USE OF A DELAYED SIGNAL TO STOP A VISUAL
REACTION-TIME RESPONSE [1]

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In a visual RT experiment, 5 male Ss were each confronted with 2
lights and instructed to respond to 1 light but not respond when
both lights occurred. The onset of the 2 lights was made asynchronous
by 0, 12, 33, or 63 msec. Probability of inhibiting the response
declined markedly for each delay and increased with RT. It was con-
cluded that choice RT is correlated with the extent of the stimulus
information processing and the duration of effective stimulation which
has preceded initiation of the motor event.

This experiment was motivated by an earlier attempt (Lappin & Eriksen, 1964) to replicate a finding that a simple visual reaction time can be inhibited by a second stimulus (Helson & Steger, 1962). No effect from the second stimulus was obtained in the replication. However, extension of the original experiment suggested another approach to the phenomenon found by Helson and Steger. If *S* is instructed to respond when one of two lights occurs but not to respond if both lights occur, how asynchronous can the onset of the two lights become before *S*'s ability to inhibit is impaired?

In light of the demonstrations (Raab & Fehrer, 1962; Raab, Fehrer, & Hershenson, 1961) that the simple RT response is sensitive to only the first millisecond or so of the visual stimulus, perhaps a retroactive inhibitory effect from a second stimulus should not have been expected in the previous experiment. However, some question still remains as to *S*'s ability to make use of a delayed signal when the experimental task *requires* the response to be modified when the signal appears.

Thus, when *S* must decide on each trial whether or not to respond, the time span of the effective visual stimulus may be greatly increased; the "psychological moment" (cf. Stroud, 1956) may be longer for choice RT than for simple RT. Indeed this is one way of viewing the results of Fehrer and Biederman (1962) and Fehrer and Raab (1962) who found no difference in the reaction times to visual stimuli phenomenally masked by metacontrast when compared with those which were not masked. A somewhat similar suggestion also appears in some recent data of Kristofferson's (1965). The decrement which he expected to result from modal uncertainty in a bisensory RT task was not obtained with simple RT, but only when some discrimination was required of the signals in each modality.

The present experiment is relevant also to observations of what is called the "psychological refractory period." In general it is found that the response to the second of two successive stimuli is less rapid than to the first (cf. Adams, 1961; Reynolds, 1964). However, numerous experiments have indicated variously that the source of this effect lies in (*a*) the operation of a central decision process (e.g., Davis, 1959; Nickerson, 1964; Welford,

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1952), (*b*) a multichanneled stimulus but single-channeled stimulus detector (Adams & Creamer, 1962; Creamer, 1963; Kristofferson, 1965), (*c*) an inadequate "set" to respond to the second stimulus (Adams, 1962; Adams & Chambers, 1962; Elithorn & Lawrence, 1955), or (*d*) response competition (Reynolds, 1964).

The apparent discrepancies and diversities in these studies may result from the fact that there are a number of conceptually distinct stages in the stimulus-response sequence where selection of one sort or another may occur. "Channels" might impose restrictions on load at perceptual, decisional, or motor levels, and so also "expectancy" might rear its head at several points. It remains to be shown that the decision necessitated in the choice RT experiment does or does not modify the temporal organization of visual signals from that operating in simple RT.

The present experiment can be described as follows: Two stimuli are presented in what is presumably the same sensory channel. One of these, the "go signal," appears on every trial, and the other, the "stop signal," has event uncertainty. Associated with the two stimuli are perfectly competitive responses—response vs. no response—which might also be assumed to occupy the same "channel." From some points of view the existence of event uncertainty and response competition are likely to place the delayed stop signal at a disadvantage in affecting the response. On the other hand, the fact that both members of the stimulus and response pairs are handled by the same channel might imply that only the operation time of a decisional stimulus-response mediator exists to modify their asynchrony from input to output.

In short, this experiment attempts to examine the relation between psychological and real time in effecting a disjunctive response to a visual stimulus.

