Components of attention

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COMPONENTS OF ATTENTION [1]

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The study of human attention may be divided into three components. These are alertness, selectivity, and processing capacity. This paper outlines experimental techniques designed to separate these components and examine their interrelations within comparable tasks. It is shown that a stimulus may be used to increase alertness for processing all external information, to improve selection of particular stimuli, or to do both simultaneously. Development of alertness and selectivity are separable, but they may go on together without interference. Moreover, encoding a stimulus may proceed without producing interference with other signals. Thus, the contact between an external stimulus and its representation in memory does not appear to require processing capacity. Limited capacity results are obtained when mental operations such as response selection or rehearsal must be performed on the encoded information.

The subject of attention is a broad one. There are many definitions of it and subcategories included under it. In a recent book, Moray (1970) has proposed at least six different meanings of the term attention in current psychological research. It would be premature to propose any single taxonomy or exhaustive set of categories for the term. However, both in looking at the various definitions that Moray proposes and in reviewing the literature, there do appear to be three major topics under which studies of attention might be grouped.

First is the notion of alertness. Maintaining attention in the sense of alertness [3] is presumably involved in human ability to perform in long, boring tasks like those that psychologists design to study vigilance (Mackworth, 1970). The ability to develop and maintain an optimal sensitivity to external stimulation is also studied when subjects (*S*s) receive a warning to prepare themselves to take in information. The foreperiod of a reaction time task may be considered as a miniature vigilance situation where alertness must be developed rapidly and maintained over a relatively brief interval. Recent studies have investigated the time course (Bertelson, 1967) and the brain activity (Karlin, 1970; Näätänen, 1970; Posner & Wilkinson, 1969) during this interval. It appears that there is some similarity between the brain processes which take place during the foreperiod and those involved in vigilance tasks (Wilkinson & Haines, 1970). These studies provide some rationale for including alertness as a general component of attention.

A second sense of attention is the ability to select information from one source or of one kind rather than another (Egeth, 1967; Triesman, 1969). Studies of selective attention may require that *S*s report information from a particular sensory modality, spatial location, or content (letters rather than digits). Broadbent (1958) has argued that at least some aspects of selection are performed by filtering mechanisms which block out or attenuate input. Other theories have stressed additional operations which are performed on information of particular importance (Deutsch & Deutsch, 1963; Norman, 1968). These views bear a relationship to physiological models of attention that have stressed

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[3] The term alertness is used here rather than arousal to avoid the emotional connotation of many uses of the latter term. The degree of separation of the terms is not clear at this point.

three theoretical components of attention outlined above. Two major questions are considered. First, Can the warning function and the selective function of the first letter be separated? If so, how do the two functions relate? Second, What is the relationship between these two components of attention and central processing capacity?

PREPARATION

Many investigators have studied the period of time between a warning signal and a signal related to the required response (Bertelson, 1967). Of primary interest are studies where *S* has little uncertainty about when the response-related signal will occur. This is achieved by using blocks of trials with a fixed warning interval. Whether the response task involves reaction time (Bertelson, 1967), signal detection (Egan, Greenberg, & Schulman, 1961), or other types of processing (Leavitt, 1969), the results are similar. Performance is worse with no warning and improves as the warning interval increases to some optimal value. This value is most frequently about .2–.5 second. An interval longer than optimal tends to produce a decrease in performance, but this is usually not as pronounced, particularly when feedback is used to keep motivation high.

Figure 1 indicates functions obtained using two-letter matching tasks (Posner & Wilkinson, 1969). Both tasks involved a warning signal followed after a foreperiod by a pair of letters. The foreperiod was constant for a block of trials but varied between blocks. The *S*s had a single key which they pressed when the letter pair was defined as "same" for that task. The solid line is for a task which required *S* to press a key if the letters were physically identical, while the dotted line required him to press the key if both letters were either vowels or consonants. Although RT differs greatly in the two tasks, the time course of preparation is very similar and like that described in the studies cited above.

