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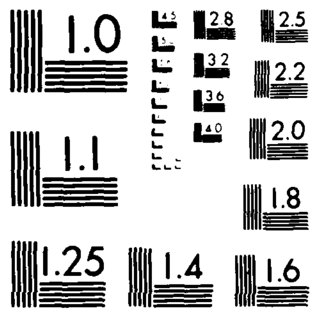

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BINARY CLASSIFICATION AND THE SUBTRACTIVE APPROACH

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Air Force Aerospace Medical Research Laborotory

SEPTEMBER 1983

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief, Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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Two experiments were performed using a modification of the subtractive approach to the partitioning of human reaction time. This investigation provided information concerning the effects of display size, classification rules, and interference stimuli on input and output latencies. The major findings from this investigation showed that input and output latencies were affected by different independent variables and provided information regarding the cognitive processes within a binary classification task not observed with previous methods. Suggestions for further research are presented.

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SUMMARY

This report describes two experiments designed to extend and refine the within-task subtractive (WITS) method of partitioning choice reaction time. The ability to provide separate and independent temporal measures of cognitive processes allows for a more complete and accurate assessment of factors which influence human performance, e.g., workload, display coding, display and control layout.

Experiment I provides information concerning the effects of different stimuli and hand of response on input and output latencies. In addition, this experiment served as a check on between group differences for Experiment II. Experiment II was designed to assess the effects of display load, classification rules, proportion of targets, display location, and interference stimuli on human performance.

In Experiment I the subject viewed two randomly presented stimuli, "x" and "initiate", on the display terminal. The subject was instructed to respond rapidly to the onset of the stimulus by depressing and releasing a response key until the stimulus disappeared.

The stimulus in Experiment II was a set of two distinct and sequentially presented columns of X's and O's which appeared in different locations on the display. In some trials, an interference stimulus occurred between the onsets of the two columns. The subject's task was to classify the stimulus according to one of two decision rules based on the proportion of X's, or targets, appearing in the columns, and to depress the target or nontarget key a number of times determined by the decision rule used. The between group factor was display load size.

The dependent measures analyzed for Experiments I and II were the latency of the first response, the mean of the subsequent response latencies (output latency), and the difference between the first response latency and the mean output latency for correct responses. The conclusions based on these analyses were: (1) some type of hemisphere difference between hand used for responding and the processing of verbal material may exist (Experiment I); (2) output latencies are influenced by hand used to respond (Experiment I); (3) the percent of correct responses decreases with increased display load and presence of an interference stimulus (Experiment II); (4) display load and proportion of target items influence the first response latency (Experiment II); (5) a .50 proportion of targets is the most difficult condition to process (Experiment II); (6) the processing of the different display loads appears to be in different stages when the interference stimulus occurs (Experiment II); (7) there appear to be different processing strategies for the various target proportion levels (Experiment II); and (8) the results confirm the advantage of using the within-task subtractive (WITS) method over the single response method (Experiment II).

The within-task subtractive (WITS) method of partitioning input and output functions of cognitive processing is recommended in all cases where reaction time measures can be obtained. This procedure provides valuable information that may be masked or lost using traditional partitioning methods.

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PREFACE

This work was performed for the Human Engineering Division, Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433, in support of Project 71842701, C^3 Operator Performance Engineering. The research was sponsored by the Air Force Office of Scientific Research/AFSC, United States Air Force, under Contract F49620-82-C-0035 for the Summer Faculty Program.

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SECTION I
INTRODUCTION

Reaction time measures have been used to estimate the number (Briggs, 1972), rate of processing (Sternberg, 1968) and duration (Donders, 1868; Teichner, 1979) of cognitive processes. The present investigation is primarily concerned with a methodology that partitions reaction time into components which estimate the duration of the cognitive processes involved in human performance. However, while the primary concern is with the methodology, additional empirical statements and theoretical advances are developed.

CURRENT METHODOLOGIES

A review of the literature (Patchella, 1974) has identified two different approaches in the use of reaction time. The additive factor approach (Sternberg, 1969; 1969b) suggests that relative changes in the duration of mental processes can be estimated with a regression technique. Using a task specifically designed to test this proposal, subjects were required to remember a small number of items called the positive set. A series of items were presented to the subjects who were required to respond with "yes", if the item was a member of the positive set, or "no", if it was not. Using the regression notion, the model proposed was:

$$RT = A + M(X) \qquad (1)$$

where A represents that portion of the latency associated with the processing involved in stimulus encoding, response selection, and response execution; while M represents the processing time per element, or the central processing time per item; and X represents the number of items in the positive set. While several problems and criticisms of the additive factor method have been noted (Patchella, 1974; Taylor 1976), its major deficiency for human performance rests with the fact that independent estimates of the stages cannot be determined. That is, with the additive factor approach the only latency measure available is the total latency associated with each response. *Consequently, separate measures of each stage cannot be determined.*

The subtractive approach (Donders, 1868) suggests that the duration of a cognitive process can be estimated by subtracting the reaction times obtained from two different tasks, where one task involves an additional cognitive process that is lacking from the other task. The difference between the latencies resulting from each task can then be used as an estimate of the duration of the particular cognitive process under investigation. The major problem associated with this approach is determining whether one task in fact does not require the cognitive process under investigation.

A refinement of that approach, proposed by Teichner (1979), appears to avoid that problem. The procedural modification involves the presentation of a matrix of stimuli, where each stimulus must be identified by separate and sequential responses. Using this procedure, the latency from the onset of the matrix to the performance of the first response is always longer than the latencies between any of the remaining sequential responses. Teichner (1979) suggested that the longer first response latency was the result of additional processing times that are missing from the remaining response latencies. Specifically, because the matrix is not physically available for processing after the first response, all response latencies after the first response do not reflect processes required to encode and process the information into memory. That is, the latencies associated with these responses reflect only output processing. Following Donders' lead, separate times can be derived for the encoding and processing functions, and the output functions by subtracting the mean of the latencies associated with each sequential response performed after the first response from the first response latency.

The shortcoming of the additive factor approach does not appear to pose a problem for the subtractive approach (Teichner, 1979). Traditionally, the additive factor approach has been applied to binary classification tasks, while the modification of the subtractive approach proposed by Teichner (1979) has been applied to identification tasks. Corso and Warren-Leubecker (1982) have adapted the Teichner modification and applied it to binary classification tasks. Their procedure involves the use of a matrix of stimuli in which each stimulus is to be classified as either a positive set stimulus, or a negative set stimulus. If all the stimuli in the matrix are from the positive set, the positive set key is depressed a number of times equal to the number of positive set stimuli. Likewise, if the stimuli in the matrix are all from the negative set, the negative set key is depressed a number of times equal to the number of negative set stimuli in the matrix. In cases where some of the stimuli are from the positive set and some are from the negative set, the appropriate key is depressed successively for the number of times equal to the appearance of those stimuli in the matrix. While the procedure has only been used with a matrix of two stimuli, there does not appear to be any reason why this procedure cannot be used for larger matrices of stimuli.

