Set and temporal integration[1]

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An experiment was conducted to explore the temporal structure of set formation in a complex reaction time (RT) task. On each trial an instruction (I-event) was given telling Ss whether identity of color or form on a separately presented alternative display (A-event) was the dimension relevant on that trial. The A-event consisted of a pattern of four colored forms. The two forms on one side were matched for color and on the other side for form. S's task was to depress one of two keys. The correct key was homolateral to the matched relevant dimension. The basic independent variable was the time interval separating the I- and A-events (ISI). At short ISIs, RT was a linear function of ISI with slope equal to -0.5. RT was independent of the order in which the events occurred at short ISIs, although at longer ISIs (3 sec) RT was longer when the A-event followed the I-event. Also, RT was shorter at short ISIs when color was the relevant dimension rather than form, although this difference disappeared at longer ISIs. The results were discussed in relation to information processing models and previous research dealing with partial advance information.

In a paradigm first referred to as the "effects of partial advance information" (Leonard, 1958), the information required for response selection in a reaction time (RT) task is not presented simultaneously but, rather, separate components of the information are presented at different times. The time interval between the components is called the interstimulus interval (ISI). For example, Leonard (1958) varied the time separating two events: The first event reduced a six-choice RT task to a three-choice task, and the second provided the specific RT signal from the residual set of three alternatives. In addition, he also obtained RT measures under standard six-choice and three-choice conditions. He found that there was only a 50-msec mean difference between these latter two conditions; however, it was necessary to have an ISI of 500 msec separating the advance information from the specific signal in order to achieve performance comparable to the three-choice condition. Moreover, there was an apparent interference effect; RT was longer at 200-msec ISI than at shorter ISIs.

Similar results have been reported by Shaffer (1965, 1966), who also presented S with a sequence of two events. One was a signal as would be used in an ordinary two-choice task; the second signal called for either a contralateral or a homolateral mapping of the other signal onto a response. As in the Leonard study, a given ISI did not generate a comparable decline in RT. Moreover, Shaffer found definite differences in RT as a function of the order in which signals occurred. RT was generally less when the mapping signal preceded the identification signal than when the events occurred in the other order.

The theoretical model from which Shaffer worked in the above experiments is of relevance to the concept of set. His interest was in the mechanism by which an instruction (I–the mapping event) interacts with a stimulus event (A–the specific signal), providing the stimulus alternatives to determine a response. The analogy between Shaffer's (1965, 1966) paradigm and set may be seen more directly if a pair of numbers, e.g., 8, 2, is substituted for each A-event, an instruction, e.g., add, subtract, is substituted for each I-event, and a pair of numbers provided as response alternatives, e.g., 10, 6. The result is a textbook demonstration of set (Hebb, 1966, p. 92).

That the ISI should be a fruitful variable in connection with set is not surprising when set is examined in its original historical context. Arising from experiments done on controlled vs free verbal association time conducted at the Wurzburg laboratories, becoming set or *eingestalt* was viewed as a process mediated by the effects of a *determining tendency* established by instructions or *aufgabe.* Becoming set was assumed to be a process that evolved over time.

Experiments on set and related topics have, with the above exceptions, paid little attention to such temporal variables as ISI. Often, in such studies as "learning how to learn" A and I do not occur at discrete points in time but, in contrast, I emerges gradually as a function of experience (for a partial review of the set literature, see Thune & Bernstein, 1964). Yet, a variety of problems relevant to inferring hypothetical stages through which information is passed as it is transduced into an overt response can be stated in terms of the relation between ISI and RT.

One aspect of the temporal integration of set which is of general interest is the question of serial vs parallel processing (Christie & Luce, 1956; Lindsay & Lindsay, 1966; Egeth, 1966). Assume that RT is a function of the time required to process A (t_a) and the time required to process I (t_i) and the residual time (t_r) involved in response selection, sensory read-in, etc. The question of parallel vs serial processing would then be stated in terms of whether t_a and t_i could or could not be allowed to overlap.