ENCODING

If *S* is provided with part of the information he needs to perform a speeded task, his RT when he receives the remainder will be reduced (Cohen, 1969; La Berge, Van Gelder, & Yellott, 1970; Leonard, 1958). If the time between the two signals is varied, it is possible to discover how long it takes to encode the first signal in a form which is op-

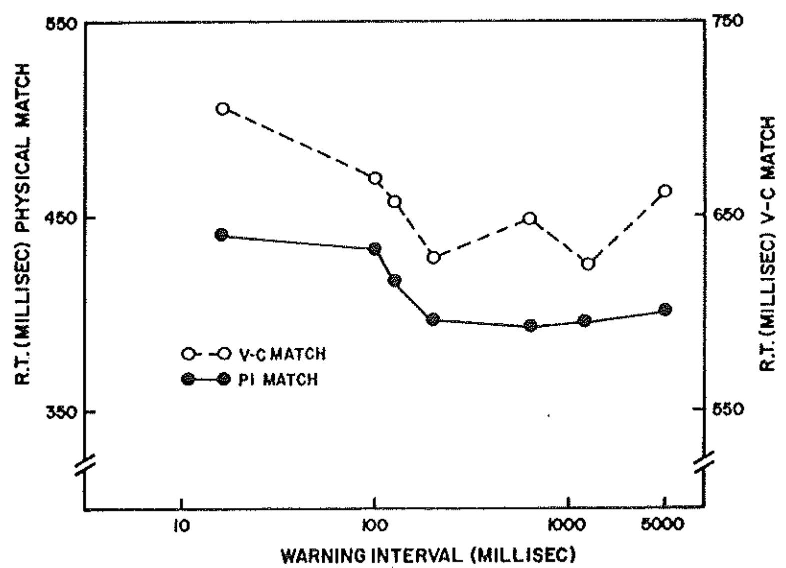

FIG. 1. Preparation functions for physical (PI) match task (solid line, left ordinate) and vowel–consonant (V–C) match task (dotted line, right ordinate). (Data are from constant block foreperiods of each warning interval collapsed across four days; after Posner & Wilkinson, 1969.)

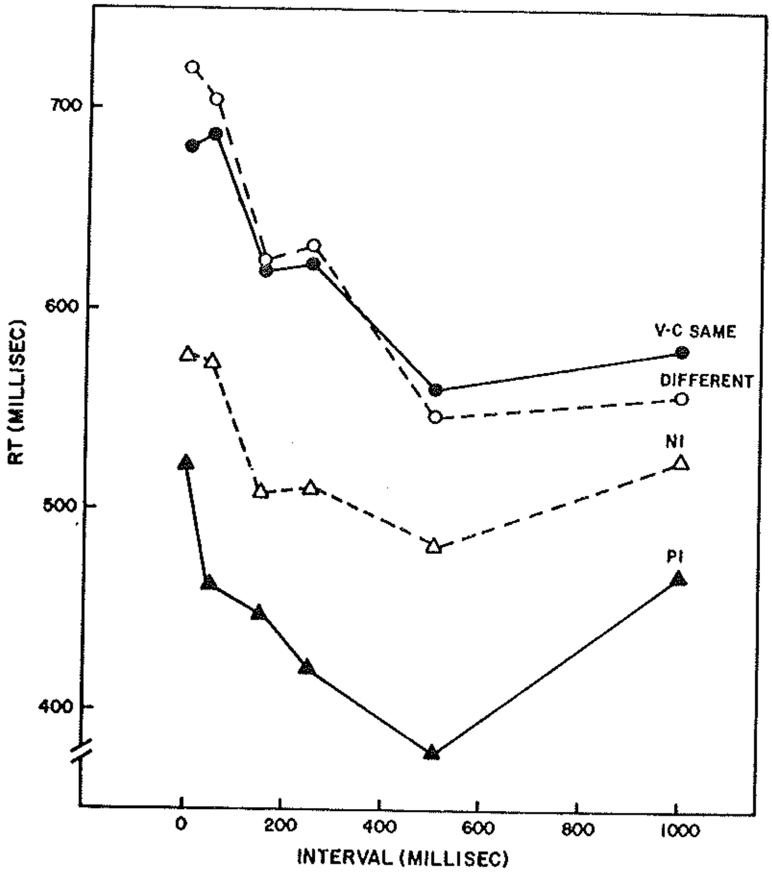

FIG. 3. Encoding functions for vowel–consonant (V–C) match task. (Constant warning interval of 500 msec. with constant blocks of various ISIs. NI = name identity, PI = physical identity.)