Corso and Warren-Leubecker (1982) have demonstrated the validity of their approach against the classical Sternberg procedure. The results of their investigation have demonstrated the superiority of the Teichner modification over the Sternberg procedure. Specifically, the Teichner modification eliminates some masking effects that occur with the Sternberg procedure, and it allows for the independent assessment of the effects of the independent variables on input and output latencies.

OBJECTIVES

The present investigation was concerned with extending the modification of the subtractive approach in five different ways. Specifically, two experiments were designed to assess the effects of:

(1) display loads on input and output processing times;

(2) interference stimuli that occur between the onset and offset of the display;

(3) different decision rules on the dependent variables;

(4) different kinds of stimuli on input and output items; and,

(5) the proportion of target items on input and output times.

SECTION II
EXPERIMENT 1

The purpose of this experiment was to provide information concerning the effects of different stimuli and hand of response on input and output latencies. In addition, this experiment was performed as a check on between group differences since the participants were going to be subjected to a between-subject variable in the second experiment.

It was hypothesized that different stimuli should result in changes in input latencies with no corresponding changes in output latencies. Likewise, the hand used to perform the response should alter output latencies with no changes in the input latencies.

METHOD

Subjects

Sixteen paid volunteers from Systems Research Laboratories (SRL) and DOD participated. Each subject was placed in one of two groups with the restriction that an equal number of males and females were in each group.

Equipment

Since details of the equipment and computer programs used to present the stimulus and r[illegible] the responses are presented in another report (Kelly, Corso, and Bridges, 1982), only a brief descriptio[illegible] be given. A VT-11 graphic display terminal, driven by a PDP 11/34 minicomputer, was used to present the stimuli. The response panel consisted of two keys. Upon depression of a response key, both the latency and identity of the key depressed was stored. The subjects' chamber was *the Shielded Experimental* room of the COPE facility at AFAMRL/HEC.

Design

In order to assess between-group differences in addition to the hand of response and stimulus material differences a split-plot experimental design was employed. Two levels were used for each of the three independent variables: (a) subject group assignment; (b) hand used to respond; and, (c) stimulus material. The dependent measures were the latency to the first response, the mean of subsequent response latencies (output latency) and the difference between first response latency and the mean output latency for each subject (input latency).

Stimulus

The letter "X" and the word "INITIATE" were the stimuli. One of the stimuli was presented in the center of the VT-11 display unit until the subject performed 10 key presses. The two different stimuli were presented in a random order over 20 trials.

Procedure

The subject was instructed to respond as rapidly as possible to the onset of the stimulus. The response was performed by depressing and releasing one of the two response keys until the stimulus disappeared. Unknown to the subject, the stimulus was turned off after the tenth key-press. After ten stimulus trials the subject was instructed to change both response hand and key. The right key was depressesd with the index finger of the right hand, while the left key was depressed with the index finger of the left hand. The key used first was counterbalanced between subjects.

RESULTS AND DISCUSSION

The first response latency and subsequent response latencies were subjected to separate three-way ANOVAs (group to be placed in by hand by stimulus). The analysis of the latencies associated with the first response showed a significant interaction between the stimulus material and the hand used to perform the response, $F(1,14) = 5.10$, $p < .05$. This interaction showed no difference in latency between the right and left responses when the stimulus was the letter "X". However, when the stimulus was the word "initiate" the latency for the right response was shorter, by approximately 11 percent, than that for the left response (361 ms versus 403 ms). This finding may suggest some type of hemisphere differences between the hand used for responding and the processing of verbal material.

The output latencies were influenced by the hand used, $F(1,14) = 37.73$, $p < .01$. The right hand key was depressed faster than the left hand key (171 ms versus 209 ms). This finding was expected since only right-handed subjects were used.

Following Teichner's approach, a subsequent analysis was performed on the input latencies, where the input latency is the first response latency minus the mean of the subsequent key presses for each trial. No significant main effects were observed. The significant interaction observed in the analysis of the latencies of the first response, between stimulus material and hand used to perform the response, was not observed in this analysis. The lack of an interaction is discussed in depth in the general discussion section.

SECTION III
EXPERIMENT 2

The task used in this experiment was a binary classification in which the subject viewed a column of X's and O's. If the quantity of X's equalled or exceeded a critical proportion, the target key was depressed a number of times equal to the number of target items. If the quantity of X's did not equal or exceed the critical proportion, the nontarget key was depressed a number of times equal to the number of nontarget items. The proportion of target items, the critical proportion or decision rule, and display load were systematically varied. Within a trial, two distinct columns of target items appeared in two locations (one to the left, the other to the right of the display center). In some of the trials, an interference stimulus occurred between the onset of the columns at the two locations. Therefore, this experiment was designed to assess the effects of display load, classification rules, proportion of targets, display location, and interference stimuli on human information processing using the within-task subtractive methodology (Teichner, 1979). Specifically, it was hypothesized that display load would influence input but not output latencies. Since the response categories were constant, changes in the display should effect only those processes involved with encoding and organizing the displayed information into memory.

The rule used by the subject to classify the stimuli should only influence the input latency. Since the number of response classes remains constant there does not appear to be any reason for suggesting that the classification rule should influence the output latency. Likewise, the proportion of targets should have an influence on the input latencies. The greater the proportion of targets the longer the input latency. This is in line with Hick's (1952) Law. However, since the proportion of targets is, by design, confounded with the proportion of nontargets, the resulting function may show a nonlinear trend. The notion is that the processing takes into account the relative differences between the number of target and nontarget items.

Since the number of responses to be performed and which response to select are also determined by the proportion of targets, there could be an influence of this variable on output latency. However, no specific hypothesis concerning these variables is proposed.

The interference stimulus randomly occurred after the onset of the left display and continued into the left display response interval for half the trials. The variable should have two effects. First, it is expected that the input latency will be increased by this stimulus. The onset of this stimulus should occur while the displayed information is being processed. However, it is conceivable that an interaction between display load and the interference stimulus could occur. Since different kinds of processing may occur within the binary classification task and the duration of those different types of processing varies as a function of display load (Briggs and Swanson, 1970), the interference stimulus could have no effect or a beneficial effect on the processing of a small display load and an inhibitory effect on a large display load. Second, since the interference stimulus occurs within the response interval, this variable could serve to either disrupt or facilitate responding as measured by the output latency.

METHOD

Subjects

The same participants used in the first experiment were retained.

Equipment

The equipment from the first experiment was used. In addition, a bell on the console was used for the interference tone.

Design

A 2×2×3×2×2 split-plot design was used. The between-subject factor was the display load of either four or eight items. Within-subject factors were: (a) the proportion of target items (.25, .50, and .75); (b) the decision rule used to classify the stimuli (50 and 75 percent); (c) the presence or absence of an interference tone; and (d) the location of the displayed items. The dependent measures were accuracy, first response latency, and subsequent response latency.