Relatively simple models can be generated to evaluate these possibilities if the additional assumption is made that t_a and t_i are constants and t_r is a random variable regardless of the ISI. This assumption will be denoted as the *independence* assumption in contrast to a particular alternative, namely that t_i and t_a are functions of ISI. In the *independent serial model,* it is assumed that a given event is processed only after the preceding event has been processed. Predicted RT is therefore the sum of the three components minus that portion of t_i or t_a that had been processed prior to the second event. Denoting sequences in which A precedes I and vice versa as A-I and I-A sequences, this particular model generates the following equations:

$$\left.\begin{array}{l} RT = t_a + t_i + t_r - ISI,\ ISI \leq t_i \\ RT = t_a + t_r ISI > t_i \end{array}\right\} \text{for I-A sequences}$$

$$\left.\begin{array}{l} RT = t_a + t_i + t_r - ISI,\ ISI \leq t_a \\ RT = t_i + t_r ISI > t_a \end{array}\right\} \text{for A-I sequences}$$

The second model will be referred to as the *independent parallel model,* in which case t_a and t_i are allowed to overlap. Hence RT is a function of the residual amount of time to process the first event or the amount of time to process the second event, whichever is greater. To reduce the number of equations it will be assumed that $t_a > t_i$, as is generally plausible, since t_a usually controls a larger response class, contains more uncertainty and is perceptually more complex than t_i. For situations in which the reverse might hold, however, the resulting equations may be modified simply by reversing the roles of t_a and t_i and the sequences A-I and I-A. Thus:

$$RT = t_a + t_r \text{ for all ISI, I-A sequence}$$

$$\left.\begin{array}{l} RT = t_a + t_r - ISI,\ ISI \leq (t_a - t_i) \\ RT = t_i + t_r,\ ISI > (t_a - t_i) \end{array}\right\} \text{for A-I sequences}$$

The above equations, descriptive of the two models, have been presented graphically in Fig. 1. Although the values of the RT components estimated from the data and the unit of measurement for RT and ISI is consequently not specifiable a priori, the independence assumption made in both models makes one prediction that is testable independently of the absolute values of the parameters. This prediction is that there is a slope of -1.0 between RT and ISI equal to -1.0 at short ISIs. This is because the time between the onset of the first and second events is assumed to be used efficiently in processing the first event, and RT is measured from the onset of the second event.

The tenability of the independence assumption would seem to be an important question for those interested in the serial-parallel dichotomy. If the independence assumption is not valid, then other theories of information processing need to be generated. The data cited above in the context of partial advance information, by noting a decline in RT less than a given change in ISI and by obtaining order effects (differences in RT between A-I and I-S sequences) raise empirical doubt as to the assumption.

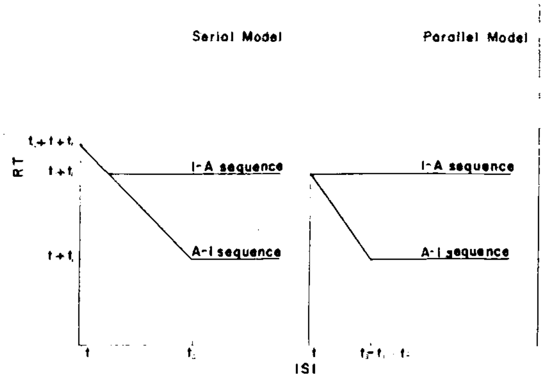

Fig. 1. Theoretical functions relating RT to ISI for the independent serial and independent parallel models. RT and ISI are expressed in arbitrary but equivalent units.

The present study was designed in an attempt to evaluate the nature of sequential information processing in a situation designed to approximate the traditional set paradigm discussed above. By examining the relation between ISI in RT for both I-A and A-I sequences, it was hoped to gain further knowledge as to the tenability of the independence assumption, the validity of independent serial and parallel processing models and the existence of possible order effects. A consisted of a set of four geometric forms arranged in a square array. The vertical pair of forms on one side was identical in form but differed in color and the remaining pair was identical in color but differed in form. I was the presentation of the letter "F" or the letter "C" which instructed S to select either the identically shaped or the identically colored forms by depressing a telegraph key on the side where the requisite identity was present. Because it was designed as the first study of a more general inquiry, the present study involved only the two dimensions stated above; no irrelevant information was present.

