Response time to the second of two signals following varied vs constant intersignal intervals¹

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The Ss made choice responses under three experimental conditions: (1) a variable interval between the warning signal and the signal to respond, (2) a constant interval between the warning signal and the signal to respond, and (3) omission of the warning signal. With variable intersignal intervals (ISI), response time (RT) was inversely related to ISI at least when the latter was in the 10 to 225 msec range. When ISI was constant its duration had no perceptible effect on RT. RT tended to be shorter with constant ISI, independent of its duration, than when the warning signal was omitted altogether.

It has been demonstrated repeatedly that the time to respond to the second of two signals (RT_2) may be unusually long when the interval between the signals is sufficiently brief. More specifically, various experimental conditions have yielded an inverse relationship between RT_2 and the duration of the intersignal interval (ISI), over a limited range of intervals. For recent reviews of the pertinent literature, see Bertelson (1966) and Smith (1967). A few experiments have been reported, however, in which this effect was not obtained; that is, RT_2 did not vary with ISI even over the range of intervals for which the inverse relationship most frequently had been found to hold (Borger, 1963; Davis, 1962; Poulton, 1950; Rubinstein, 1964). In these cases, it may be noted that (1) S_1 did not require an overt motor response, (2) it did not carry information that had to be assimilated in order to perform the RT task, and (3) with the exception of Rubinstein's (1964) experiment, the intersignal interval was constant over a block of trials.

One of the situations investigated by Davis (1962) might appear to constitute an exception to (2) since the task involved reporting which of two possible signals had occurred as S_1 . However, the report was made following the response to S_2 . Davis suggested the possibility that in this case S_1 might have been stored momentarily and analyzed only after the response to S_2 had been made. At any rate, it seems fair to say that S did not have to attend to, or extract information from, S_1 in order to respond correctly to S_2 .

The importance of the third point is emphasized by the fact that an interval effect sometimes has been obtained with variable intervals even when S_1 required no overt response and could have been ignored (e.g., Davis, 1959, 1962; Nickerson, 1965, 1967).

The present experiment was designed to investigate further the role of the trial-to-trial variability of ISI in determining the relationship between RT_2 and the duration of the interval. The design was similar in many respects to that of Davis' (1962) experiment and to a study reported more recently by Gottsdanker and Way (1966).

METHOD

The following three experimental conditions were used.

Variable Interval (V)

A pair of visual signals was presented on each trial. S_1 was a 1/8-in. square which appeared in the center of a 14-in. cathode ray tube; S_2 was a 3/16-in. square which appeared either 2-1/4 in. to the left or 2-1/4 in. to the right of center. Nine different ISIs were used; the briefest was 10 msec, and the remaining eight ranged in 75 msec steps from 75 to 600 msec. (These numbers refer to the time between signal onsets.) The order of occurrence of the different ISIs and the left-right positioning of S_2 were random with the restriction that each ISI occurred once in conjunction with an S_2 on the left, and once with an S_2 on the right, in each successive block of 18 trials. Fifty-four trials constituted an experimental run. The S 's task was to press one of two telegraph

keys, specifically that key indicated by S_1 , as quickly as possible following the occurrence of that signal. No response was required to S_1 . The offset of S_1 coincided with the onset of S_2 ; the latter remained illuminated until S pressed a key. The duration of the interval from a response to the following S_1 was constant at 3 sec.

"Dummy" Interval (D)

This condition was identical to that just described, except that S_1 was omitted altogether. Only a single signal occurred on each trial: the S_2 of condition V. The duration of the interval from a response to the following signal varied from 3 sec 10 msec to 3 sec 600 msec, i.e., it included both the 3-sec constant and the variable interval of condition V. Thus, for the sake of comparing the results across conditions, we may look at RT under condition D as a function of the duration of the "dummy" ISI, understanding this to represent what the ISI would have been, had S_1 occurred as in condition V.

Constant Interval (C)

Condition C differed from condition V in that the ISI was constant during an entire experimental run. It assumed the same values as in condition V, but varied only between runs, never within. The left-right positioning of the signal was random with the restriction that nine of each occurred within each successive block of 18 trials.

It should be stressed that all three conditions were disjunctive RT situations. That is, the signal to which S was to respond indicated not only *when* to respond, but also it identified *which* of the two possible responses to make.

Four female college students served as S s, each of whom encountered the different experimental conditions in the following order: One practice and three data runs under condition D, one practice and three data runs under condition V, one practice and two data runs with each of the nine ISIs under condition C, one additional practice and three additional data runs under condition V, and one additional practice and three additional data runs under condition D. In the case of condition C, two of the S s encountered the different ISIs in the order of increasing duration and two of them in the reverse order. An experimental run took approximately 4 to 5 min to complete; S s received at least a 5-min break between successive runs. The experiment was conducted under the control of a PDP-1 computer that was programmed to schedule and present signals, measure RTs and produce a trial-by-trial punched paper tape record of each run.