levels is strikingly similar in both experiments. The optimal RT is at 500 msec. in all functions. This finding appears to be robust over the distribution of intervals, since a control study using intervals of 0, 1, 50, 150, 250, and 500 showed almost the same function as that obtained for the first five points of Figure 2. The same result is also obtained in encoding functions discussed in the next section (see Figures 4 and 5). There is some tendency for sharpest improvement in RT to occur later for more complex matches. Most of the improvement for physical matches appears to come in the first 150 msec. This is much less true of vowel–consonant matches, which show a sharp improvement between 250 and 500 msec. The extent of improvement appears to be slightly greater for vowel–consonant matches than for other types, but name matches do not show much more improvement than physical matches.

In general, encoding and preparation functions appear to be rather similar. Both show an optimal point at about 500 msec. Both tend to give greater improvement for vowel–consonant than for physical matches. The next experiment is designed to compare them more directly.

PREPARATION AND ENCODING

If S is given 500 msec. to prepare, his RT will be about optimal. If he is given information at the end of that 500 msec. about what he is to select, he shows a further improvement which also goes on for about 500 msec. Are these two improvements due to two separate processes, or are they merely two different ways of studying the same overall process? A paradigm was designed

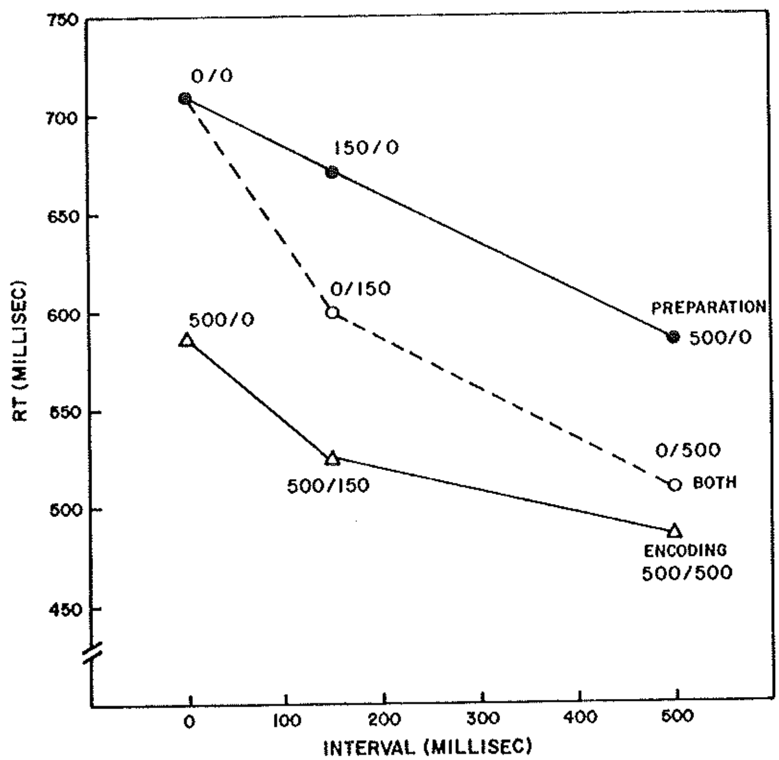

FIG. 5. Preparation, encoding, and "both" functions for name matching task. (Values of WI/ISI are shown for each point.)

Results

Three functions can be drawn from the seven conditions. Each condition involving a combination of one WI and one ISI. A preparation function involves conditions 0/0, 150/0, and 500/0 (WI/ISI). This function is shown in the upper curve of Figures 4, 5, and 6.

The encoding function is obtained from conditions where *S* has always had a full 500-msec. WI and either 0-, 150-, or 500-msec. ISI. This is shown in the lower curve of each figure. When there is no warning signal, the first letter serves both as a warning signal and to provide selective information. The function obtained from conditions 0/0, 0/150, and 0/500 is called the "both" function and is shown as the middle line of each figure. The figures show the mean of the median RTs for each condition.

The main effects of WI and ISI on RT are highly significant in all experiments. In all three experiments there is an interaction between WI and ISI. An interaction between two independent variables has been interpreted (Sternberg, 1969) as indicating that they affect the same stage of processing. In the present case, WI and ISI may be thought to interact because they both affect alertness. At zero WI, alertness must be varying during the ISI, while with an optimal WI, *S* may already be alert and thus ISI would mainly involve encoding of information from the first letter.

