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S-R RELATIONSHIPS AND REACTION TIMES TO NEW VERSUS REPEATED SIGNALS IN A SERIAL TASK [1]

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Previous experiments showed that, in a serial responding task, RTs to repeated signals are longer than RTs to new signals. The influence of S-R relationships on this phenomenon was examined. In Experiment I, 9 Ss gave 550 responses under each of 3 S-R conditions in a 2-choice task with a spatial display. RTs to both repeated and new signals were significantly (.01) affected by the conditions, but covariance analysis shows that the effect is significantly (.05) larger on RTs to new signals. These results are fully confirmed by Experiment II where 33 Ss, after prolonged practice on a 4-choice task with a numerical display, under a straightforward S-R pairing, did 4 short runs of 50 responses under the same pairing and then under a less compatible one.

In a previous paper (Bertelson, 1961), it was shown that in a serial self-paced responding task, reaction times (RTs) to repeated signals are shorter than RTs to signals which are "new," i.e., different from the immediately preceding one. It was proposed that this phenomenon be called "repetition effect." The effect was shown to be at least partly transitory, being greatly reduced when a .5-sec. time lag is introduced between the end of the response and the appearance of the next signal.

The existence of the repetition effect suggests either (*a*) that different mechanisms are involved in reactions to repeated signals and in reactions to new signals, or (*b*) that the same mechanisms are involved but work faster in the case of repetitions, due to some sort of facilitative aftereffect. One way of deciding between these alternatives is to consider the influence on the RTs to the two categories of signals, of factors which are known to affect overall RT. Such factors are: number of alternative signals, signal probability, and signal-response relationships. The main purpose of the present experiments was to consider the effect of the latter variable.

The choice of an S-R relationship involves two operations: the selection of sets of stimuli and responses, and the matching of sets of points in the stimulus space with those in the response space (Deininger & Fitts, 1955, p. 319). Fitts has shown that one can affect "S-R compatibility" either by modifying the matching of elements of two constant sets (Fitts & Deininger, 1954) or by changing the set of stimuli which is coupled with a constant set of responses (Fitts & Seeger, 1953). In Exp. I, both types of variation were used: two lights lying on the same horizontal axis were matched with two similarly disposed keys, either in the straightforward way or in the inverted one, and these two conditions were compared with one where the same set of keys was coupled with two lights lying on a vertical axis. In Exp. II only the matching of elements was varied.

A further way of affecting mean RT was tried out in Exp. I. It consists of having the *S* work with one S-R condition immediately at the end of a period of work with the opposite

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pairing. In this way one could hope to obtain an interference effect on RT, which would amount to "short-term incompatibility."

Experiment I

The task used in this experiment was nearly the same as in the previous experiments (Bertelson, 1961). The display consisted of two spatially separated lamps and the controls of two keys. The main difference was the fact that the relative positions of the two lamps could be varied so as to change S-R compatibility. Another difference was the introduction of an automatic recording of RTs to new and to repeated signals.

Method

Apparatus.—The display consisted of two separate pairs of neon lamps, inserted into a vertical panel. Only one pair was used in each condition. The lamps of the *horizontal* pair were 5 cm. apart horizontally, the lamps of the *vertical* pair 5 cm. apart vertically. The whole set of lamps formed a Y shaped pattern. Two bakelite keys, resting on microswitches, were placed in a near-vertical plane, 15 cm. apart, behind an inclined board. The *S* rested his hands on the upper edge of the board, his finger tips poised over the keys (see Fig. 1).

Three different S-R conditions were used: (*a*) *Direct* (D): horizontal pair of lamps, the correct response being left key for left lamp and right key for right lamp; (*b*) *Crossed* (C): horizontal pair of lamps, the correct response being left key for right lamp and right key for left lamp; (*c*) *Perpendicular* (P): vertical couple of lamps, the two possible combinations (high-right/low-left and high-left/low-right) being given to alternate *S*s.

When either key was pressed, the stimulus light went off. The next signal appeared .05 sec. after the key was released. The task was noncorrective: incorrect responses had the same effect on the display as correct ones, but they activated an error counter.

The sequence of signals was controlled by a programing unit, based on the use of two uniselectors, which has been described previously (Bertelson & Davidson, 1959). This programmer generates a series which is not repeated before thousands of steps. In the present experiment, both signals were equiprobable, i.e., the series was random as far as the principle of the programmer permitted (Bertelson, 1961, p. 91).

The apparatus stopped automatically after 50 responses. The RTs to repeated signals and to new signals were cumulated on two separate chronoscopes. Electromagnetic counters counted signals pertaining to both categories, so that mean RT in each category could be obtained for each run. The RT to the first signal in each run, which was neither new nor repeated, is excluded automatically from the recording.