METHOD

Apparatus.—The apparatus was basically similar to that of a previous experiment (Lappin & Eriksen, 1964). The stimulus lamps, however, were slightly brighter NE51H bulbs, operated with dc power in order to eliminate variation in onset asynchrony. Both remained on until *S* responded. The two lamps, mounted ¾ in. apart, subtended about 1.5° of visual angle. Separate Hunter interval timers controlled the three foreperiods and an automatic tape reader and relay device was used to select the foreperiod and stimulus events according to a preset random sequence. In addition, a second Hunter klockounter was placed in front of *S* to provide feedback on every trial.

Subjects.—Two graduate and three undergraduate male students in psychology at the University of Illinois served as paid volunteers.

Procedure.—Each experimental session consisted of 300 trials and was approximately 1 hr. long. The foreperiod was 1.5, 2, or 2.5 sec. and there were 5 sec. between the onset of the stimulus for one trial and the warning signal (a buzzer) of the next trial. Ten practice trials preceded the experiment proper. A break was taken after each 75 trials. Two conditions were run within a session, each consisting of 150 trials. The stop signal (a designated one of the two lamps, unchanged for a given *S*) was presented on a randomly selected 50 of these trials, and on the remaining 100 trials *S* responded to only the go signal (the other lamp). For a given condition, the stop signal was simultaneous with the go signal on 25 trials and delayed by a fixed amount on the other 25 trials. Four experimental conditions are distinguished by the delay of the stop signal: 0, 12, 33, and 63 msec. Each *S* was run three times in each condition and six sessions were run using each possible combination of two conditions. Prior to the six experimental sessions each *S* served in two practice sessions, using all four experimental conditions.

The *S* was instructed to respond as fast as possible to the go signal and still be able to inhibit the response on about 75% of the stop-signal trials. Thus, were it possible,

TABLE 1

MEAN RT TO GO SIGNAL (RT$_G$), PROBA-
BILITY OF INHIBITING TO SIMULTANEOUS
[$P(I_S)$] AND DELAYED [$P(I_D)$] STOP
SIGNALS, AND SD OF RT$_G$ FOR
EACH S AND EACH COND.

Cond.	RT$_G$	$P(I_S)$	$P(I_D)$	SD
S1				
0	226	.68	.77	38
12	229	.79	.65	31
33	243	.89	.53	29
63	265	.96	.39	37
S2				
0	233	.69	.60	47
12	232	.75	.55	39
33	274	.99	.48	48
63	301	.96	.41	57
S3				
0	229	.72	.75	36
12	240	.85	.65	43
33	266	.91	.43	44
63	293	.99	.43	48
S4				
0	236	.77	.83	53
12	229	.87	.60	60
33	257	.89	.32	65
63	252	.95	.31	50
S5				
0	272	.77	.64	45
12	277	.73	.57	42
33	316	.93	.59	67
63	342	.95	.56	71
Average				
0	240	.73	.72	44
12	241	.80	.60	44
33	271	.92	.47	52
63	291	.96	.42	54

he was to inhibit to 100% of the simultaneous stop signals and 50% of the delayed signals.

RESULTS

In Table 1 appear the mean RT to the go signal (RT$_G$), probability of inhibiting the response to the simultaneous stop signal [$P(I_S)$] and to the delayed stop signal [$P(I_D)$], and SD (square root of average variance) of the RT$_G$s for each S and condition. The pooled $P(I_S)$ and $P(I_D)$ for each condition are plotted in Fig. 1 as a function of mean RT$_G$. (For the 0 delay condition $P(I_S)$ and $P(I_D)$ derive from identical conditions but different random sequences.) It is readily apparent from these data that de-
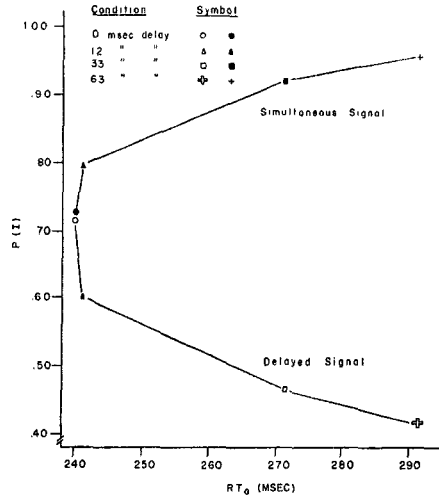