Procedure

One group of subjects viewed four stimuli while the other group of subjects viewed eight stimuli. For both groups of subjects, the stimuli were the letters X and O, with X being designated as the target. The letters were arranged as a column and the columns appeared sequentially, first at a position to the left of center of the display, and then to a position to the right of center of the display. The duration of each column was 25 ms and the interval between their onsets was 3.5 sec.

The interference tone, if it did occur, occurred 225 ms after the onset of the first column, and continued in a pulsed fashion for 1.5 sec. It had a probability of occurrence of .50. The onset of the first column occurred 3.5 sec after the onset of the second column. Each column could contain 25, 50, or 75 percent X's. In other words, the subjects viewing a display size of four saw one, two, or three X's with three, two, or one O's, respectively; and, the subjects viewing a display size of eight saw two, four, or six X's with six, four, or two O's, respectively.

For both display conditions the subjects used two different decision rules to classify their response. For decision rule-1, the subjects were instructed to press the key designated as the target key if the proportion of X's in the display was equal to or greater than 50 percent of the total number of items. The target key was to be depressed a number of times equal to the number of X's that appeared. If the proportion of X's did not equal or exceed 50 percent of the total number of items displayed, the nontarget key was to be depressed a number of times equal to the number of nontarget items displayed. For decision rule-2, the proportion of items changed so that the proportion of X's had to equal or exceed 75 percent of the total number of items displayed before the target key was to be depressed. The proportion of target items displayed was .25, .50, and .75 of the total number of items and they occurred with a probability of one-third.

A response was required immediately after the onset of the first display and after the onset of the second display. Each subject viewed 144 trials in both decision rule conditions. The decision rule used first was counterbalanced between subjects. The trial stimulus, for both the four and eight item displays, was selected from the following pairs of target proportions: (.75, .75); (.75, .50); (.75, .25); (.50, .75); (.50, .50); (.50, .25); (.25, .75); (.25, .50); and (.25, .25). The two entries in a pair represent the proportion of target items in the first and second columns as they appeared in the left right sequence of the stimulus presentation of a trial. Each pair randomly appeared 16 times under both decision rule conditions. The interference tone was present in eight of the 16 trials. The response was performed by depressing the right key with the index finger of the right hand and the left key with the index finger of the left hand. The target key was counterbalanced between subjects. Subjects were instructed for both speed and accuracy.

RESULTS AND DISCUSSION

The correct responses and their associated latencies (first response latencies, output latencies and input latencies) were subjected to a two (display load) by two (decision rule) by three (proportion of targets) by two (side of display) by two (presence or absence of interference) split-plot analysis of variance. The raw data for the latency analyses were the mean of the latencies associated with each correct response over the 144 trials.

Percent Correct

The percent correct was influenced by display load, $F(1,14) = 17.71$, $p < .01$, and the interference stimulus, $F(1,14) = 5.35$, $p < .05$. Both of these results were expected. Increases in display load resulted in decreases in accuracy. The accuracy for the display loads of four and eight items was 92 and 57 percent, respectively. For those trials where the interference stimulus was absent, the percentage of correct responses was higher than those trials where the interference stimulus was present (77 versus 73 percent). Additionally, a significant interaction between the side of the display and the interference stimulus was observed, $F(1,14) = 9.05$, $p < .01$. This interaction, presented in Figure 1, shows the interference stimulus effected the response for the left display location. This effect was expected since the occurrence of the interference stimulus was during the presentation and response interval of the left display. No carry-over effect to the right display location was observed. The means and standard deviations are presented in Table 1.

First Response Latency

The latency associated with the first response when a correct series of responses occurred was influenced by display load, $F(1,14) = 20.07$, $p < .01$, and by the proportion of target items, $F(2,28) = 6.90$, $p < .01$. As expected, the first response latency was faster for a display load of four items than for a display load of eight items (752

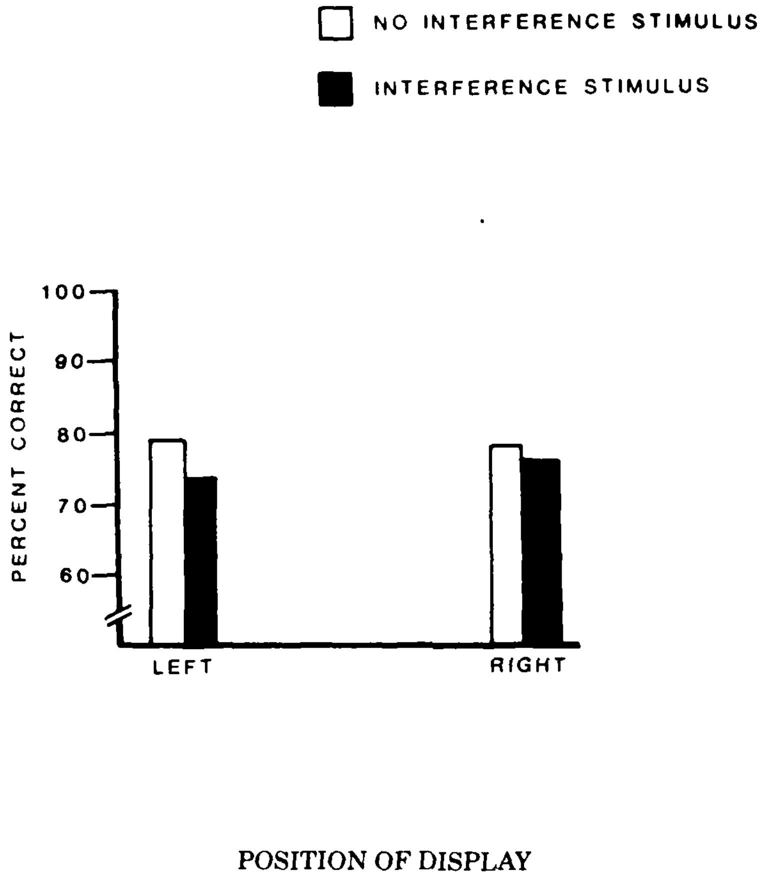

Figure 1. PERCENT CORRECT AS A FUNCTION OF THE POSITION OF THE DISPLAY AND THE INTERFERENCE STIMULUS.

TABLE 1. Means and Standard Deviations for Percent Correct as a Function of Display Load, Decision Rule, Proportion of Targets, Interference Stimulus, and Display Location.