RESULTS

Under conditions D and V, each of the nine different ISIs occurred six times during a single experimental run. In these cases, means were computed for each set of six RTs associated with a particular ISI and an individual run. Under condition C, the same ISI occurred 54 times during a run. In this case a mean RT was determined for the entire run. All RTs were used in determining means except those collected on practice runs and those associated with incorrect (wrong key) or early (pre- S_2) responses. Figure 1 shows these means averaged over S s and runs.

The figure clearly indicates the importance of the trial-by-trial variability of ISI in determining the inverse relationship between ISI and RT_2 under the conditions of this experiment. With a variable ISI, all four S s showed the characteristic sharp decrease in RT with increases in ISI, at least for ISI < 225 msec. For two of the S s RT continued to decrease, although not sharply, as ISI increased beyond this range. With constant or "dummy" intervals, the sharp decrease in RT with increasing ISI was not obtained.

Fig. 1. Response time to S_2 as a function of the duration of the intersignal interval.

Figure 1 also indicates that RT tended to be shorter with constant than with "dummy" intervals. This was generally true of the data of individual Ss; that is, each S produced shorter RTs with constant intervals at nearly all interval durations.

The overall error rate, including both early and incorrect responses, was very low, the relative frequency of errors being about .01. Table 1 shows error rates in terms of experimental conditions and the duration of ISI. No obvious pattern emerges from this breakdown. The only suggestion of any effect is the possibility that in the case of constant ISI the error rate may have been relatively high for the shortest (10 msec) interval.

DISCUSSION

The results corroborate earlier studies showing an inverse relationship between RT_2 and the duration of a variable ISI, even when S_1 carried no information that was essential to the performance of the task (Davis, 1959, 1962; Nickerson, 1965, 1967). They also agree with the results obtained by Davis (1962) in showing no delay in R_2 with ISIs of constant duration even with the briefest durations used. The present data even suggest that the occurrence of S_1 may have facilitated the response to S_2 with constant ISIs that were well within the range usually associated with the "psychological refractory period."

As noted in the introduction this experiment was similar in many respects to one recently reported by Gottsdanker and Way

(1966). The major procedural difference between the experiments was the fact that in the latter both signals required a choice response, whereas in the present case no response was required for S_1 . Other differences involved the range, number, and distribution of ISIs used, the nature of the required responses, and the set of conditions studied. In spite of these differences, the curves showing RT_2 as a function of variable ISI are very similar for the two experiments. The results also agree in showing RT_2 to be generally shorter for a constant ISI than for a variable ISI of the same duration, the difference increasing as the duration of ISI decreases.

The major differences between the results of Gottsdanker and Way's experiment and those of the present one were the following. First, the former gave some evidence of an interval effect under the constant ISI condition. For four of eight Ss, RT_2 varied significantly with ISI; however, apparently not all of these Ss produced the longest RTs with the shortest ISIs. Second, in Gottsdanker and Way's experiment, RT_2 was not generally shorter with constant than with "dummy" intervals. Third, also in that experiment, the RT_2 curves for variable and "dummy" ISI conditions did not cross. The last two points may be summarized by saying that relative to the RT_2 s obtained with variable or constant ISIs, those obtained with "dummy" intervals were shorter in Gottsdanker and Way's experiment than in the present one. Possibly this difference may be attributed to the specifics of the trial-by-trial procedures used. On every trial in Gottsdanker and Way's experiment, a warning signal was given 1 sec before the occurrence of S_1 (or before the time that S_1 would have occurred had it not been omitted). In the present experiment no warning signal was used. Thus in the Gottsdanker and Way experiment the time between warning signal and the signal to respond, in the "dummy" interval condition, varied from 1.05 sec to 1.80 sec; whereas in the present case, the only time marker in the "dummy" interval condition was the just prior response; the time between it and the signal to respond varied between 3.01 sec and 3.60 sec. If 1-2 sec is a more effective warning interval than is 3-4 sec, then we might expect relatively shorter RTs in the former case.

At first glance, the results of the present experiment might appear to support an expectancy explanation of the delays obtained under condition V, the argument being that the important difference between conditions V and C is the greater degree of temporal uncertainty associated with the former. Remove the temporal uncertainty and you eliminate the cause of delay. With such an argument, however, one is left with the problem of accounting for the fact that RT_2 was greater when a variable ISI was very brief than when S_1 was omitted altogether (condition V vs condition D). In both conditions V and D, the objective momentary probability of the occurrence of S_2 increased monotonically with waiting time (following the occurrence of S_1 in condition V and following the point at which S_1 would have occurred, had it not been omitted, in condition D). Clearly, uncertainty concerning the moment of occurrence of S_2 is not increased by the occurrence of S_1 . Indeed, it may be argued that S_1 should reduce the temporal uncertainty since it marks the beginning of the interval during which S_2 would occur. Perhaps it is the very fact that S_1 did serve this function that accounts for the obtained delays.