FIG. 1. Average probability of inhibiting to simultaneous and delayed stop signals as a function of RT for each condition.

laying the stop signal by only a few milliseconds is sufficient to produce a marked change in S's ability to inhibit his response. That is, while the Ss maintained a $P(I)$ of about 75%, the inhibitions were less likely to occur to the delayed stop signal as its asynchrony increased.

From the upper curve of Fig. 1, which was obtained from those trials where the stop signal was simultaneous with the stimulus to respond, it may be seen that the $P(I_S)$ increases rapidly as the RT$_G$ lengthens. In order to obtain further information on this aspect of the data, product-moment correlations were computed for the 12 mean RT$_G$ and $P(I_S)$ obtained for each S. The five r's for these data from S1 to S5, respectively, are as follows: .94 ($p < .001$), .81 ($p < .005$), .76 ($p < .005$), .33 ($p < .15$), and .69 ($p < .01$). It seems clear that for a given S, $P(I)$ is quite dependent upon RT.

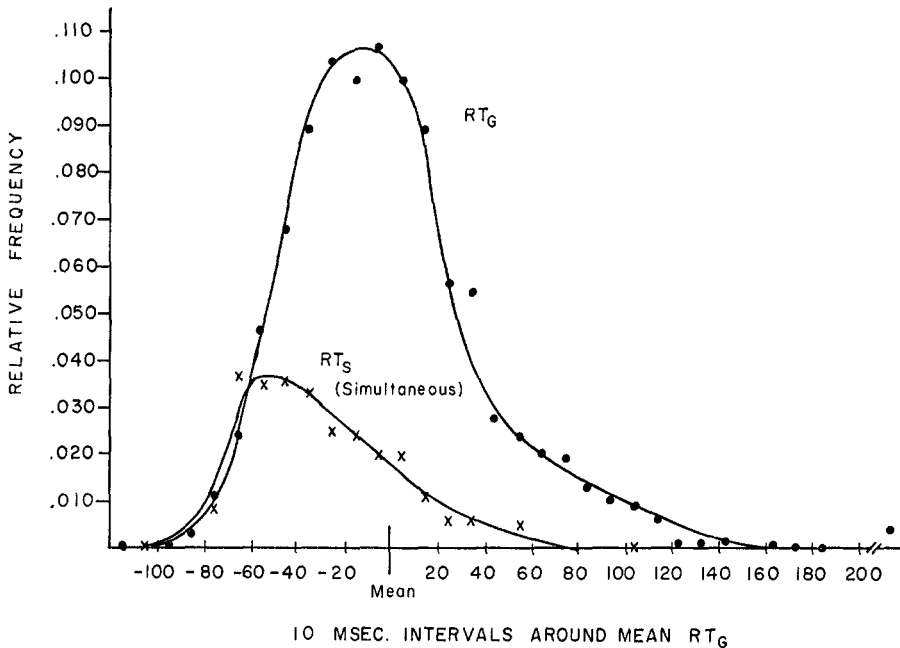Another aspect of the data which is related to the correlation of $P(I)$ with

FIG. 2. Relative frequency distributions for RT_G and RT_S from the pooled data of the zero delay condition, standardized about the mean RT_G of each session.