				4 Items		8 Items	
Decision Rule	Proportion of Targets	Location	Interference	Means	Standard Deviations	Means	Standard Deviations
.75	.75	Left	No	96	4.5	57	21.7
.75	.75	Left	Yes	93	4.7	54	28.8
.75	.75	Right	No	95	3.3	64	24.8
.75	.75	Right	Yes	93	8.8	64	23.4
.75	.50	Left	No	95	2.8	53	19.9
.75	.50	Left	Yes	92	5.7	49	26.4
.75	.50	Right	No	91	8.9	57	23.9
.75	.50	Right	Yes	88	12.6	61	19.8
.75	.25	Left	No	94	7.6	56	31.6
.75	.25	Left	Yes	89	8.3	52	22.5
.75	.25	Right	No	91	5.8	50	30.6
.75	.25	Right	Yes	89	15.5	48	29.3
.50	.75	Left	No	92	8.5	56	28.6
.50	.75	Left	Yes	88	14.5	48	23.4
.50	.75	Right	No	94	4.7	54	28.5
.50	.75	Right	Yes	92	7.6	56	28.1
.50	.50	Left	No	92	9.5	63	26.1
.50	.50	Left	Yes	93	7.7	57	24.2
.50	.50	Right	No	91	12.1	64	28.9
.50	.50	Right	Yes	91	5.4	64	23.3
.50	.25	Left	No	93	8.2	65	30.1
.50	.25	Left	Yes	86	13.8	52	25.9
.50	.25	Right	No	92	6.7	55	31.5
.50	.25	Right	Yes	92	6.7	55	29.6

ms versus 942 ms). The function relating the proportion of target items to latency increased from 821 ms to 885 ms and then decreased to 835 ms for the .25, .50, and .75 proportions of targets. This suggests the .50 proportion of targets was a more difficult condition to process.

Significant two-way interactions occurred between the decision rule and the proportion of targets, $F(2,28) = 25.18$, $p < .01$ and between the location of the display and the interference stimulus, $F(1,14) = 6.97$, $p < .05$. Significant three-way interactions occurred (a) between display load, the proportion of targets and the decision rule, $F(2,28) = 4.82$, $p < .02$, (b) between display load, the proportion of targets and the interference stimulus, $F(2,28) = 6.61$, $p < .01$, and (c) between the proportion of targets, the location of the display, and the interference stimulus, $F(2,28) = 8.56$, $p < .01$.

The display load by proportion of targets by decision rule interaction is presented in Figure 2. No interpretation of this interaction can be proposed at this time.

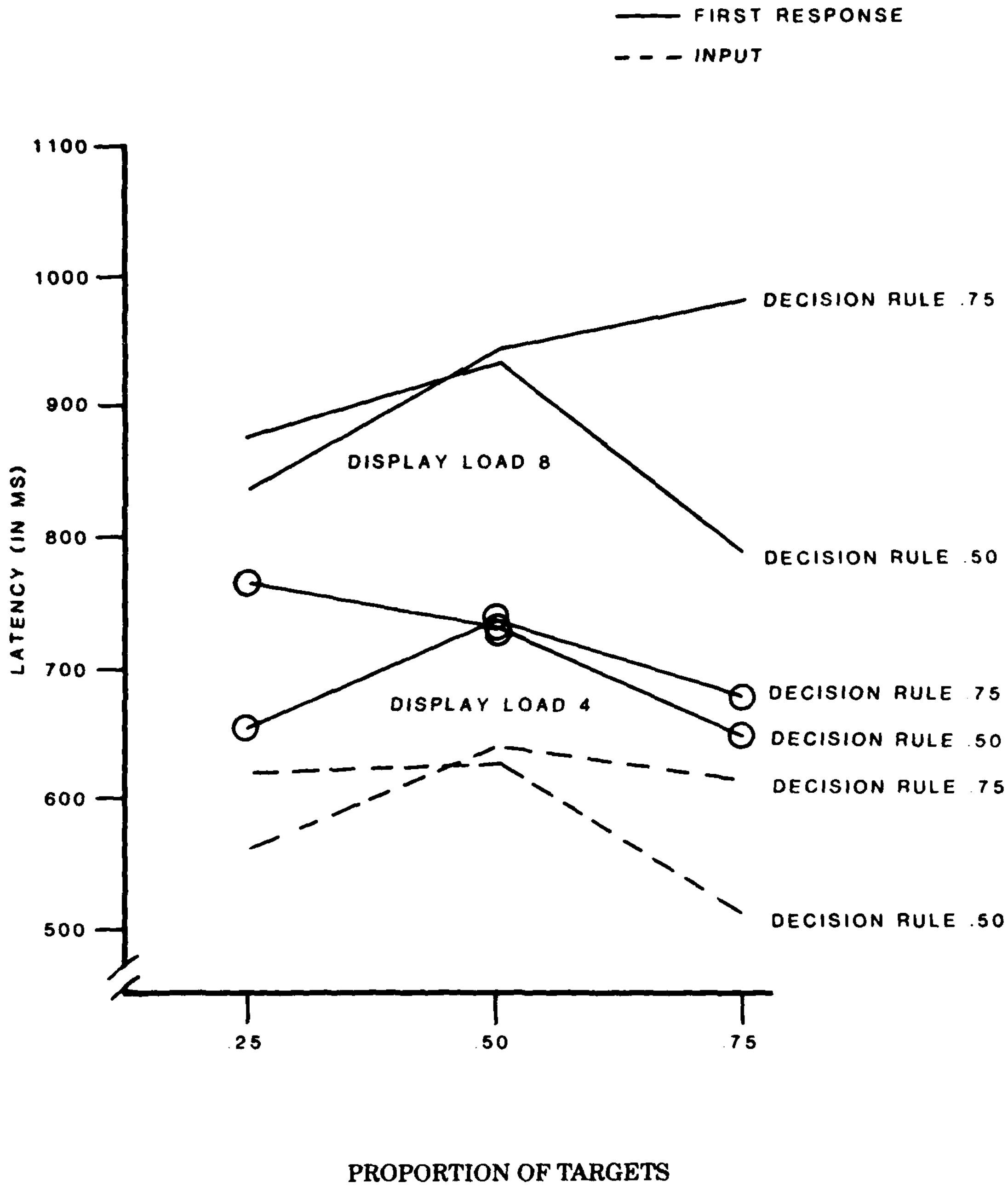

Figure 2. FIRST RESPONSE LATENCY AND INPUT LATENCY AS A FUNCTION OF THE PROPORTION OF TARGETS WITH DISPLAY LOAD AND DECISION RULE AS THE PARAMETERS FOR THE FIRST RESPONSE LATENCY AND WITH THE DECISION RULE AS THE PARAMETER FOR THE INPUT LATENCY.

The proportion of targets by interference stimulus by display load interaction presented in Figure 3 suggests two points. First, when the proportion of targets is .50, the decision is the most difficult for both display conditions. Second, at that point the interference stimulus has both a facilitory effect for a display load of four items and an inhibitory effect for a display load of eight items. This interaction suggests the time required to input the information and perform a classification is less for the smaller display load. Consequently, those processes are performed prior to the onset of the interference stimulus. For the larger display load, the amount of time to perform input processing increases. As a result, the interference stimulus occurs and interferes with the input processes.