METHOD

Subjects

Three advanced undergraduate male Ss, majoring in psychology, comprised the sample. Two of the Ss (CN and DB) served for 10 sessions of approximately 1 h duration each. The third S (DR) was forced to terminate the experiment after eight sessions of approximately 1 h duration. For all three Ss the first two sessions were considered practice and the results not analyzed. CN had had extensive experience as an RT S in several of the senior author's previous experiments.

Procedure

Each session consisted of a set of practice trials followed by 192 experimental trials, 16 trials at each of 12 ISIs. These ISIs were 50, 100, 200, 400, and 3,000 msec for both the A-I and I-A sequences, a 0 msec (concurrent) ISI and an 800 msec ISI in the A-I sequence. The 800 msec ISI was included as a part of the A-I but not the I-A sequence because pilot data indicated that the I-A sequence had approximately reached asymptote at 400 msec but the A-I sequence had not. All trials at a given ISI were run consecutively. Thus, there was no time uncertainty of ISI in the experiment. On each block of 16 trials, color was the selected dimension half of the time. Although sessions were normally set up for an hour, trial blocks were run ad lib to minimize Ss fatigue. Trials on which an error was made were rerun to facilitate data analysis.

Apparatus and Stimuli

Stimulus events were presented on a three-channel Scientific Prototype model GB tachistoscope. The blank field for the tachistoscope contained a 20 min visual angle black line which served as a fixation area. The luminance of this field, as measured with a SEI spot photometer was 12 footlamberts (ft-L). A warning signal was provided for two of the Ss (DB and DR) by means of a 100 msec offset of the fixation area 2 sec prior to the onset of the first stimulus event. For the third S (CN) the warning signal was provided by the onset of the black line between trials when all three channels were off. The I events were presented in Field I of the tachistoscope (a reversing field). This consisted of the appearance of the letter C (color) or the letter F (form). The letters subtended a vertical angle of 20 min at the 60 in. viewing distance and were colored red. They appeared in the middle of an area that subtended a horizontal angle of 50 min and a vertical angle of 36 min. The area outside of this was painted black in order to minimize luminance summation and consequent contrast reduction with the A field. The luminance of the area containing the letter was 18 ft-L. In order to keep figure-ground contrast relatively constant for the I event the tachistoscope was programmed so that either the fixation field or the field containing the alternatives, but not both, was on when the I event field was on. The remaining field, in which the A events appeared, also had a luminance of 18 ft-L. Both the I and A fields remained on until S's response had occurred.

Occurrence of the second of the two stimulus events (e.g., the A event in I-A sequences) controlled the onset of a pair of Hunter clockcounters through a system of Scientific Prototype DC powered electronic buffers, read relays, and flip-flops. One clock was connected to the left hand telegraph key and the other to the right. Hence, information was provided on both RT and correctness of S's choice.

A set of eight four-form arrays constituted the A stimuli. Each array consisted of squares and circles colored either red or black. On one side (e.g., left) the forms were the same but different in color whereas on the other the forms would differ but the colors would be identical. The eight arrays were selected to fulfill several criteria of independence. Color and form identity were balanced as to side. Similarly, half of the form identities were square and half were circles, and half the color identities were red and half were black. Finally, a given form identity (e.g., square) was independent of a given color identity (e.g., red). The figures were hand drawn on white 3 x 5 in. cards and contained in a specially designed holder in the back of the tachistoscope. The figures were located at the vertices of an imaginary 1 deg 50 min square. The squares were .25 in. on a side and the circles .28 in. in diameter, generating forms of approximately equivalent area; both, therefore, subtended approximately 20 min visual angle. The entire display including I and A events would therefore be foveal for a S who did not shift fixation appreciably from the fixation line, thereby minimizing both time due to visual search and the probability of an increase in reaction time due to discriminanda falling outside the foveal area.