RT is the distribution of the RTs obtained on those trials when the stop signal was presented but the S failed to inhibit the response (RT_S). Relative frequency distributions of RT_G and RT_S were made from the data of the 0- and 12-msec. delay conditions. Frequencies were tallied for each 10-msec. interval above and below the mean RT_G, rounded to the nearest .01 sec., of each session. The resulting RT_G distributions based on 1,500 trials and RT_S distributions based on 325 trials from each of the two stop signals, are shown in Fig. 2 and 3. (It should be realized that these distributions are affected to some degree by between-session variability and that the number of RT_S obtained from each session is not constant.) It may be seen that up to a point the two distributions are quite similar. Of particular interest is the overlap occurring at the lower tail

of the distributions, where the response appears to have been made too rapidly to permit the *simultaneous* stop signal to have any effect. As RT increases it becomes less likely that a response will occur in the presence of a stop signal.

An important question raised in the present experiment concerns the amount of time by which RT must be increased in order that S may inhibit his response when the stop signal is delayed. In Fig. 1, the increases in mean RT_G which result from stop-signal delays are also accompanied by a decrease in ability to inhibit [a decrease in $P(I_D)$]. It is necessary to correct the RT measure for the change in $P(I_D)$. Perhaps the most meaningful statistic for this purpose is the percentile point in the RT_G distribution corresponding to $1 - P(I)$. This statistic might be taken to represent a
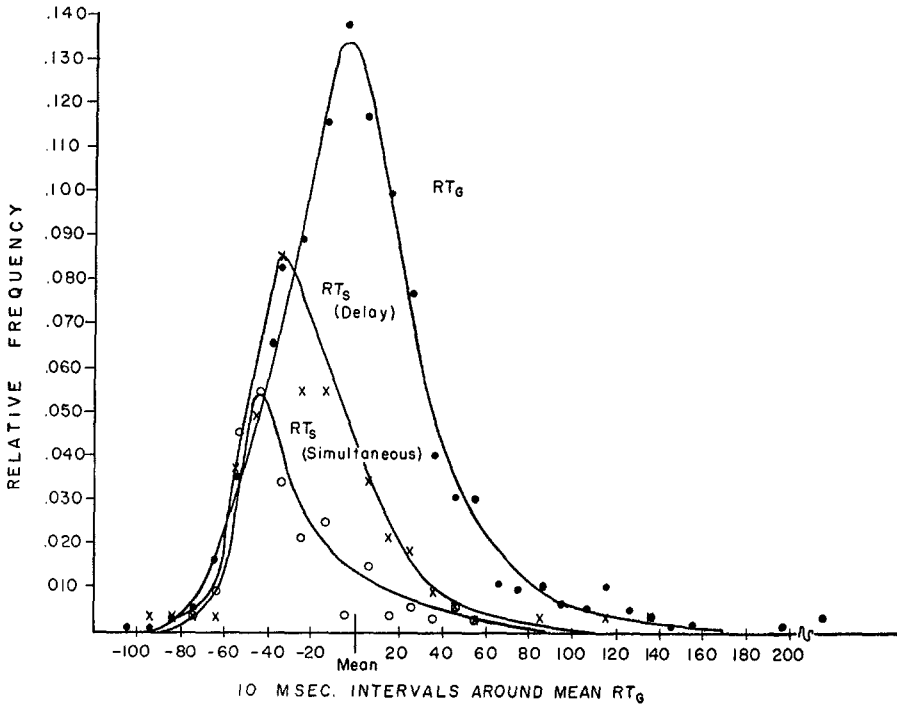
FIG. 3. Relative frequency distributions for RT$_G$ and RT$_S$ from the pooled data of the 12-msec. delay condition, standardized about the mean RT$_G$ of each session.

critical RT such that for faster RT$_S$ inhibition is unlikely and for longer RT$_S$ the response may usually be inhibited. Thus, the relationship between the increase in this RT statistic and in the stop-signal delay provides some notion as to the changes in RT necessary for S to make use of the delayed information. This data is provided in Table 2. It may be seen that

TABLE 2

PERCENTILE POINT IN RT$_G$ DISTRIBUTION CORRESPONDING TO $1 - P(I_D)$ FOR EACH S AND COND.

