On the locus of the divided-attention effects*

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Reaction times in a choice reaction task were used to localize the divided-attention effect (less proficient performance under dual than under single-task conditions) in a sequential-stage model of human information processing. Experiment 1 eliminated a central (memory-dependent) processing stage, while Experiment 2 suggested that a stimulus sampling process within the initial encoding stage was the locus of the effect. Thus, the effect was localized to the input, not the central or an output stage of processing. A slower stimulus amplifying rate was indicated under dual- than under single-task conditions.

When S is required to perform two tasks simultaneously, he usually is less proficient on one if not on both than when he encounters the two tasks separately. For example, Keele (1967) found a decrease in proficiency on a serial reaction time task when a second task (counting backwards) was introduced; Smith (1969) observed that performance on either a signal detection task or on a stimulus discrimination task was less proficient when S simultaneously performed on a choice reaction task than when the tasks were experienced separately; and Hulman and Greenberg (Experiment II, 1971) obtained an increase in reaction time on a simple perceptual task (judging the relative lengths of two lines) when the memory demands of a concurrent task are increased beyond a critical level. Each of these (and other similar studies) suggests that S must share his limited capacity between the information processing demands of the two tasks. If the total demand is less than capacity, then little or no divided-attention effect should be noted, as in the Shulman and Greenberg (1971) research when memory demands of the one task were below a particular level. However, at and beyond the point where the total load exceeds the processing capacity of S, performance on one or both tasks would be expected to deteriorate.

The present research is concerned with localizing this divided-attention effect within a sequence of processing stages. The E. E. Smith (1968) paradigm is useful in defining four possible loci of the effect: Stage 1, or the encoding processes, wherein

stimulus information is initially registered, sampled, and subject to gross analysis (preprocessing); Stage 2, or central processing, where detailed analysis of the sampled stimulus information is carried out for purposes of stimulus definition or identification; Stage 3, or response decoding; and Stage 4, or response execution and control. In his brief review of the literature on this topic, Welford (1968) concludes that the deficiency probably is not motor in nature (our Stage 4); instead, he suggests that a translation process (our Stage 3) probably is the locus of the divided-attention effect. M. Smith (1969) is somewhat less specific in her conclusion on the probable locus of the effect: "... the limited capacity mechanism probably occurs at a rather central stage, where the information carried by the particular stimuli is analyzed [p. 526]." This would seem to be Stage 2 in the E. Smith (1968) paradigm, although Stage 1 is not eliminated in the above conclusion as that stage does include pre- (central) processing of stimulus information. Nevertheless, it does seem that M. Smith favors Stage 2 as the locus of the divided-attention effect.

Now it may be that the locus of the effect varies from stage to stage as a function of the particular processing demands of the two tasks. Moray (1969) favors this view in preference to the proposal by Broadbent (1958) and Treisman (1960) that the limited capacity to deal with simultaneous signals is in an input or at least in an early stage of processing. If Moray is correct, then the locus of the effect will be task specific. It is felt that an attempt to localize the effect should use one task which loads S broadly across all stages of processing, including the processing of feedback information from responses in progress; an appropriately designed concurrent task, then, could serve as a diagnostic tool to determine whether the input, central, or output stage is most influenced by the dual-task

loading. A tracking task seems admirably suited to provide the broad loading (across stages) that is desired.

In the present research, an experimental-group S performed on a one-dimensional tracking task with a visual display while responding in the Sternberg (1966) choice reaction task, which utilized an auditory presentation of stimuli. Control groups encountered only the Sternberg task. The latter task required that S memorize a set of one, two, or four letters and then make one of two responses to each in a series of test stimuli: either "yes," that the stimulus matches the one being held in memory (it is a member of the positive set), or "no," there is no match (it is a member of the negative set). Typically, one finds a linear relation between reaction time (RT) and central processing uncertainty (H_c) in this task:

$$RT = a + b(H_c)$$

where H_c is determined primarily by memory load (see Briggs & Swanson, 1970).