Following the regular study, a brief supplemental study was conducted. Each of four Ss, one of whom participated in the main study (DB), was run in each of two conditions. The C-F condition involved a two-choice discrimination between the letters "C" and "F" used in the main study. The S-D condition involved a same-different judgment on a pair of forms which varied independently in color (red or black) and form (square or circle). The dimensions of the forms and the spacing was identical to that used for a given vertical pair of forms in the main experiment. In order to allow a relevant comparison with the main experiment, the location of the indicator keys was randomly varied across trials and the Ss informed prior to each trial which key denoted which event. Similarly, the relevant dimension in the S-D condition varied randomly and Ss were informed the relevant dimension prior to each trial. A total of 100 C-F and 256 S-D trials were run per S. The purpose of the supplemental study was to evaluate findings discussed below regarding asymptotic differences between the A-I and I-A sequences.

RESULTS

The RT data at each ISI were pooled across the eight experimental conditions for Ss CN and DB and across the six experimental conditions for DR. Thus, two Ss made 128 responses at each ISI and one 96 at each ISI. The RTs for C and F instructions were kept separate for the analysis. Presented in Table 1 are the means and standard errors of the means of the RTs as a function of ISI and instruction for each S. Presented in Fig. 2 are the RT means as a function of ISI and order, pooled across the three Ss, as a function of type of instruction, as well as averaged across type of instruction. The maximum reaction time (mean RT = 752 msec) occurred when I and A were simultaneously presented. The minimum (mean RT = 409 msec) occurred when A preceded I by 3,000 msec. As expected, AT and ISI were inversely related in both the A-I and I-A sequences. The minimum I-A reaction time was 151 msec longer than the minimum A-I reaction times (mean RT = 560 msec).

As can be seen in Table 1, the standard errors of the distributions were relatively large compared to typical choice RT distributions. One factor accounting for this is the relatively great task complexity. In addition, relatively large practice effects were obtained over sessions suggesting task complexity, although the trends contained in Fig. 2 were consistent over trials. Because RTs were pooled across sessions, this systematic source of variance was included in the overall within distribution variation.

The following trends may be observed in Fig. 2 for the I-A sequence trials on which form was the relevant dimension result in a relatively constant 100 msec longer RT than when color was relevant for ISIs of 400 msec or less. The same held true for the A-I sequences for ISIs of 200 msec or less. In general, the Ss verbalized that their strategy was to identify the pair of stimuli which were the same color on all trials and to choose the homolateral response given a C instruction and the contralateral response given an F instruction. Their reasons for adopting this strategy were that they found the colors to be more discriminable than the forms. At the longer ISIs the differences between color and form instruction trials disappeared, which suggests that the processing of the alternatives was complete by 400 msec after the onset of A. In the 3,000 msec ISI condition for the I-A sequence, the failure to find a difference between F and C RTs suggests that there were no inherent differences between the "same" and "opposite" type of identification process within the present experiment given sufficient time to process the instructions.

A second important aspect of Fig. 2 for the I-A sequence is that the relation between RT and ISI is essentially a linear decreasing one between 0 and 200 msec ISI. The curve tends to flatten out thereafter. By 400 msec ISI the RTs had almost, but not completely, reached asymptote. In the case of the A-I sequence, the relation is likewise essentially linear but in this case the range extends to 800 msec. The slope of the linear function for both A-I and I-A sequences is approximately -0.5, indicating a decrease in RT of one-half the ISI at short ISIs. It should be noted that the same linear function fits both the sequences despite later asymptotic differences; in essence, there is no difference in RT as a function of the order in which the stimulus events occur for ISIs less than 400 msec. Since overall RTs were less than 1 sec, it can be assumed that the processing of the first stimulus event had been completed by the onset of the second in the 3,000 msec condition. Hence, the 151 msec difference between the I-A and A-I sequences at this ISI is attributed to the longer processing time required for the A-event than for the I-event.

DISCUSSION

The basic findings were that, at short ISIs, RT decreased linearly with slope of -0.5, the order in which the A and I events were presented was not important, and there was a consistent RT difference favoring responses to color as a relevant dimension. At longer ISIs, RT reached asymptote sooner but at a higher level for the I-A than A-I sequences. Also, the difference between color and form as relevant dimensions disappeared.