The three-way interaction, proportion of targets by location of display by interference stimulus, presented in Figure 4, shows once again that the most difficult display condition is where the proportion of targets is .50. It is also at this value where the interference stimulus results in an effect. The onset of the interference stimulus occurs 225 ms after the onset of the left display location and is absent in all right display locations. The presentation of this stimulus facilitates the responses associated with the left display location but interferes with right display location responses. While it might be expected that the latencies associated with the right display location on the interference stimulus trials should be equal to the latencies on those trials without the interference stimulus, this does not occur. This suggests that the interference stimulus reduces a criterion for responding, and the value assumed by the criterion changes when the stimulus changes. Furthermore, the sudden shift, from an interference stimulus to no interference stimulus within a trial results in a larger change, or a rebound effect, in such a way as to overshoot the normal noninterference trial criterion position. However, an alternative explanation could also be that since the interference stimulus was also present during the response interval associated with the left display location, the interference stimulus was being processed and that it inhibited the encoding and processing of the visual stimuli in the right display location. The means and standard deviations for the first response latency are presented in Table 2.

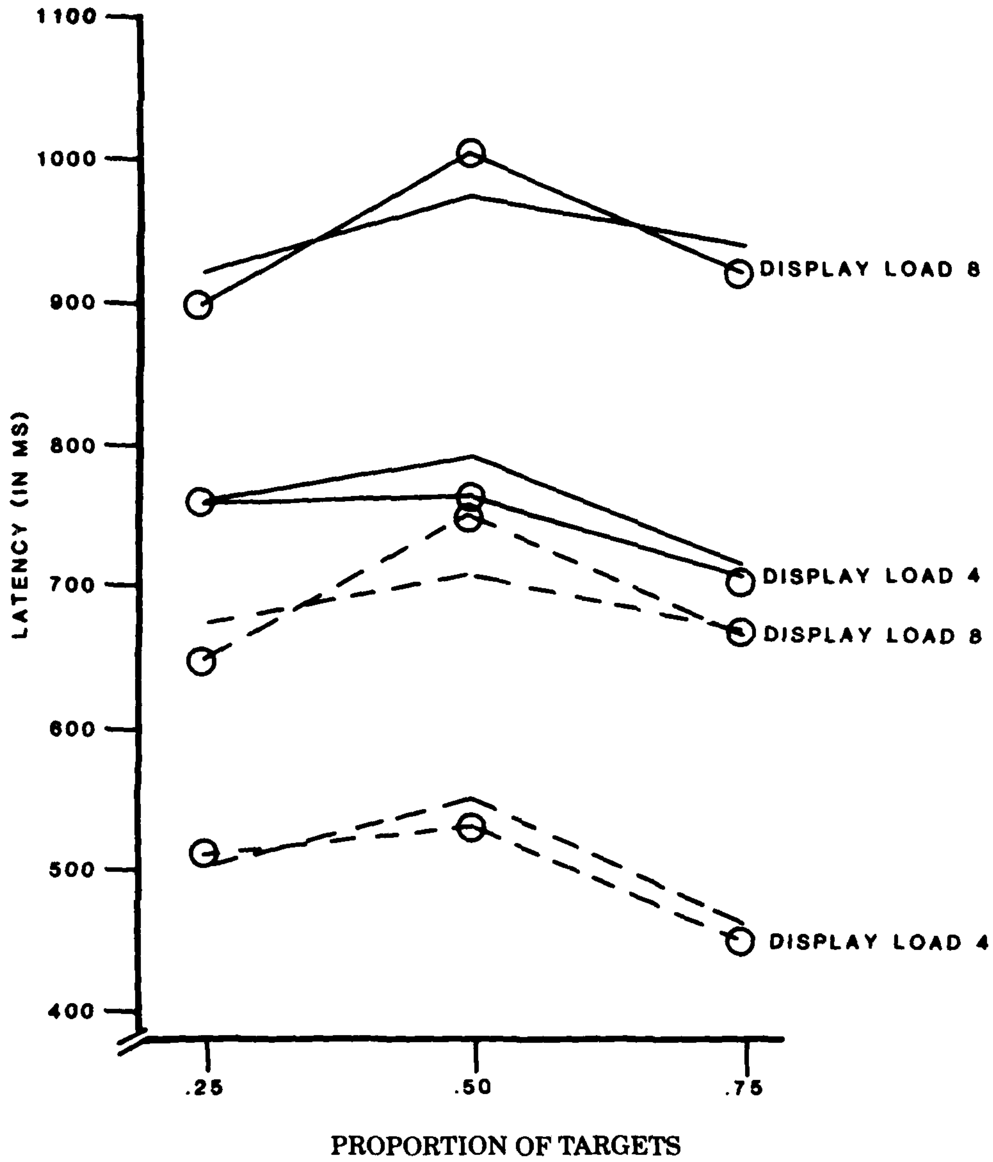

Figure 3. FIRST RESPONSE AND INPUT LATENCIES AS A FUNCTION OF THE PROPORTION OF TARGETS WITH DISPLAY LOAD AND INTERFERENCE STIMULUS AS PARAMETERS.