The Sternberg task is particularly appropriate for the purpose of localizing experimental effects within the E. Smith (1968) paradigm. One finds that the intercept constant, a , is influenced by variables which affect processes in Stages 1 or 3, while the slope constant, b , reflects the influence of variables on Stage 2 or central processing (see Sternberg, 1969a; Briggs & Swanson, 1970; Lyons & Briggs, 1971).

EXPERIMENT 1

An initial experiment was performed to determine if the locus of the divided attention effect was in Stage 2 or in either Stage 1 or Stage 3. There was a single experimental group (dual tasks) and one control group (single choice reaction task). If the effect is manifested in central processing, or Stage 2, then the slope constant, b , should differ significantly between the two groups, i.e., there would be a Groups by Memory Load interaction; however, if the locus is in either the encoding or the decoding stage, then the intercept, but not the slope constants, should differ in the $RT-H_c$ additivity statement.

Method

Apparatus and tasks. The tracking task consisted of a 14-cm cathode ray tube display, a spring-centered control stick which S manipulated with her right hand, and rate-control dynamics through which S tracked a low-frequency random input in the pursuit mode. The control-display gain was such that the displayed cursor

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Table 1
Calculation of H_c for Memory Loads $M = 1, 2$, and 4 Under the
Sternberg (1966) "Fixed" Set Procedure

Memory Load	Test Number	Memorial Representation	p_i	$p_i \log p_i$	H_c
1	1	S1	.50	.50	1.0
		N1	.50	.50	
2	1	S1	.25	.50	2.0
		N1	.25	.50	
	2	S2	.25	.50	
		N2	.25	.50	
4	1	S1	.125	.375	3.0
		N1	.125	.375	
	2	S2	.125	.375	
		N2	.125	.375	
	3	S3	.125	.375	
		N3	.125	.375	
	4	S4	.125	.375	
		N4	.125	.375	

moved 1.06 mm/sec for each degree of control-device displacement. The input was a band-limited Gaussian signal (.2 to .4 Hz) which moved the target over approximately 5 cm of the display. The S was seated about 55 cm from the display. It was felt that the random input signal and the rate-control dynamics would provide the broad loading across processing stages which was desired in the basic research strategy (see above).

The choice reaction apparatus consisted of headphones over which S received the test stimuli and a two-button response device by which she could signal a match or a no-match of test to a positive set stimulus. The test stimuli were recorded in a male voice on audio tape and were presented at the rate of 1 every 4 sec. An electronic timer, accurate to millisecond units, was activated by a voice relay and was stopped by S's response. The S rested the index and middle fingers of her left hand lightly on the response buttons, and a movement of 0.5 mm was required to stop the timer. Assignment of button to match and no-match status was counterbalanced across (not within) Ss. The buttons were located 15 cm above S's left knee on a panel which provided space to rest the hand.

Subjects and procedure. There were 12 female Ss assigned to each of the two groups. Each was paid \$1.25 per session for four 30-min sessions. All Ss were right-handed and were assigned to groups on the basis of order of response to an ad in the campus newspaper.

The single-task group received instructions in the first session and then experienced two blocks of 24 trials under each of three memory load (M) conditions: $M = 1, 2$, or 4 items in memory. During each of the three succeeding sessions, there were three

blocks under each memory load, a daily total of nine 24-trial blocks. Order of memory load was counterbalanced for each S across these nine blocks of trials. The letters A, B, F, G, I, L, N, O, Q, R, U, and Y served as stimuli, and the Sternberg (1966) "fixed" set procedure was followed: At the beginning of a block, S was presented with one, two, or four letters to be memorized, and then she heard a single test letter every 4 sec for a total of 24 test stimuli. To each, she signaled match or no-match. In randomized order, half of the test stimuli were from the positive (memorized) set and half were from the negative set (from the remaining 8, 10, or 11 letters, depending on the memory-load condition). A different letter or set of letters defined the positive set for each block such that each of the 12 letters was used equally often in each memory-load condition across Ss and (to the extent possible) within each S. The S was instructed to respond as quickly and as accurately as possible.