Suppose that S can maintain a maximum preparedness to

Table 1
Relative Frequency of Early (pre- S_2) and Incorrect (wrong-key) Responses
for Each ISI under Each Experimental Condition

Type error	Condition	ISI (msec)								
		10	75	150	225	300	375	450	525	600
Early	V	0	0	<.01	0	.02	<.01	.01	.01	.02
	D	.01	<.01	0	.01	.01	.01	.01	.01	.01
	C	.03	0	0	0	0	0	0	0	.01
Incorrect	V	<.01	<.01	.01	<.01	<.01	.01	0	.02	.02
	D	.01	<.01	<.01	0	<.01	0	<.01	0	<.01
	C	.03	<.01	0	0	0	0	0	0	.01

respond only for very short periods of time. Or, more generally, suppose that the higher the level of preparedness maintained, the greater the cost, in terms of effort, of maintaining it. Suppose further that S is unable, or unwilling, to expend more than a fixed amount of effort over a given period of time. For the same total effort then, he might maintain a constant intermediate level of preparedness for the full period, or he might maintain a relatively high level for some portion of the time, compensating for that with lower levels for the remaining portion. In the latter case, he would, presumably, attempt to maximize his preparedness during that period of time in which he considered the signal most likely to occur. As noted above, the difference between conditions V and D was that the beginning of the period during which the signal to respond (S_2) could occur was clearly marked (by the occurrence of S_1) only in the former case. That is, under the V condition, there was a distinct demarkation between the time during which it was not important for S to maintain peak preparedness and that during which it was. Assuming that he maintains a relatively low level of preparedness during the intertrial interval and that he treats S_1 as a cue to prepare to respond, we might expect results such as those obtained under condition V. Moreover, we would judge from the shape of the curve in Fig. 1 that reaching maximum preparedness takes on the order of 200-300 msec. In the case of condition D, the only basis that S has for marking the beginning of the interval during which the signal can occur is his ability to estimate the time that has elapsed since his last response. Because his ability to estimate time is limited, it might be better if he did not rely on it, and, instead, attempted to maintain an intermediate level of preparedness throughout a large proportion of the intertrial interval and until S_2 occurs. This strategy then might lead to results such as those obtained under condition D.

To the question of why should S adopt the suggested strategy under condition V, there are at least two plausible answers. First, attempting to maximize preparedness only during critical moments may simply make the experiment a less boring game from S's point of view than it would be were he to maintain a constant intermediate level of preparedness at all times. Second, it would be a reasonable strategy if, *on the average*, it led to shorter RTs. Note that for ISIs of greater than 150 msec, RT was generally shorter under condition V than under condition D. Mean RTs for these two conditions, pooled over all intervals, were, respectively, 253 and 256 msec; that is, under condition V, the time saved with the longer ISIs just about compensated for the delays incurred with the shorter ISIs. Thus, it is not clear that S *should* have ignored S_1 , if he *could* have.

Concerning the results obtained with ISIs of constant duration, two questions arise: (1) Why is the duration of the interval of no apparent consequence in this case? (2) Why is RT_2 shorter with a brief but constant interval than when S_1 is omitted altogether?

To the first question, one possible answer is that under these conditions, S simply ignored S_1 . We should note, however, that that signal could not have been ignored in a trivial way by "turning off" the receptors, as, for example, might have been the case if S_1 had been a visual, and S_2 an auditory, signal. Because of the spatial arrangement of the lights, maintenance of receptive posture with respect to S_2 assured a receptive posture with respect to S_1 . Thus, if S were to filter S_1 , he had to do so by means of a post-reception process; moreover, to account for the absence of delays in R_2 , the filtering process would have to be such that it did not interfere with the processing of S_2 . Whether this is indeed possible is, in fact, the question at issue, and the present results suggest that the answer to that question is yes.

Why should RT_2 be shorter with a brief but constant interval than when S_1 is omitted altogether? On the assumption that S successfully ignores S_1 under condition C, should we not expect

the results obtained under that condition to be identical to those obtained under condition D? The answer is not necessarily. The appropriate control against which to compare the results of condition C would have been a second D condition in which the "dummy" interval was constant. It is conceivable that the constancy of the R-S interval is sufficient to account for the relatively short RTs. Unfortunately, the appropriate control condition was not included, and its omission represents a serious flaw in the design of the experiment.

But is the conjecture that S may ignore S_1 a reasonable one? In keeping with the earlier argument concerning the advantage of maximizing preparedness for that period of time during which the signal is most likely to occur, would it not seem that S_1 is more worthy of attention in the case of condition C than in that of condition V? Clearly, it carries more precise temporal information under the former condition than under the latter.

Thus, in combination, the results are somewhat problematic. The delays obtained under condition V might be interpreted in at least two ways: (1) one might argue that S_1 , which could not be ignored, momentarily occupied the S's single-channel signal processor thus causing a delay in the processing of S_2 ; (2) alternatively, one might assume that S_1 could have been ignored, but was not because it served the function of reducing S's uncertainty concerning the moment of occurrence of S_2 . Underlying the second interpretation is the tacit assumption that informative signals require time to be processed. Either of these interpretations, however, would lead us to expect delays in R_2 with very short ISIs under condition C. If, indeed, S_1 cannot be ignored under condition V, there is no reason to believe that it can be under condition C. And, if it is reasonable to assume that S_1 carries time information under condition V, it seems clear that it carries even more precise time information under condition C.

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NOTES

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