Subjects.—Nine male adults, aged 21–27, all postmen learning machine sorting, served as *Ss*. They were tested during normal school hours. All had already served in another experiment with the same apparatus, about 6 mo. before, but with a different display (numerical indicator), in which they had made 2,000 responses each.

Procedure.—Each *S* participated in three sessions. On each session he gave 11 runs of

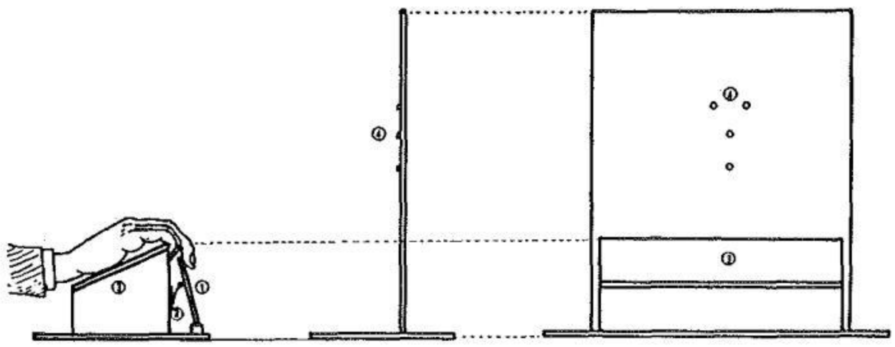

Fig. 1. View of the task: left, from the side; right, from *S*'s position. (1 = key, 2 = microswitch, 3 = resting board, and 4 = display lights.)

50 responses on one of the three S-R conditions, the order of conditions from session to session being organized in Latin squares. The first run was considered as practice and discarded for the analysis. Between 2 runs, there was an interruption of about 45 sec. during which *S* was told the total RT and the number of errors for the previous run. The *Ss* were asked to go as fast as possible and to avoid errors. Total results per session were recorded in a table, which was displayed for inspection by all *Ss*.

Immediately after the 11 runs which constituted the main task for the session ("main condition runs"), *Ss* were asked to do 2 runs with the opposite S-R relationship, i.e., C after D; D after C; and after one P combination, the other P combination ("interference runs").

TABLE 1

RTs in the Main Condition Runs (in Msec.): Exp. I

Cond.	Signals: New	Signals: Repeated	Difference New − Repeated
Direct (D)	377	307	70
Crossed (C)	443	333	110
Perpendicular (P)	410	320	90
Differences between conditions			
C − D	66	26	40
P − D	33	13	20
C − P	33	13	20

Results

Main condition runs.—For each *S*, the mean RTs to new and to repeated signals were obtained for each session. The averages over all 9 *Ss* for each condition are given in Table 1. If we measure the repetition effect by the difference between RTs to new vs. repeated signals, it can be seen from the third column that it is larger in both the C and P conditions than in the D condition. Another way of looking at the phenomenon is to consider the three bottom lines of the table: much larger changes are induced by modifications of S-R relationships in RT to new signals than in RT to repeated signals.

Analysis of covariance was applied to RTs to new signals with RTs to repeated signals serving as predictor. The results are given in Table 2. A significant condition effect is observed. This means that the whole of the effect of conditions on RT to new signals cannot be predicted on the basis of

TABLE 2

Analysis of Variance and of Covariance of Main Condition Runs: Exp. I

Source	Variance Analyses: *df*	*MS*: x^2	*MS*: xy	*MS*: y^2	Covariance Analysis of *y*: *df*	Adjusted *SS*	*MS*	*F*
Ss								
Between Latin squares	2	1.303	1.984	3.404	2	2.897	1.448	
Within Latin squares	6	1.860	−863	1.579	6	7.220	1.203	
Conditions (C)	2	1.432**	3.565	9.636[a]**	2	6.067	3.033	11.1[a]*
Order (O)	2	2.137**	514	1.718	2	3.294	1.647	10.6[b]*
C × Sq. (b)	4	98	412	312*	4	1.096	274	4.7*
O × Sq. (b)	4	138	− 43	660	4	624	156	2.7
Residual	10	119	−114	54	9	527	58.6	

Note.—*y* = RT to new signals; *x* = RT to repeated signals.
[a] Tested vs. C × Sq. (b).
[b] Tested vs. O × Sq. (b).
* $p < .05$.
** $p < .01$.