The dual-task group encountered the tracking task simultaneously with the choice reaction task. Their instructions emphasized that both tasks were equally important, and at the end of each daily session, S was shown her reaction time and tracking-performance scores; thus the equality-of-emphasis instructions were reinforced. A S in the single-task condition received feedback on her reaction-time scores, and both groups were encouraged thereby to improve performance across blocks and sessions.

Central processing uncertainty. The H_c index was introduced by Swanson and Briggs (1969) and later validated by Briggs and Swanson (1970). It is a Shannon (1948) expression defined as $H_c = -\sum p_i \log p_i$, where p_i is the

probability of the i th outcome of central (memory-dependent) processing and the summation is across all possible outcomes. In the earlier research, assignment of items to the positive and negative sets was permanent for a particular S. Thus, if a particular S encountered the letter B as the $M = 1$ stimulus, that letter was always used for that condition and never appeared as a member of the $M = 2$ or $M = 4$ set; nor did it ever serve as a negative set stimulus. Under these conditions, H_c values of 1.0, 1.5, and 2.0 bits were calculated for memory loads of $M = 1, 2$, and 4 , respectively.

Now, in the Sternberg (1966) "fixed" set procedure (that used in the present study), a particular S can encounter a specific letter in both the positive and negative sets on different blocks of trials. It has been noted in previous research at this laboratory (Johnsen, 1971) that the RT/memory-load functions have considerably greater slope constants when the Sternberg "fixed" set procedure is used than when the permanently fixed set procedure is employed during data collection. This suggests that S probably utilizes somewhat different testing procedures to classify a test stimulus into the positive or the negative set in the two situations. The calculation used in the permanently fixed set conditions assumed that S could perform a single test for a negative set match, and this is a reasonable assumption, since the negative set did not vary in membership across data collection for a particular S. In the case of the Sternberg "fixed" set procedure, however, the negative set varies from one block to the next, and it is reasonable to assume that S must resolve more uncertainty at Stage 2, at least for memory loads of $M = 2$ and $M = 4$. How might one express this greater uncertainty?

One straightforward model is based on the assumption that S performs a series of tests. On each test, the encoded test stimulus is compared to the memorial representation of a positive-set stimulus (S_i) vs features of a *proportional* subset of the negative-set stimuli (N_i) to determine if the evidence favors the positive or the negative set. It is assumed that this testing is exhaustive and that, on the average, each of the items in the negative set appears in at least one test of the series. Table 1 summarizes the consequences of this model for the calculation of H_c . It may be noted that $H_c = 1.0, 2.0$, and 3.0 bits for the memory-load conditions $M = 1, 2$, and 4 , respectively.

Results and Discussion

While tracking performance per se

was of little interest here, it may be noted that there was a statistically significant improvement in these scores (relative tracking error) across the final three sessions for the dual-task group, $F(5,55) = 9.82$, $p < .001$. Memory load in the choice reaction task did not have a significant effect on tracking performance, $F(2,22) = 1.09$, $p > .05$.

Accuracy was uniformly high in the choice reaction task for both groups: the range across memory-load conditions was from 0.7% to 2.2% errors, with no significant differences between groups or across memory-load conditions. The reaction time data for the second and third blocks within each memory-load condition from Sessions 2-4 were subjected to an analysis of variance. This provided six blocks of data for each memory-load condition, and, to maximize the reliability of individual data points, the reaction times for both match and no-match trials were pooled. A median was determined across the 24 trials for each S in each block.