Table 2 shows the amount of improvement (from the 0/0 condition for preparation and "both" and from the 500/0 for encoding) due to preparation, encoding, and both together. The results clearly indicate that in the case of physical and name instructions, the improvement obtained in the "both" condition is almost exactly the sum of that obtained separately from the preparation and encoding functions. In the vowel–consonant case, there appears to be a more substantial departure from additivity, but these are not significant due to high variability among *S*s in this condition.

responses are identical in simultaneous presentation has not been universal (Krueger, 1970; Posner & Mitchell, 1967). This appears to depend on many factors. It was suspected that one such factor was assignment of hands. To check on this, a control study was run which assigned six *S*s "same" on the left and six *S*s "same" on the right. The experiment involved ISIs of 0, 50, 150, and 500 msec. with a 500-msec. WI. The physical match instruction was used. The data for left-hand "same" *S*s replicated Figure 7 perfectly. For *S*s assigned "same" on the right, however, "same" was faste even with simultaneous presentation. However, regardless of hand assignment, the significant divergence over time between "same" and "different" responses was found (see also Figure 2 and Corballis, Lieberman, & Bindra, 1968).

TABLE 2

AMOUNT OF IMPROVEMENT IN REACTION TIME FROM PREPARATION, ENCODING, AND BOTH

Match	Interval[a]	
	150	500
Physical		
Preparation	58	122
Encoding	53	73
Both	101	195
Name		
Preparation	42	127
Encoding	58	98
Both	111	201
Vowel-Consonant		
Preparation	71	170
Encoding	124	150
Both	157	296

Note.—Improvement is measured by subtracting RT at specified interval from RT at 0/0 for preparation and "both" function and 500/0 for encoding.
[a] In milliseconds.

The finding that presentation of the first letter improves the efficiency of handling an identical letter suggests that the first letter changed *S*'s sensitivity to a letter of identical form. One way of conceptualizing this is in terms of Sokolov's neural model idea (Sokolov, 1963). The first letter serves as

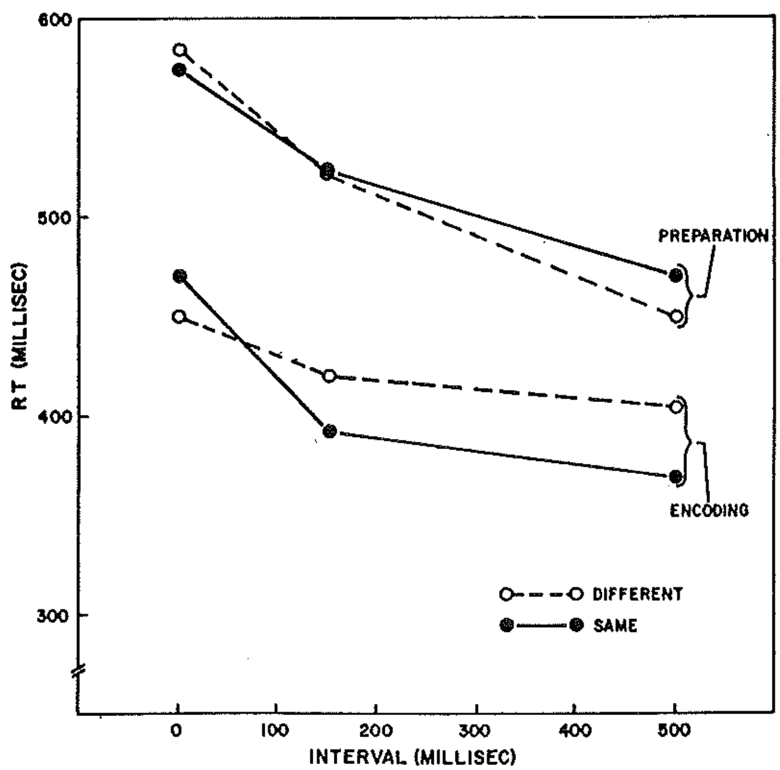

FIG. 7. "Same" versus "different" match RTs as a function of interval for preparation and encoding functions of physical match task.

now remains to relate each of them to the third component of attention.