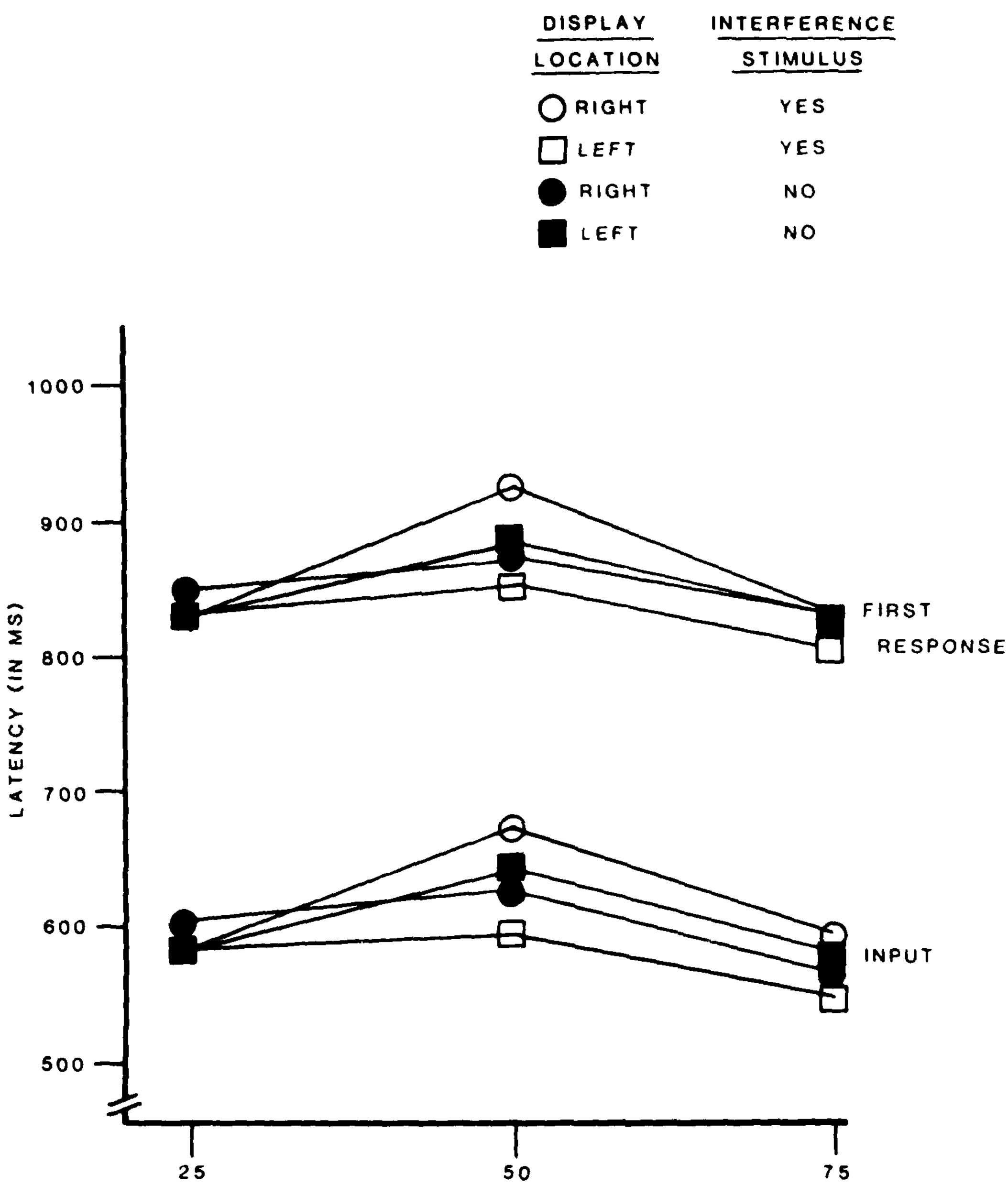

Figure 4. LATENCY AS A FUNCTION OF THE PROPORTION OF TARGETS WITH DISPLAY LOCATION AND INTERFERENCE STIMULUS AS THE PARAMETERS.

TABLE 2. Means and Standard Deviations for First Response Latency as a Function of Display Load, Decision Rule, Proportion of Targets, Interference Stimulus, and Display Location.

Decision Rule	Proportion of Targets	Location	Interference	4 Items Means	4 Items Standard Deviations	8 Items Means	8 Items Standard Deviations
.75	.75	Left	No	733	70.6	1002	160.8
.75	.75	Left	Yes	713	78.4	1028	197.2
.75	.75	Right	No	717	62.1	1022	141.6
.75	.75	Right	Yes	733	72.7	992	128.2
.75	.50	Left	No	810	85.6	979	114.4
.75	.50	Left	Yes	738	72.9	966	154.4
.75	.50	Right	No	736	87.5	949	187.1
.75	.50	Right	Yes	806	84.6	1077	166.8
.75	.25	Left	No	686	71.3	887	96.5
.75	.25	Left	Yes	705	91.9	883	172.9
.75	.25	Right	No	711	54.1	918	167.9
.75	.25	Right	Yes	719	76.6	862	144.3
.50	.75	Left	No	697	71.7	844	165.7
.50	.75	Left	Yes	658	101.2	815	100.4
.50	.75	Right	No	712	117.8	833	126 0
.50	.75	Right	Yes	724	105.9	940	170.3
.50	.50	Left	No	796	58.6	985	123.2
.50	.50	Left	Yes	725	77.7	968	121.6
.50	.50	Right	No	791	94.0	961	150.6
.50	.50	Right	Yes	803	122.9	1019	117.1
.50	.25	Left	No	817	84.8	922	187.6
.50	.25	Left	Yes	792	114.9	943	162.6
.50	.25	Right	No	828	102.3	941	132.5
.50	.25	Right	Yes	830	100.6	906	80.8

Input latency

The primary purpose of this investigation was to investigate a new method in the partitioning of latency, and to use the method to gather additional information that could not be gained by traditional approaches. A traditional approach was demonstrated with the analyses of the first response latency. It should be recalled that the first response latency contains both input processing time and output processing time. Therefore, the input latency was derived by subtracting the mean output latency for a trial from the corresponding first response latency. In relation to the first response time analysis, all main effects and interactions found to be significant, (with the exception of the display load by decision rule by proportion of target interaction), were also significant in the analysis of the input latencies. The means and standard deviations for the input latencies are presented in Table 3.

The main effects of display load, $F(1,14) = 11.98$, $p < .01$ and the *proportion of targets*, $F(2,28) = 7.02$, $p < .01$ were significant. A third main effect of display location was also significant, $F(1,14) = 5.49$, $p < .05$. The left display location was faster than the right display location (587 ms versus 603 ms). This finding is not surprising since the left display always occurred first and people read from left to right. It is surprising, however, that this effect was not observed in the prior analysis. A significant display location by interference stimulus interaction, $F(1,14) = 8.08$, $p < .05$ was observed. A significant decision rule by proportion of targets interaction, $F(2,28) = 16.6$, $p < .01$ was also observed and is presented in Figure 2.

The significant display load by proportion of targets by interference stimulus interaction, $F(2,28) = 6.18$, $p < .01$, and the significant proportion of targets by interference stimulus by display location interaction, $F(2,28) = 6.52$, $p < .01$ are presented in Figures 3 and 4. The similarities between the first response and the input time latencies are obvious. The implications from the first response latency analysis appear to hold for the input latencies. This suggests that no information is lost using the Teichner procedure.

TABLE 3. Means and Standard Deviations for Input Latency as a Function of Display Load, Decision Rule, Proportion of Targets, Interference Stimulus, and Display Location.

				4 Items		8 Items	
Decision Rule	Proportion of Targets	Location	Interference	Means	Standard Deviations	Means	Standard Deviations
.75	.75	Left	No	476	109	804	177.5
.75	.75	Left	Yes	461	106	756	209.6
.75	.75	Right	No	461	94	764	164.0
.75	.75	Right	Yes	478	102	735	151.1
.75	.50	Left	No	561	107	711	133.9
.75	.50	Left	Yes	501	96	702	176.2
.75	.50	Right	No	547	89	712	209.8
.75	.50	Right	Yes	567	97	822	190.1
.75	.25	Left	No	431	102	637	149.9
.75	.25	Left	Yes	450	116	638	182.4
.75	.25	Right	No	455	82	673	196.2
.75	.25	Right	Yes	477	101	615	185.7
.50	.75	Left	No	444	87	592	168.1
.50	.75	Left	Yes	398	116	564	111.3
.50	.75	Right	No	453	105	586	140.0
.50	.75	Right	Yes	463	104	599	185.1
.50	.50	Left	No	548	82	723	126.8
.50	.50	Left	Yes	486	93	695	122.0
.50	.50	Right	No	545	107	705	149.8
.50	.50	Right	Yes	558	127	760	141.4
.50	.25	Left	No	557	119	679	209.8
.50	.25	Left	Yes	535	125	586	179.0
.50	.25	Right	No	570	118	692	158.9
.50	.25	Right	Yes	571	125	680	127.7

Output Latencies

The analysis of the output latencies showed a significant main effect for the location of the display, $F(1,14) = 9.32$, $p < .01$. Output time was slower for the left display location than for the right display location (256 ms versus 251 ms).