In this analysis, all three main effects were significant at $p < .001$: groups $F(1,22) = 26.88$, memory load $F(2,44) = 201.97$, and blocks $F(5,110) = 11.90$. Further, of the several interaction terms, only the Groups by Blocks interaction was significant, $F(5,110) = 3.38$, $p < .01$. The significance of groups indicates that a divided-attention effect was obtained and, as expected, that the single-task group was superior to the dual-task group (average reaction times were 489 and 636 msec, respectively). The significance of blocks indicates a practice effect and the interaction of Groups by Blocks indicates a differential practice effect: whereas both groups improved with practice, the single-task group improved to a greater extent. Thus, the divided-attention effect increased with practice.

Figure 1 summarizes the data of interest: average reaction time as a function of central processing uncertainty. Best-fit parallel linear functions are listed in the figure. This type of fit is justified by the lack of a significant Groups by Memory Load interaction, where $F(2,44) = 2.80$, $p > .05$. This result indicates that Stage 2 of the E. Smith (1968) paradigm was not the locus of the divided-attention effect in this study. It may be recalled that variables which influenced the central processing stage manifest that influence in the slope constant, b , of the additivity statement, $RT = a + b(H_c)$; the intercept constant, a , reflects the influence of variables which affect processes in either Stage 1 (stimulus encoding) or Stage 3 (response

Fig. 1. Reaction time as a function of central processing uncertainty in Experiment 1.

decoding). Since the intercept, not the slope constant, was different for the two groups, it follows that Stage 2 may be eliminated from consideration as the locus of the effect. A second experiment was designed to determine if the divided-attention effect would be localized in either Stage 1 or Stage 3.

EXPERIMENT 2

From the logic of the Sternberg (1969b) additive-factor method, the locus of effect of a variable, e.g., divided attention, can be determined if that variable interacts with another variable and there is evidence that the second variable influences a particular processing stage. From Briggs and Swanson (1970), we may conclude that the speed-accuracy variable influences Stage 1 while response load influences Stage 3. Therefore, by combining factorially two levels of accuracy, two levels of response load, and two levels of divided attention, it should be possible to localize the latter effect in either the initial stimulus-encoding stage or in the subsequent response-decoding stage. The two levels of the divided-attention variable were defined by single-task vs dual-task conditions. The two levels of accuracy were set by instructions and a bonus system which encouraged either 5% or 15% errors in the choice reaction task. Response load is defined by the number of response possibilities from which S must select that one response to express the outcome of Stage 2, or central processing (see Briggs & Swanson, 1970). In the present study, S emitted either one of two possible responses or one of four possible responses to each test stimulus in the choice reaction task.

Method

Apparatus and tasks. The only difference in tasks from those in Experiment 1 was in the choice reaction task. In the earlier study, the test stimuli were recorded by a male assistant; in the present study, half the stimuli were recorded by a male and

half were recorded by a female assistant. Within each block of 24 trials, the occurrence of the male or the female voice was randomized, with the restriction that half the stimuli be of each voice under each of the three memory-load levels, $M = 1, 2$, and 4.

As in Experiment 1, there were two response buttons for those Ss who were required to decode the outcome of Stage 2 into one of two responses (match vs no-match of test to positive-set stimuli). This will be identified as the $R = 2$ condition. For Ss in the $R = 4$ condition, there were four response buttons to indicate match/male, no-match/male, match/female, and no-match/female, as appropriate. These four responses were equally appropriate within each memory-load level. All Ss heard the same audio tapes, but those in $R = 2$ could ignore voice quality, while those in $R = 4$ had to take sex of the speaker into account during response decoding.

Subjects and procedure. There were 12 female Ss assigned to each of eight groups. Each S received \$1.25 per session for four 30-min sessions plus a bonus (see below) on the second, third, and fourth sessions. All were right-handed, and nine had served in Experiment 1. Assignment to groups was on the basis of order of response to an ad in the campus paper.