PROCESSING CAPACITY

One sense of attention involves competition between signals for some limited capacity system (James, 1890). The idea is that many tasks place demands on a central limited capacity system and thus tend to interfere. This basic idea has led to a number of experiments which have attempted to measure the attention demands of one task by its interference with a secondary task (Welch, 1898; Welford, 1968). One way of doing this is to use a probe as the standard secondary task. For example, Näätänen (1970) measured the evoked potential to auditory clicks, which were probes occurring during a visual RT task. Posner and Keele (1967) and Ells (1969) used a simple or choice RT task as a probe during a movement task. Foss (1969) used a probe RT to study processing of sentences. The advantage of a probe RT task is that the experimenter can measure both the RT to primary and secondary tasks and thus be certain what effects each is having on the other. In studying movements, it was found that the probe had little effect on the primary movement task, but that the probe RT reflected the central processing demands of the primary task in a very sensitive way. For example, prior to the movement, probe time was a function of a number of alternative movements and was unrelated to target width. During the movement, probe time was a function of target width and unrelated to number of alternatives (Ells, 1969). These findings suggested very strongly that probe RTs could provide a dynamic picture of the central processing demands of primary tasks.

The probe technique applied to the letter-matching sequence might indicate how preparation and encoding are related to central processing capacity. Of particular interest is whether preparation for a visual signal served to improve or retard RT to signals coming from another modality (Hernandez-Peón, 1966; Näätänen, 1970). Another question is whether encoding itself requires processing capacity in the sense of interference with a probe RT. Finally, there is the question of what aspects of letter matching seem to demand the greatest involvement of processing capacity.

Method

The same apparatus was used as described previously. A trial consisted of a warning signal followed after a WI with the first letter, which remained on until the presentation, after an ISI of a second letter adjacent to it. After each trial, feedback was provided on the correctness and RT for the letter match. The values of the WI, ISI, and intertrial interval (ITI) are given for each experiment in Table 3. On half of the trials, 50 decibels of white noise was turned on in *S*s left ear at one of eight positions in the trial. The probe occurred equally often in each of the eight positions. The *S*s were instructed that the letter task was primary and that they were to press their right index finger if the letter had the same name and their right middle finger if the names were different. They were told to press their left index finger whenever they heard the white noise burst. Feedback on the letter-matching task did not occur until both responses were complete. No feedback was provided on the noise RTs.

In Experiment I, *S*s ran six 48-trial blocks per day. Each block was identical in form. All the first letters were uppercase and the second letters

TABLE 3

INTERTRIAL, INTERSTIMULUS, AND WARNING INTERVALS AND FIRST-LETTER EXPOSURE DURATIONS (IN SECONDS) FOR EACH EXPERIMENT

Experiment	ITI	WI	Exposure duration	ISI	Probe positions (milliseconds following warning signal) 1	2	3	4	5	6	7	8
I	8–15 variable	1	.5	.5	−3000,	−2000,	150,	600,	1100,	1300,	1600,	1900
II	4–6 variable	.5	1	1	−500,	150,	550,	650,	800,	1000,	1650,	1800
III	4–6 variable	.5	.05, .150, .500, 1.000 variable	1	−500,	150,	550,	650,	800,	1000,	1650,	1800

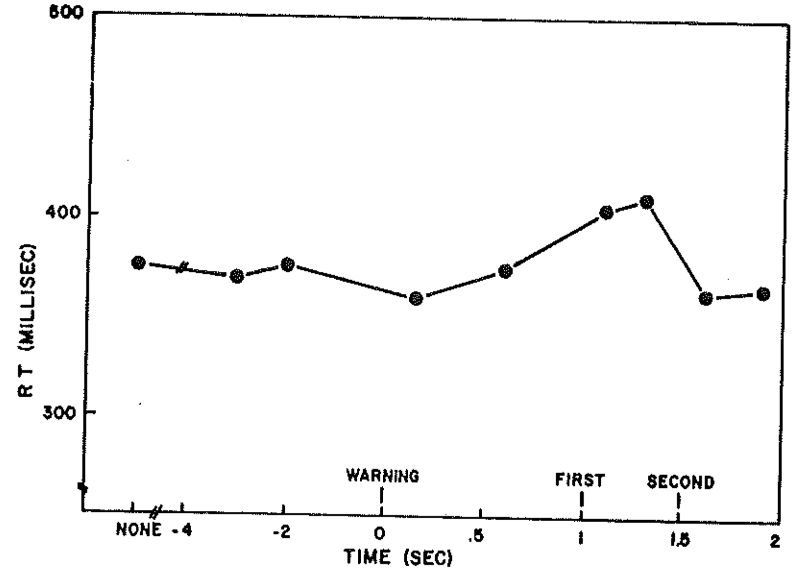

FIG. 10. Letter match RTs as a function of probe position for Experiment I.

