assertion. Even stronger evidence for the insertion assumption would have been provided had a factor been discovered that produced an outcome like that of outcome (2) in table 1, *i.e.*, producing the same magnitude of effect on both the stimulus-limited and response-limited tasks. However, the present failure to identify such a factor cannot be interpreted as decisive evidence against the insertion assumption; it may be that most factors that influence an early stage do generally also influence a later stage. At the very least, the present results suggest that the insertion assumption needs to be examined on an individual, case-by-case, basis, and not merely rejected as a general and universal 'fallacy' without direct objective evidence.

An interesting discovery in these experiments concerns the nature of the processing in the stimulus-limited task. The factors of stimulus discriminability and number-of-stimulus-alternatives had an effect on performance in this task, but the factor of stimulus degradation did not. The stage or stages involved in the task must therefore contain operations which are susceptible to the quantity and distinctiveness of the stimuli, but which are unaffected by their quality. The establishment of a distinct representation of the stimulus is apparently facilitated when stimuli are highly discriminable, and when there are only a small number of possible stimuli that can be presented. However, the absence of a degradation effect in the stimulus-limited task suggests that identification occurs after the stimulus representation is created. This implication that a stage of forming a stimulus representation occurs prior to a stage in which the representation is identified, and that it is only the former stage that is involved in visual masking situations, should be investigated further.

An additional feature of the present application of the comparative-influence stage analysis technique is that it serves to integrate a large body of literature involving speed and accuracy dependent variables, and reaction time and tachistoscopic experimental tasks. The generation of complete time-accuracy functions makes the particular dependent variable merely a matter of theoretical preference or convenience since the time and accuracy measures can be interchanged once the empirical relationship between the two is known. The current results supporting the notion that reaction time tasks consist of all of the stages involved in tachistoscopic tasks *plus at least one additional stage* also broadens the data base from which one can draw when attempting to make speculations about stages of information processing by including the vast literature on tachistoscopic perception within the realm of stage-relevant research. It therefore seems reasonable to conclude that the current stage-analysis technique represents a substantial extension, and not merely a minor modification, of the previous subtractive and additive-factor stage-analysis techniques.

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