Cond.	S1	S2	S3	S4	S5	Average
0	200	222	204	192	253	214
12	218	230	225	216	265	231
33	236	271	267	271	293	267
63	269	306	294	264	322	291

when the stop signal was delayed by 12, 33, and 63 msec, the RT statistic showed an average increase of 17, 53, and 77 msec., a rather close correspondence. It seems clear that when the stop signal is delayed, a very slightly greater amount of time than this delay must be added to the RT$_G$ in order for S to inhibit his response with equal success.

DISCUSSION

The above results portray three phenomena: (a) The effective visual stimulus for the disjunctive RT response may include only the first 12 msec. or less of the physical stimulus. (b) The ability to inhibit the response improves as a function of RT. In fact, a response may be made to the mere onset of stimulation which is faster than the choice response capable of utilizing the informa-

tion in a simultaneously presented stop signal. (*c*) If the signal to stop is delayed by a few milliseconds from the signal to respond, then *S* must slow his RT by a slightly greater amount of time if he is to maintain the same ability to stop the response.

These results offer strong support for the conclusion from the earlier experiment (Lappin & Eriksen, 1964) that delayed stimulation should not be expected to interfere with a simple RT response. This conclusion is also reminiscent of previous work with the simple RT (Fehrer & Biederman, 1962; Fehrer & Raab, 1962; Raab & Fehrer, 1962; Raab, Fehrer, & Hershenson, 1961).

It seems clear that the longer RTs which are commonly observed with the disjunction procedure have not resulted merely from a marked lengthening of the "critical duration" of the stimulus for simple RT (Raab & Feher, 1962; Raab, Fehrer, & Hershenson, 1961). It is striking that the physical energy for instigation of this choice response is integrated over such a brief portion of time.

The results of this study point to two specific components of the variance in RT for a voluntary response to a visual stimulation. First, since RT is shown to correlate with the ability to modify the response in accord with stimulus information, RT reflects the degree of stimulus processing which underlies the motor output. In Hyman's (1953) words, RT varies with information transmitted. Secondly, from the fact that RT must be lengthened in order for the response to be inhibited when the stop signal is delayed, it is evident that when RT increases so also does the duration of effective stimulus which has preceded the response event. Suggestion of a similar effect appears in Hershenson's (1962) finding that maximal intersensory facilitation of simple RT occurs with an interstimulus interval equal to the mean difference in auditory and visual RTs, declining rapidly with deviation from this interval. Thus, the motor portion of both simple and disjunctive RT seems to be an event with relatively constant

duration, which is unmodifiable once initiated. Taylor and Birmingham (1948) several years ago concluded that control of the responses made in tracking behavior is complete once the motor event is underway.

An interesting question arising from the above response model concerns the voluntary control of RT. Certainly, the fact that *S*s were able to adjust RT to yield a *P*(I) of approximately 75% for each session implies that some aspect of the stimulus processing time may be regulated. One may wonder how such voluntary control interacts with stimulus intensity and temporal uncertainty effects on RT. The question is: What makes RT so variable?

With respect to the psychological refractory period phenomenon, this study indicates that such an effect probably does not reside with the operation of signal reception or processing portions of the stimulus-response sequence. That is, utilization of a second signal required only that RT be increased by approximately the same time as the delay of the second signal. The fact that this response delay is actually slightly greater than the delay of the second stimulus might be expected since the delayed stop signal is accompanied by a slightly longer go signal which may thus be effectively more intense. This interpretation of the psychological refractory period conflicts with Nickerson's (1964) report which indicates a refractory period from delaying part of the stimulus information for the response. The reason for this discrepancy is not clear. Although the present study agrees with Reynolds' (1964) conclusion that the refractory period is not sensory, his response competition hypothesis would seem to have predicted a greater increase in RT for the delayed signal conditions than was observed. Support from this study leans toward a response expectancy interpretation of some of the earlier findings.

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