The observed slope value supports findings presented by Leonard (1958) and Shaffer (1965, 1966) that a given increase in ISI does not facilitate RT by that amount. The lack of complementarity for ISI separating stimulus components and RT indicates that sequential stimulus events are not processed independently. There was no evidence, however, to support Leonard's (1958) finding of a nonmonotonicity between ISI and RT due to an apparent interference effect at intermediate ISIs.

To the extent that there is a dependency between the sequential stimulus events, it is difficult to assess the relative merits of parallel and serial models. In the RT situation, the serial-parallel distinction has been applied primarily in an examination of feature-testing models of form perception or the effects of stimulus uncertainty (see Smith, 1968, for a relevant review). Most applications have found at least one of the alternative models to provide an acceptable fit to the data, although Nickerson (1966) has found major inconsistencies between his data and both models.

The present study generates a paradox if either model is accepted. Except for the slope value, the details of the ISI-RT relation fit the independent serial model rather well. Yet, the less than unit slope, denoting an increase in RT less than a given

Table 1
Mean RT to Form Instructions ($\bar{X}_f$), Mean RT to Color Instructions ($\bar{X}_c$), Mean RT Pooled Across Type of Instruction ($\bar{X}_{c+f}$), and Standard Errors of the Mean (S.E.) for Each S as a Function of Order and ISI

		Order											
		I-A						A-I					
S	ISI:	0	50	100	200	400	3000	50	100	200	400	800	3000
DB	$\bar{X}_f$	893	910	916	773	743	560	875	797	776	628	543	445
	S.E.	26	28	32	28	27	24	28	24	22	24	24	17
	$\bar{X}_c$	771	773	753	648	566	557	748	740	670	616	524	418
	S.E.	22	18	24	16	15	16	26	27	12	18	15	13
	$\bar{X}_{f+c}$	832	841	834	711	654	559	812	769	723	622	533	432
	S.E.	18	18	21	17	17	14	20	18	13	15	14	11
DR	$\bar{X}_f$	792	776	727	635	652	581	778	761	728	668	390	418
	S.E.	29	32	24	24	28	29	26	32	34	43	16	14
	$\bar{X}_c$	635	604	605	574	503	517	625	599	546	552	410	364
	S.E.	20	22	19	21	23	21	29	20	27	26	17	13
	$\bar{X}_{f+c}$	713	690	666	605	578	549	702	680	637	610	400	391
	S.E.	20	22	17	16	20	18	21	21	24	26	11	10
CN	$\bar{X}_f$	735	661	637	666	527	559	711	659	583	465	481	400
	S.E.	30	22	22	28	23	25	32	23	18	23	26	16
	$\bar{X}_c$	668	640	603	575	531	577	667	657	593	517	505	401
	S.E.	26 25	25	18	21	23	24	31	28	28	27	27	21
	$\bar{X}_{f+c}$	702	651	620	621	529	568	689	658	588	491	493	400
	S.E.	20	16	14	18	16	17	22	18	16	18	19	13

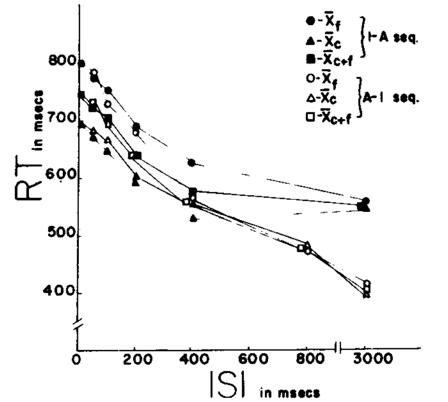

Fig. 2. RT as a function of ISI and order for color instructions, form instructions, and averaged across type of instruction.

increase in ISI, suggests processing is more efficient when I and A are both present together than when only one is present. However, the more efficient processing of a whole rather than parts suggests, in turn, a form of parallel processing in the sense of a shift in processing the first event to occur to the processing of the aggregate. What is normally meant by the organizing properties of a "set" seems to be empirically described by this facilitation in processing. The present data do not suggest a simple way in which their organization occurs. Even analyzed in terms of individual S's performance, the basic data reflect a relatively smooth transition in RT across ISIs which implies a relatively efficient part-to-whole shift in processing when the second event occurs.