TABLE 3

RT IN THE TWO LAST MAIN CONDITION RUNS OF EACH SESSION AND IN THE TWO INTERFERENCE RUNS UNDER THE SAME CONDITION: EXP. I

Cond.	Runs	Signals		Difference New − Repeated
		New	Repeated	
Direct	Main condition	373	304	69
	Interference	389	304	85
	Difference	16*	0	16
Crossed	Main condition	437	322	115
	Interference	453	335	118
	Difference	16	13	3
Perpendicular	Main condition	407	317	90
	Interference	436	319	117
	Difference	29*	2	27

* Difference between main condition runs and interference runs significant at $p < .05$.

the effect on RT to repeated signals. The latter effect is significant, as appears in the analysis of variance which is also given in Table 2.

Interference runs.—The RTs for the two interference runs of each session were compared with those for the last two main condition runs under the same condition. This means that for Cond. D and C the comparison is made with runs performed on another session, while for the P condition, it is made with the two immediately preceding runs. The results which are given in Table 3 show that the repetition effect is always larger in the interference runs. Analysis of covariance was applied separately to the data for each condition. A significant interference effect was found for the P condition, $F(1, 7) = 6.4$, $p < .05$, and for the D condition ($F = 12.7$, $p < .01$). The influence of interference of RTs to new signals cannot be predicted from its influence on RTs to repeated signals. The latter is in fact practically nonexistent, as can be seen from the means in Table 3. For the C condition, the small interference effects on both categories of RTs which are suggested by the means in Table 3 are nonsignificant.

The conclusion is that under the two conditions where an interference effect on RT could be obtained, it affected mainly RT to new signals.

The reason why no interference effect could be obtained under the C condition is probably that performance under that condition is permanently hampered by interference from the very familiar relationship which defines Cond. D so that no short-term interference could be effective. In this experiment, the largest interference effect was obtained under Cond. P, and this suggests the hypothesis that short-term interference can best be observed with systems where no very dominant S-R pairing exists.

EXPERIMENT II

The data to be presented next were collected during a larger experiment which is described elsewhere (Bertelson & Joffe, 1962). The main purpose of that experiment was to study the effect of two tranquilizers on prolonged performance in a serial four-choice task. After the main task, part of the *S*s were given four runs of 50 responses each, first with a straightforward S-R relationship, which had been used in the main experiment, then with a different presumably less compatible relationship. These conditions were introduced mainly to see if a less compatible task would be more sensitive to drug effects. The results from the four runs under the compatible condition were analyzed in terms of the repetition effect. They showed (*a*) that the effect is present in a four-choice task as well as in the two-choice one and (*b*) that it is not affected by the drugs. The measurements taken under the second, less compatible, condition now offer an opportunity to validate the results of Exp. I on a somewhat different task and with a larger number of *S*s.

Method

Apparatus.—The task, described more fully elsewhere (Bertelson & Joffe, 1962), consisted of pressing one of four keys in response to the appearance of the numerals 1–4 on a Nixie numerical indicator. The display was switched off by the response, and the next signal appeared either when the key was ***released*** or 150 msec. after it was ***pressed***, according to whichever gave the longer interval. The sequence of signals was random and was controlled by a punched tape programmer. The RTs to new and to repeated signals were cumulated separately on two decatron chronoscopes, while magnetic counters recorded the number of signals in each category.

Subjects.—A total of 33 male students, aged 21–30, volunteered to take part in the experiment. For the two sessions, they were paid a fixed wage of 500 Belgian francs ($10.00) plus a bonus ranging from 0 to 200 francs, according to their speed and accuracy.

Procedure.—The data to be reported here were gathered at the end of two long sessions, during which the *S*s had worked uninterruptedly for 30 min. on the first task and 40 min. on the second one. This was done with a straightforward S-R correspondence, the first key on the left corresponding to the numeral 1, the second to the numeral 2, etc. (Cond. 1234). At the end of the second session, about 5 min. after having completed the 40 min. of uninterrupted work, the *S*s did four short runs of 50 responses with the same S-R relationship, and then four runs with a different relationship, the numerals corresponding to the keys being, from left to right: 3, 2, 4, and 1 (Cond. 3241). For the second session, the *S*s were divided into three groups, on the basis of speed and accuracy during the first one. One group received 1,200 mg. meprobamate, another 1,200 mg. emylcamate, and the third a placebo, 1 hr. before the experiment.

Results

The relevant data for each *S* are mean RT to new signals and mean

TABLE 4

ANALYSES OF VARIANCE AND COVARIANCE: EXP. II

Source	Variance Analyses				Covariance Analysis of y		
	df	*MS*			*df*	*MS*	*F*
		x^2	xy	y^2			
*S*s							
Between groups (G)	2	218	285	398	2	63	
Within groups	30	172	160	318	30	169	
Conditions (C)	1	1.532**	4.284	11.975**	1	1.564	74.5**
C × G	2	9	12	15	2	1	
Residual	30	28	31	55	29	21	
Total	65				64		

Note.—y = RT to new signals; x = RT to repeated signals.
** $p < .01$.