The analysis also showed a significant interaction for display load by interference stimulus by proportion of targets by decision rule, $F(2,28) = 3.82$, $p < .01$ and is presented in Figure 5a. The major portion of this interaction is, once again, where the proportion of targets is 0.50. There is an increase in output latency for a display load of eight items and a decrease in the output latency for a display load of four items. This interaction suggests that the proportion of target items is not the critical factor. In fact, by recoding the abscissa to reflect the number of response items, a better understanding of this function can be realized. This interaction replotted as a function of the number of response items is presented in Figure 5b.

Figure 5b suggests that the output latency is an increasing function of the number of items, up to and including four items. Newman-Keuls multiple-comparisons of the original interaction show that in general ($p < .05$) the output latencies for the response set of two items for display load four are significantly different from the response set of four items for display load eight. However, the latencies associated with the three and six response items were not significantly different from any other conditions. This suggests a decrease in the output latencies for the response set of six items. One possible reason for this decrease in output latency may be due to the time available for responding. Since the inter-display interval was a constant, the amount of time available for a response would decrease, and could, therefore, produce a decrease in the output latencies. The means and standard deviations for the output latencies are presented in Table 4.

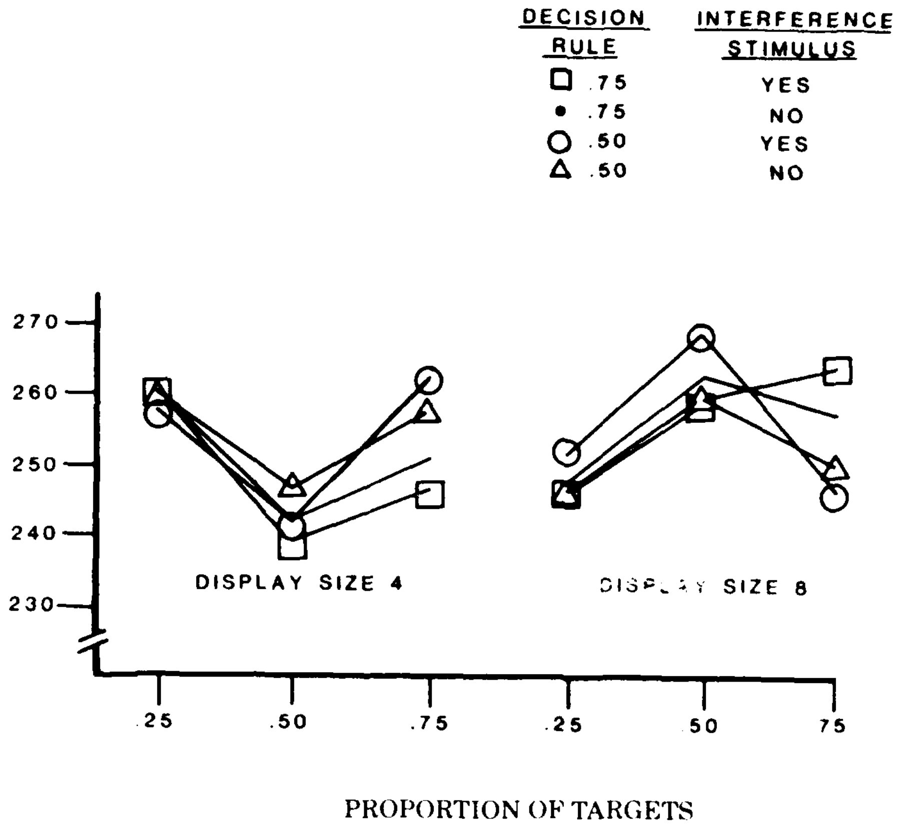

Figure 5a. OUTPUT LATENCIES AS A FUNCTION OF THE PROPORTION OF TARGETS WITH THE DECISION RULE AND INTERFERENCE STIMULUS AS PARAMETERS.

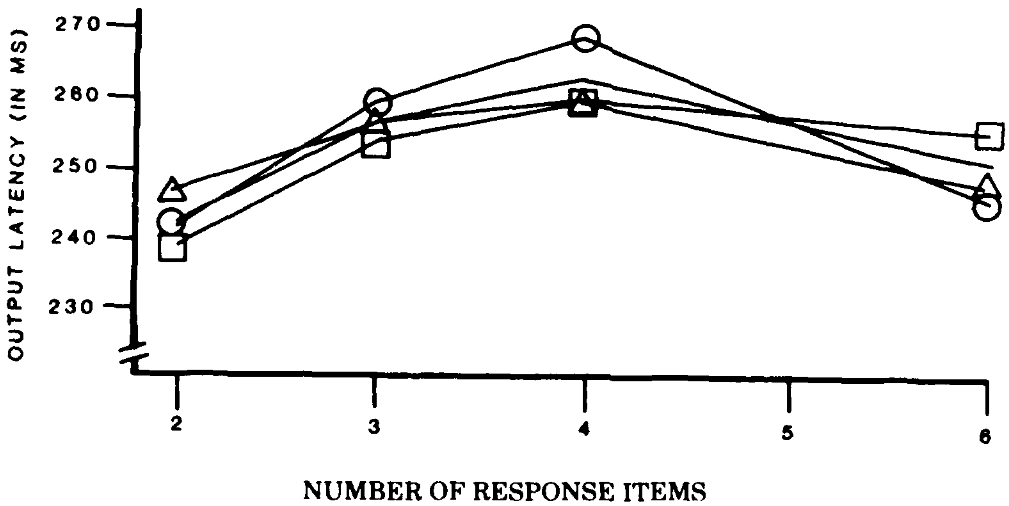

Figure 5b. FIGURE 5a RECODED. SEE TEXT FOR DETAILS.

TABLE 4. Means and Standard Deviations for Output Latency as a Function of Display Load, Decision Rule, Proportion of Targets, Interference Stimulus, and Display Location.