Four groups experienced the dual-task condition, while the other four groups worked only in the single-task condition. Within each set of four groups, the speed (15% errors)-accuracy (5% errors) variable and response load were assigned factorially as between-group variables. The first session involved an introduction to the task (or tasks) and two blocks of practice trials under each of the memory loads, $M = 1, 2$, and 4. There were three blocks of 24 trials under each memory load in each of the succeeding three sessions. At the beginning of the second session, S was shown a feedback panel which was located to the right of the tracking display. This device consisted of four counters to indicate whether a response on the choice reaction task was fast or slow, correct or incorrect. Those Ss in the speed condition were awarded 10 points for a fast-correct response, but they were penalized (a) 1 point for a fast-error response, (b) 5 points for a slow-correct response, and (c) 10 points for a slow-error response. Those Ss in the accuracy condition observed the same point system, except that a fast error cost 5 points rather than only 1 point. The criterion times to define fast vs slow responses were adjusted during the second session so as to generate either 5% errors (for the accuracy

Table 2
Percent Errors Obtained in Experiment 2

	Speed vs Accuracy	Response Load	Memory Load		
			M = 1	M = 2	M = 4
Single Task	Speed	R = 2	14.0	14.4	15.0
	Speed	R = 4	17.1	15.2	16.4
	Accuracy	R = 2	5.1	4.8	5.3
	Accuracy	R = 4	5.2	4.2	5.7
Dual Task	Speed	R = 2	13.5	13.8	14.1
	Speed	R = 4	14.2	13.9	14.7
	Accuracy	R = 2	4.2	4.0	5.1
	Accuracy	R = 4	4.7	4.9	5.5

group) or 15% errors (for the speed group). These criterion times then were further adjusted, if necessary, on the basis of performance during the first block of trials under each memory-load condition during the third and fourth sessions in order to maintain the desired level of accuracy. The S was never informed of the accuracy level desired. Only the data from the second and third blocks under each memory-load condition on Sessions 3 and 4 were utilized in the analyses (below).

The points earned under each memory-load condition were converted to money at a 15-to-1 rate. This resulted in an average bonus of 60c per session. As in Experiment 1, S was shown her performance at the end of each session.

Results

Again, tracking performance per se was of little interest. It may be noted that of the three primary variables (memory load, response load, and accuracy level), only accuracy level (which applied to the choice reaction task) was statistically significant, $F(1,40) = 4.72$, $p < .05$. Superior tracking performance occurred under the speed (15% errors) condition.

Preliminary examination of the choice reaction-time data revealed that five Ss (one in each of five groups) produced average times far in excess of the other Ss within those groups, i.e., well over three standard deviations above the mean on either or both of the last two sessions. Otherwise, the distributions within each group were only slightly skewed, but comparably so for the several experimental conditions. These five Ss were eliminated from data analysis, along with a randomly selected S from each of the other three groups. Thus, the choice reaction analyses were based on an N of 11 Ss per group. Four of the aberrant Ss were found in the single-task condition; the fifth was in the dual task, R = 2, speed group.

Table 2 lists the percent errors for each group. It may be noted that the bonus system was successful in separating the speed and accuracy conditions and in achieving

comparable error rates between response-load levels and across memory-load levels. The information transmitted (H_t) metric was calculated separately for each S across Sessions 3 and 4, and an analysis of variance revealed that only accuracy level was statistically significant, $F(1,84) = 5.64$, $p < .05$. The speed condition resulted in an average H_t of .89 bits, while

1.24 bits was the average H_t under the accuracy condition.

An analysis of variance of the reaction time data showed that each of the independent variables was highly significant ($p < .001$); however, none of the interactions was significant at $p < .05$. The basic results are summarized in Fig. 2, which also shows best fits of the basic equation:

$$RT = a + b(H_c)$$

The least-squares fits were carried out in parallel within the single- and dual-task conditions. As expected from the lack of an interaction of Divided Attention by Memory Load, the two slope constants are quite close in Fig. 2.