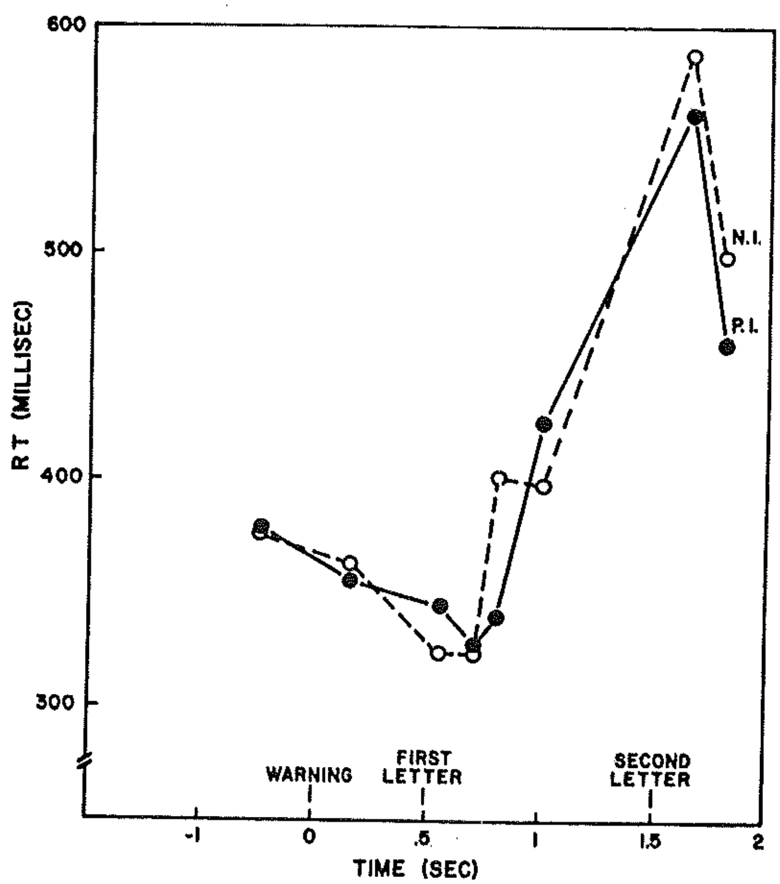

FIG. 11. Probe RTs as a function of probe position for Experiment II.

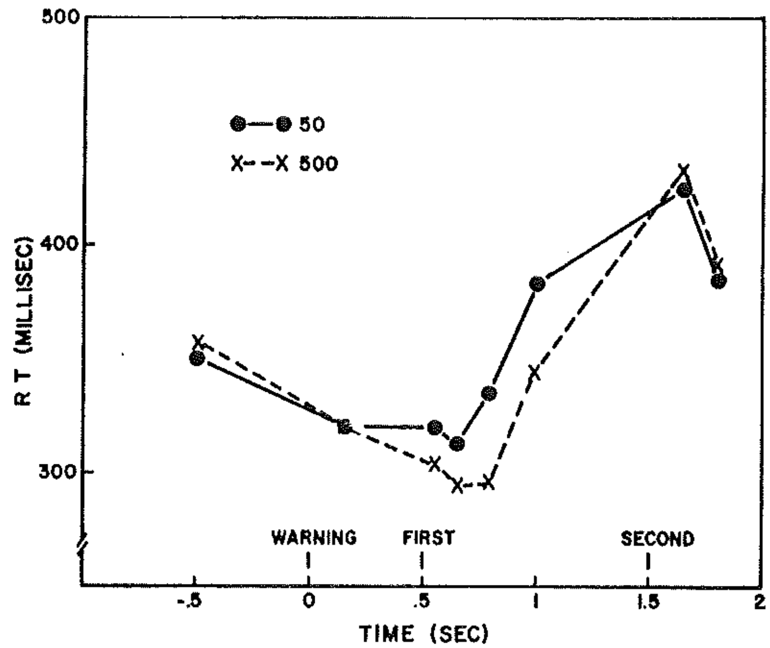

FIG. 13. Probe RTs compared for exposure durations of the first letters of 50 and 500 msec.