Decision Rule	Proportion of Targets	Location	Interference	4 Items Means	4 Items Standard Deviations	8 Items Means	8 Items Standard Deviations
.75	.75	Left	No	257	57.7	258	[illegible]
.75	.75	Left	Yes	251	59.9	272	[illegible]
.75	.75	Right	No	243	55.8	251	69.1
.75	.75	Right	Yes	241	47.5	254	[illegible]
.75	.50	Left	No	243	51.3	268	69.3
.75	.50	Left	Yes	237	57.1	263	68.8
.75	.50	Right	No	239	56.5	257	[illegible]
.75	.50	Right	Yes	238	49.7	255	66.5
.75	.25	Left	No	263	44.1	250	69.8
.75	.25	Left	Yes	265	47.5	245	60.2
.75	.25	Right	No	255	46.1	245	62.7
.75	.25	Right	Yes	253	44.2	247	69.2
.50	.75	Left	No	253	52.2	252	47.9
.50	.75	Left	Yes	263	63.7	251	48.5
.50	.75	Right	No	259	55.3	246	43.6
.50	.75	Right	Yes	261	54.9	241	41.9
.50	.50	Left	No	247	58.8	262	56.9
.50	.50	Left	Yes	239	50.9	272	59.7
.50	.50	Right	No	245	62.2	257	50.9
.50	.50	Right	Yes	244	54.7	264	54.4
.50	.25	Left	No	260	50.6	243	57.3
.50	.25	Left	Yes	256	42.0	256	54.9
.50	.25	Right	No	258	44.2	248	51.5
.50	.25	Right	Yes	258	43.9	245	54.0

SECTION IV

GENERAL DISCUSSION

While the results of these experiments show the advantage of using the within-task subtractive method over a single response method, several unique findings deserve discussion.

First, significant interactions observed with the analyses of the first response latency were not observed when output latency was removed. This finding supports a serial processing model and the within-task subtractive method. Consider the two-stage serial processing model and the factors, A and B, presented in Figure 6. Sternberg (1969) and Briggs (1972) suggest that factors influencing the first stage of processing result in changes in the intercept of the function relating latency to the factors. Factors influencing the second stage result in changes in the slope of that function. For example, if factor B influences stage 1 then the resulting function appears as in Figure 6a. The functions for each level of factor B are parallel. If factor B influences stage 2, then the resulting function is as shown in Figure 6b with a common intercept but different slopes. Finally, if factor B influences both stages, then nonparallel functions with different intercepts result as shown in Figure 6c.

The focus of each B effect is presented on the left side of Figure 6. In Figure 6a factor B influences the first stage, and a statistically significant main effect for factor B should be observed. In Figure 6b, factor B influences the second stage of processing, and a statistically significant A by B interaction should occur. In Figure 6c, factor B influences both the first and second stages of processing. Statistically, a main effect of factor B and A by B interaction should be observed. In all cases, there should also be a main effect for factor A; however, this main effect can be eliminated by forcing the slope of the sum of the B functions to equal O.

The approach taken with the within-task subtractive method is to provide an estimate of the duration of stages 1 and 2. Consequently, if the separation of these two stages of processing by this method is correct, and assuming a serial processing system, then the following conclusions appear warranted.

Figure 6a.

Figure 6b.

Figure 6c.

Figure 6. THE VARIOUS EFFECTS OF THE EXPERIMENTAL VARIABLE ON A TWO-STAGE SERIAL PROCESSING MODEL.

For Figure 6a a main effect of B for input should be observed, with no effects of B for the output. For Figure 6b a main effect of factor B for output with no effects of B for the input should be observed. For Figure 6c a main effect of B for both input and output should be observed.

Second, a main effect on output latency with no effect on input latency given an initial first response latency interaction was observed in the first experiment. This finding appears to support the within-task subtractive method. However, further investigation of the first and third conditions is required before the method can be completely supported. The second observation concerns the number of responses on output latency. Briggs and his colleagues (Briggs & Swanson, 1970) suggest that output latency is an increasing function of the number of responses. This investigation also suggests that output latency is an increasing function of the number of responses. However, there is reason to suspect that the rate of increase decreases as the number of responses increases, and that the output rate reaches a limit at approximately four responses. Further investigation of these results is required in order to substantiate this finding.

The third finding, and the most theoretically interesting, pertains to the proportion of targets by interference by display load interaction. The major point of interest is where the proportion of targets is .50. It is at this point where the interference stimulus is both facilitory and inhibitory. Facilitory effects are seen for a display load of four items, where a decrease in the input latency from 552 to 528 ms is observed. Inhibitory effects are seen for a display load of eight items, where an increase in input latency, from 713 to 743 ms, is observed.

It is possible to explain this interaction by suggesting that the information concerning the display loads of four and eight items is in different stages of processing when the interference stimulus occurs There appears to be some support for this notion. Using information from a series of investigations on binary classification tasks by Briggs and his colleagues (Briggs & Swanson, 1970; Swan & Briggs, 1969), it appears that three processes are occurring within the Teichner (1979) input function. They are encoding, stimulus sampling and comparison processes. Using the figures derived by Briggs, encoding comprises 7 ms per item, stimulus sampling operates at a rate of 64 items per second, and the classification process requires 23.5 ms per comparison. With a display of four items the total time comprised in these three processes is 185 ms, while for a display of eight items the total time involved is 369 ms. Since the interference stimulus occurred 250 ms after display onset, it can be seen that for a display load of four items the interference stimulus occurs after the three processes described by Briggs. For a display load of eight items, the interference stimulus falls within the duration of these three processes. It is also interesting to note that the input latency values associated with the noninterference trials for each display load, 713 and 552 ms, less the values obtained by using the values derived from Briggs' investigations, 369 and 185 ms, are within 23 ms of each other: 344 ms for a display load of eight items and 367 ms for a display load of four items. This suggests that an additional process occurs after classification. This process may involve a decision concerning the quantity of each kind of stimulus. Nevertheless, by increasing the onset time of the interference stimulus for a display load of eight items past 369 ms, a decrease in input latency should be observed. This notion of varying the onset valus of an interference stimulus may permit the calculation of the duration and number of processing stages.

If the preceeding inferences are correct, then one must wonder why there is no effect of the interference stimulus at other target item proportions. Why should interference occur when the proportion of targets is .50 but not occur when the proportion of targets is .75 or .25?

It is postulated that the processing strategy is altered when there is a shift in the proportion of target items. The alteration in strategy requires additional time, and it is either during or after this alteration when the interference stimulus occurs. It appears the same strategy is used in cases where the proportion of target items is not equal to .50. Support for the similar processing strategies stems from the observation that the input latencies for the case where the proportion of targets is .25 is equal to input latencies for the case where the proportion of targets is .75.

It also appears that the initial strategy for processing is to assume a nonequal target/nontarget condition. While the experimental probability of a particular proportion was one-third, it is quite probable that the probabilities used by the subject were based on an occurrence of an equal number of targets and nontargets versus a nonequal number of targets and nontarget items is still one-third; however, for the unequal conditions this probability of occurence is two-thirds.

Consequently, the first strategy would be to assume an unequal proportion of target and nontarget items and process the items based on that assumption. If the assumption fails, then switch strategies or alter the strategy and process until all items have been processed. Further research is needed to support this notion.

SECTION V

RECOMMENDATIONS

The use of the within-task subtractive (WITS) method is recommended in all cases where reaction time measures might be collected. This procedure allows for the separation of input and output functions and permits investigations into these processes. However, it must be noted that the use of multiple responses may change the task by increasing the response demands. Nevertheless, this procedure may provide valuable information pertaining to cognitive processes that are either unobservable or masked using traditional partitioning methods.

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