Following the procedure first utilized by Briggs and Swanson (1970), the intercept constants, a , of Fig. 2 are shown in Fig. 3 (top two

Fig. 2. Reaction time as a function of central processing uncertainty in Experiment 2.

nels) as linear functions of response load:

$$a = c + e(R)$$

This equation is justified by the earlier results [see especially Fig. 3B in Briggs and Swanson (1970, p. 304)]. In the present Fig. 3, parallel fits were made for the data points separately within each level of divided attention. Once again, as expected from the lack of an interaction of Response Load by Divided Attention, the slope constants, e , of Fig. 3 (top two panels) are quite close.

Finally, still following the procedure developed by Briggs and Swanson (1970), the bottom panel of Fig. 3 shows the intercept constants, c , from the upper parts of that figure as ear functions of average information transmitted ($\bar{H}_t$):

$$c = i + j(\bar{H}_t)$$

The use of a linear equation here is justified on the basis of the results of Swanson and Briggs (1969). In the present case, parallel fits were not made. Instead, each of the two functions was fit to a common value for the intercept. This is justified by the following logic. Zero $\bar{H}_t$ can occur in one of three ways: (1) S does not respond at all to the test stimuli in the choice reaction task, (2) S responds with the same response regardless of the stimulus presented, or (3) S responds with a randomly selected response equally often in the several response categories. One may disregard the no-response situation as inappropriate to the basic instructions on any reaction-time task. The other two ways of generating zero $\bar{H}_t$ are conceivable under extreme speed conditions (although no S did perform her way in the present study), and we may consider the consequence of such a situation. The major consequence is that the intercept of a fit such as that in the bottom panel of Fig. 3 would represent the minimum time to complete the initial coding (Stage 1) of just enough information to enable S to ascertain that some stimulus has occurred on the display. It is not necessary to determine which stimulus has been presented, as S can preprogram a response; therefore, only the limited information of stimulus occurrence had to be transmitted through Stage 1.

Stages 2 and 3 to release the selected response. Now, granted the above, there is no real reason to expect that this minimal Stage 1 time would differ in dual-task condition from that in single-task condition. Therefore, we may fit the two sets of data points

Fig. 3. Intercept constants a from Fig. 2 as a function of response load (top two panels), and the intercept constant c as a function of average information transmitted (bottom panel).

of Fig. 3 through a common intercept. In doing so for the present data, an iterative procedure was followed, using different common intercepts until minimal errors of prediction were achieved across all four data points in Fig. 3. The common intercept value determined by this procedure was 70 msec. As can be seen in the figure, the fitted intercepts were 71 and 68 msec for the single- and dual-task conditions, respectively.

Certainly the 70 msec suggested by these data should not be interpreted as some absolute minimum Stage 1 time. Different experimental conditions, such as degraded viewing conditions, would be expected to yield different estimates of minimal Stage 1 times. The constants of interest here are the slope constants of Figs. 2 and 3, and we now turn to interpretations of these processing time estimates.

DISCUSSION

Following the Briggs and Swanson (1970) procedure of decomposing overall reaction time into several processing-time constants, we note the following statement of additivity for the present data:

$$RT = i + j(\bar{H}_t) + b(H_c) + e(R)$$

As fit to the single-task condition

$$RT = .071 + .150(\bar{H}_t) + .072(H_c) + .079(R)$$

while for the dual-task condition, the statement is

$$RT = .068 + .214(\bar{H}_t) + .066(H_c) + .077(R)$$

The constants i and j have been interpreted as component times within Stage 1, while b has been interpreted as central processing, or Stage 2, time, and e may be interpreted as response decoding (Stage 3) time. In agreement with the results of Experiment 1, the central processing time for the dual- and single-task conditions (66 and 72 msec, respectively) are comparable, and they are only slightly faster than that time estimated in the earlier experiment (76 msec). Further, the two Stage 3 time constants are quite similar (77 and 79 msec, respectively). Only the j time constant differs considerably between the two levels of divided attention, with a shorter time constant being obtained in the single-task condition (150 msec) than under the dual-task condition (214 msec). Therefore, it may be concluded that the divided-attention effect is localized within Stage 1.