In a further attempt to describe the data, additional models were considered in which the constants assumed under the independence assumption were replaced by stochastic variables. Although the details of this analysis will not be presented, they are relatively clear in ruling out a parallel model. In a stochastic parallel model, changes in RT with ISI would arise as a function of changes in the probability that $t_a > t_i$, $p(t_a > t_i)$. Assume that the mean difference between these parameters may be estimated from the asymptotic sequence differences which, averaged across Ss, is 151 msec. For example, at 200 msec ISI, $p(t_a > t_i)$ would be much closer to 0.5 for the A-I sequence than for the I-A sequence. In the former case, the longer time required to process A would be partially offset by the ISI whereas in the latter case the effects due to ISI and processing time differences would be additive, making $p(t_a > t_i)$ virtually equal to 1.0. As a result, the change in $p(t_a > t_i)$ between 200 msec ISI to 400 msec ISI would be relatively large for the A-I sequence and virtually 0 for the I-A sequence. Hence, expected RT changes for the A-I sequence would be fairly large, but for the I-A sequence they would be nearly 0. Yet the observed RT changes, 75 and 59 msec respectively, were quite similar. In general, a stochastic parallel model would not predict the observed linearity and equivalence of the RT-ISI function for the two sequences without making ad hoc assumptions about the form of the distributions of the components. In essence, some serial component of information processing is implied. Perhaps, however, the serial-parallel distinction could be more profitably applied to the discrimination of distinctive features of a single event than to the sequential processing of events presented at separate points in time.

Part of the difficulty in understanding the mechanism underlying Ss' performance may have arisen from the decision to limit the values which, as above noted, were dictated by the desire to maintain simplicity in this initial study. Failure to obtain order effects may have also been an artifact of this decision. The effects of such a limitation were seen clearly in the strategy adopted by the Ss to make a same-different judgment on the basis of matching colors and then to select an appropriate homolateral or contralateral response on the basis of I. In this context, it is of interest to note how the same-different judgment difference and consequent effect of response compatibility disappeared when a long ISI allowed Ss to prepare adequately for the judgment.

The differences at asymptote between the A-I and I-A orders seemed to reflect differential processing time for the same-different judgments made in the former case and the letter recognition in the latter. The data derived from the supplemental study were used to evaluate this aspect of the main study. The overall RT means for the S-D and C-F comparisons were 489 and 260 msec. The resulting difference of 129 msec compared rather well with the 151 msec difference observed in the main study, considering the individual differences. The comparability of the difference was not surprising, nor was the difference itself, since a simple form discrimination would be expected to produce shorter RT than a comparison between two events in the presence of variation in the values and dimensions of possible match. On the other hand, it is interesting to note the difference in absolute level of RT for the main study and parallel conditions in the supplementary study. Values of t were obtained comparing (a) the S-D and I-A asymptotic means, and (b) the C-F and A-I asymptotic means (despite the S in common to each comparison, the heuristic assumption was made that separate groups were used). The resultant values of t were 2.95 and 12.50, respectively. These differences were both significant ($p < .05$ and $p < .001$, respectively; two-tailed comparisons, $df = 5$). Hence it cannot be assumed that the only factors determining RT in the asymptotic conditions of the main study were the discrimination of the second event. RT in the main study seems also to have been determined by the presence of the first event, even though it had already been processed.

In short, the present data imply a highly sophisticated mechanism responsible for temporal integration whose properties may be evaluated through a RT paradigm. The properties of this mechanism seem to include a capacity for rapid part-to-whole transition with the occurrence of the second event. Such integration provides more efficient processing, as it can use all available information that an independent serial model would afford, yet the mechanism appears to have properties similar to a serial (single channel device). However, research dealing with more complex discriminanda, particularly more relevant dimensions, is needed to explore the properties of this mechanism in greater detail.

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NOTES

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