experiment was otherwise identical to the name letter-matching condition of Experiment II. Figure 13 shows the results for seven *S*s who ran in this experiment for five days. The data represent probe times on Days 4 and 5 for trials which had only 50-msec. exposure of the first letter and those for which the first letter was on for 500 msec. The RT results together with genally very low error rate indicates that *S*s are not switching away from the letter task. If they were, they would miss many of the 50-msec. exposures. Moreover, the probe curves from this study are quite similar to those illustrated in the previous studies. Even if the first letter was turned off after 50 msec., *S* does not show substantial interference with the probe until 500 msec.

Another possibility is that *S*s are learning the distribution of the probes and respond most rapidly to those in the middle of the distribution. This possibility seems rather remote—in part because of the low frequency of probes at any position (only on 1/16 of the trials), but also because of the complex shape of the RTs as a function of probe position. Probe Positions 4 and 5 are the two mid positions and should be fastest based on an expectancy idea. These show very different results in both Figure 9 and in the name match condition of Figure 11. Moreover, the probes at Position 8 are quite fast although they are at the end of the distribution. In addition, the results shown in Figure 13 illustrate that the point at which the first letter is turned off has small but systematic effects on the probe RTs in the direction which would be expected if *S*s were showing interference from letters which were removed somewhat more rapidly than those which remained present. Thus, it appears that probe RT reflects the attention demands of the primary task.

CONCLUSIONS

The introduction outlined three component processes involved in the study of attention. These are alertness, selectivity, and processing capacity. In this paper each of these components was identified with a particular experimental operation. Alertness was studied by varying the time between a warning signal and a pair of letters which *S* was required to match. Since the warning signal more efficient. Thus, in the "both" condition, a single letter would lead to a general alertness and a specific activation, which contribute additively to the overall reduction in RT. Of course, the activation of such areas of memory could come either from internal or external sources.

The nearly perfect time sharing between preparation and encoding suggests that at least one of these mental operations does not require central processing capacity. If they both did, they would be expected to interfere. In order to further test whether alertness and encoding were free of demands on processing capacity, the attention demands of the letter-matching tasks were measured by introduction of a simple probe RT task to white noise. The results suggest that a warning signal serves to reduce RT both to the main task and to the probe task, even when probes were introduced on only half the trials. Moreover, the encoding of the first letter did not seem to interfere with the probe task, provided *S*s had one second before the second letter was introduced. This was the case even when the first letter was turned off so that *S* had to encode quickly. This suggests that encoding of a letter does not require processing capacity as we have defined it here. Of course the reasonableness of the conclusion depends on the assumption that probe RT will be sensitive to processing demands of the primary task.

Interference with the probe was significant when it was introduced 500 msec. prior to the second letter. The interference was not due to the physical occurrence of the second letter, since the effect was still present when all RTs above 500 msec. were eliminated. What aspect of the letter matching causes interference with the late probes? One possible explanation is that such mental operations as rehearsal or generation of distinctive features for testing, which follow encoding of the first letter, require processing capacity, while encoding itself does not.

These results suggest that attention in the sense of central processing capacity is related to mental operations of which we are conscious, such as rehearsing or choosing a response, but is not related to the contact between the input and long-term memory that leads to the letter name. Several lines of evidence have tended to relate single-channel effects to response selection rather than all forms of stimulus processing (Herman & Kantowitz, 1970; Keele, 1970). Moreover, other research has indicated that conscious awareness is itself rather late in the sequence of mental processing (Fehrer & Raab, 1962; Libet, 1966). If single-channel effects were tied to conscious processing, one would not expect to see them closely correlated with encoding of the first letter (Deutsch & Deutsch, 1962; Norman, 1968), but rather with operations on the retrieved product of such encoding. The data obtained in this study appear to be consistent with such a view.

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