Briggs and Swanson (1970) followed the earlier lead of Swanson and Briggs (1969) in interpreting $j(\bar{H}_t)$ as the cycle time for a stimulus sampling process such as the Sperling (1967) SCAN mechanism; the constant i , then, may be interpreted as the average time for all other processing within Stage 1, including the development of information in a short-term sensory store plus time for any preprocessing that may occur prior to the central processing of Stage 2. On this interpretation, the divided-attention effect is manifested in the stimulus sampling process of Stage 1.

It is convenient to utilize the reciprocals of the time constants b , e , and j in an interpretation of these results based on the sequential processing model of E. Smith (1968). Such reciprocals are estimates of the rates of gain of information through the several stages. For this purpose, average values (across the two divided-attention levels) were utilized for the b and e constants. The following is offered by way of interpretation: (1) A stimulus appeared at the auditory display; (2) more stimulus information than would be utilized was loaded into a short-term sensory store; (3) this information was sampled at a rate of

6.7 bits/sec under the single-task condition but at the slower rate of 4.7 bits/sec under the dual-task condition; (4) following Stage 1, central processing occurred at a rate of approximately 14.5 bits/sec for purposes of classifying the test stimulus as to membership in the positive or the negative set; and finally (5) the appropriate response was decoded at an average rate of 12.8 responses/sec. Since there was .5 bit of uncertainty per response, the response-decoding rate may also be identified as $12.8 \times .5 = 6.4$ bits/sec.

It follows from these results, as from those of Briggs and Swanson (1970), that Stages 1 and 3 represent the "bottlenecks" in processing information through the human operator. Further, the present results indicate that a stimulus sampling function becomes even more of a restriction in the processing of information under dual-task conditions, the estimated rate found here being about 70% as fast as that under single-task conditions. Thus, the comparable levels of accuracy under the two levels of divided attention (see Table 2) were achieved by a slower rate of stimulus sampling under dual- than under single-task conditions.

It follows also that Welford's (1968) hypothesis (that Stage 3 is the locus of the divided-attention effect) is not supported by the present results. Not supported either is the suggestion by M. Smith (1969) that the effect is localized in the central processing stage (Stage 2), where detailed analysis of the stimulus occurs. Certainly, if one constructs two tasks such that heavy loading occurs specifically in Stages 2 or 3, then it may be possible to find the divided-attention effect in processes other than the stimulus-sampling function of the initial encoding stage. But when loading is broadly based across stages, as in the present study with a tracking task, then the primary divided-attention effect seems to be

manifested rather early in the processing of information through the human observer as suggested originally by Broadbent (1958) and by Treisman (1960).

Finally, it should be noted that Broadbent (1971, pp. 280-281) does not recommend interpreting time constants, such as those derived above, as rates of processing information through several sequential stages between input and output. He uses an analogy of timing a single car from entry to exit of a stretch of road. Suppose, for example, that it took a car .5 h to traverse the course, on the average. Clearly it would be erroneous to take the reciprocal of this "reaction time" and conclude that the capacity of the highway is two cars per hour. However, this analogy is not particularly appropriate to an analysis of choice reaction time data as in the present study. Here one is talking about the rate at which uncertainty is resolved about "what class of stimulus is out there," not about the rate at which a "particle" of information moves through the system or its component parts (stages). Thus, in the present study, Stage 2 processes reduced uncertainty at a higher rate than did either the Stage 1 or Stage 3 processes, and within Stage 1, the reduction of uncertainty occurred at a slower rate under dual-task than under single-task conditions. When the human operator processes information, electrical codes do move through the system, but one's use of a communication model and the accompanying information metrics in these situations is for the purpose of assessing the resolution of uncertainty, not the speed of movement of codes through the peripheral and central nervous systems.

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