TABLE 5

RTs IN MSEC. FOR EXP. II

Cond.	Signals		Difference New − Repeated
	New	Repeated	
1234	565	422	143
3241	834	518	316
Difference (3241) − (1234)	269	96	173

RT to repeated signals in the four runs under Cond. 1234 and 3241.

Analysis of covariance was again applied to RTs to new signals, the RTs to repeated signals serving as predictor (Table 4). A highly significant ($p < .01$) conditions effect appears. Since there is no interaction between conditions and drug groups, all groups were pooled to give the average RTs given in Table 5. The RTs to new signals are much more affected by the modification of the S-R relationship than the RTs to repeated signals. The latter are nevertheless significantly affected, as the analysis of variance shows (Table 4). These results clearly confirm those of Exp. I.

DISCUSSION

The results do not give unequivocal support to either of the alternative hypotheses considered in the introduction. The fact that one category of RTs is much more affected by S-R relationships than the other is inconsistent with the second hypothesis (same mechanism with facilitation in the case of repetitions). But the fact that RTs to repeated signals are affected, although to a much lesser degree, does not permit acceptance of the first hypothesis (different mechanism). The dichotomy was probably too simple. A more sophisticated interpretation, integrating features of the two former ones, can now be proposed. Reactions to new signals involve processes the duration of which depends on S-R relationships. Reactions to repeated signals can be organized via a shorter process, with duration independent of S-R relationships. But this economical mechanism does not work reliably, so that the other, less economical, mechanism is called forth in a definite proportion of cases.

It is now customary to conceive choice RT as resulting from some sort of progressive classification process (Falmagne, 1961; Hick, 1952; Welford, 1960). The uncertainty about the response to give is progressively reduced by asking dichotomous questions about the stimulus. The optimum strategy consists of asking questions such that probability of a positive and a negative answer is as near .5 as possible. Several deviations from this optimal strategy can occur. (*a*) One type of deviation consists of asking questions with one very probable answer. An extreme case of this type of strategy is serial inspection, where questions of the type "Is this stimulus a 3?" are asked until a positive answer is obtained, or until a negative answer has been given for all alternatives but one. (*b*) Another type of deviation consists of asking redundant questions, the answer to which can be inferred from those already asked. The strategy considered by Welford (1960) under the name "serial classification with check on accuracy" is an example: it consists of checking, whenever a negative answer has been obtained for one question, that the opposite question is answered positively. Welford has shown that if such a strategy is hypothesized, the effect of frequency unbalance on *binary* choice RT can be accounted for. This effect is difficult to explain in case of an optimal strategy. (*c*) Still another type of deviation consists of asking irrelevant questions, i.e., which are of no value in choosing a response.

The effect of S-R relationships on RT can be interpreted as reflecting changes in the classification strategy. For the same amount of information to be transmitted, poor S-R relationships would involve more classification steps than more compatible ones. This is exactly how Deininger and Fitts (1955,

p. 318) interpret compatibility, if "number of operations" employed "to effect transformation" is the same as "number of classification steps." The interference from the preceding performance under a different S-R relationship could be attributed to the persistence of the classification strategy, which was used under that condition.

A classification system which would show a repetition effect would be one which, whatever the number of alternatives, would begin by asking whether the stimulus is identical to the preceding one (this step can be called the "repeat question"). For a repeated stimulus, the decision can thus be taken in one step. For a new stimulus, in the case of choice between more than two alternatives, it is obvious that more than one step will be necessary whatever the classification strategy. In the case of two alternatives, the system will take more than one step for new signals only if some sort of Type *b* (see above) deviation from the optimal strategy is involved: after finding out that the stimulus is not the same as the preceding one, the system checks to see if it is the other one, or even proceeds to classify it, as though no information had yet been gained about it.

If poor compatibility implies asking too many questions, but if for repeated signals the decision is always reached after the "repeat question," the RT to new signals only will be affected.

The fact that the RT to repeated signals is also affected, although to a much lesser degree, would mean that the "repeat question" is not always asked first. The mechanism of this question necessarily involves some memory device where the trace of the preceding stimulus is stored. If the trace undergoes a decay, the "repeat question" cannot be asked reliably. This hypothesis at the same time explains that the repetition effect is reduced when the time interval since the last response is increased (Bertelson, 1961).

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