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Latencies and interstimulus intervals in a sequence of motor responses

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The purpose of this research was to analyze response latencies when the subject is required to produce a series of different motor responses immediately after the presentation of a series of different stimuli successively presented at intervals of 200 and 800 msec. For each speed of presentation, latency increases linearly from one to three stimuli. Latencies are briefer for 800-msec than for 200-msec intervals, and this difference is interpreted as the result of a better preliminary organization of the responses at the slower speed of presentation. Interresponse intervals decrease from the beginning to the end of the responses. This result differs from previous data on verbal responses, and this difference is explained in terms of uncertainty.

Following a simultaneous or successive presentation of several letters of the alphabet, latency of the first response (LFR) was found to linearly increase with the number of available responses, within the limits of memory span (Fraisse & Smirnov, 1976). A brief and simultaneous presentation of each additional item resulted in a 70-msec increase, whereas in a successive presentation, each additional item resulted in a 50-msec increase (there was an interval of 900 msec between letters). Interresponse intervals (IRIs) were found to be equal (approximately 450 msec) in both situations when the subject was required to order his responses (successive presentation).

Results obtained by verbal responses will be compared with those occurring when a series of consecutive motor responses is elicited by a series of stimuli presented in succession.

There have been few studies on this problem. It cannot be reduced to successive responses that have been considered in research on the refractory period or central intermittency in human sensory motor activity (Bertelson, 1966). In the present study, the subject responds only after all stimuli are presented. The way in which the subject programs his responses is of primary interest. Other studies have considered reaction time (RT) as a function of response complexity. Glencross (1972) and Henry and Rogers (1960) have found that the more complex the response, the longer the RT. However, Klapp, Wyatt, and Lingo (1974) showed that an increase in RT occurs only in the case of a simple RT and does not apply to a choice RT. The above results can be explained by inadequate learning and limited experimental time.

This position has been contested by Sternberg, Monsell, Knoll, and Wright (1978). These authors chose to test the effect of response complexity by using the number of responses as the experimental parameter. After having considered several types of verbal or motor responses, they found that the LFR increases linearly with the number of responses. Slopes varied from 4 to 14 msec, according to the situation. In a motor situation, subjects (female professional typists) were simultaneously presented five letters. They were instructed to type these letters on a typewriter after receiving a signal that occurred 80% of the time after a delay of 2.4 sec. In this instance, Sternberg et al. report a latency of 231.2 msec ± 4.1 msec (n – 2). It is obvious, however, that in this situation, the subject can at least program beforehand his first response and place his finger on the proper key. This represents, however, a choice RT situation similar to Type c (Donders, 1869), since the response signal occurs only 80% of the time in order to control for anticipated responses. Donders had shown the Type c RTs were longer than simple Type a RTs and shorter than Type b RTs, in which the subject has to choose among several responses. In the Sternberg et al. experiment, subjects had enough time to program their responses, although they were uncertain as to whether or not they were to respond. Rabbitt, Vyas, and Fearnley (1975) examined the effect of the number of responses on choice RTs. Depending on the light pattern (one to four lights corresponding to the response keys), subjects (in Experiment 4) were to respond simultaneously, with one or several fingers already resting on the response keys. RT was found to increase with the number of possible responses when this number varied from one to three (430 msec with one finger and 541 msec with three fingers). When four fingers are engaged, RT is approximately the same as with one finger, since it is no longer necessary to choose from among several different responses. The subject has only to press all four keys at the same time. This research was finished at the time the studies of Teichner (1979) were published that used a series of motor responses (six pushbuttons or a panel

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of nine pennies that served as contact points using a stylus). The stimuli were a series of letters projected simultaneously on a screen. Teichner's attempt to separate the input time from the output time represents another problem. Examination of these results shows that the RT is proportional to the number of responses (still four), with a slope varying from 40 to 60 msec according to the situations and that the interval between the responses has a constant duration of about 300-400 msec.

All of the previously described experiments do not correspond exactly to the present experimental paradigm. It is the purpose of this study to examine the evolution of general response latency when the subject must produce a series of different motor responses immediately following a series of different stimuli presented in succession. This is an instance of RT involving a complex choice in which the subject must reproduce the order and the number of the stimuli without being allotted a time interval after the last stimulation. This prevents the controlled preparation of the subject's responses.

METHOD

The stimuli were presented on a screen connected to a Telemecanique computer T1600, which recorded the responses and measured the latencies of the first response, as well as the intervals between successive responses.

The stimuli were composed of four geometric figures—triangle, cross, line, and square—which appeared in succession at the same spot on the screen. The figures could be fitted into a 7-mm square. The subject was seated 1 m from the screen. The subject was seated behind a keyboard composed of six buttons. The two extreme buttons of the keyboard were not utilized, but they were present to avoid the subject's favoring the extreme spatial keys. A square, a cross, a line, and a triangle were drawn in that order on the four middle buttons. They appeared in the form of an arc. Each button was a 2-cm square. The buttons were 1 cm apart. There was another button located 7 cm from the response buttons that corresponded to the starting position of the movement. The subject pressed this button in order to begin the stimulus presentation sequence; he was not to lift a finger until he heard the response signal sound. All subjects were right-handed. This sound occurred after an interval of time equal to that which separated two successive stimuli.

If the subject took his finger off the button before the onset of the signal, the trial was not counted; the subject was informed of this by the appearance of a square on the left-hand side of the screen. If the RT of the first response or the interval between two responses was greater than 1,500 msec, the trial once again did not count, and the subject was informed by the appearance of a little square on the right-hand side of the screen. The canceled trials were at once subject to a random selection of N trials and replaced. In addition, trials in which either the number or the order of the stimuli was not respected were not counted in the calculation of the means. The number of incorrect responses was calculated by the computer.

The number of stimuli (four) was limited after some preliminary experiments, so that the number of correct responses would be equal to at least 50% after learning.

Two rhythms of stimulus presentation were chosen (200 msec and 800 msec) in order to study the possible effect of verbalization on the stimuli presented. At 200 msec, this verbalization was estimated to be practically impossible, since for this type of stimulus, a minimum of 400 msec is needed for verbalization to take place.

For each rhythm, the duration of presentation was half that of the interval presentation (i.e., for 200 msec, a 100-msec presentation and a 100-msec interval, and for 800 msec, 400-msec presentation and a 400-msec interval). The sound that indicated the onset of the response followed the last stimulus of the series after a delay of 200 msec for the 200-msec rhythm and 800 msec for the 800-msec rhythm.

The experiments occurred in blocks of 40 trials. In each block, the number and order of the stimuli varied randomly with number (one to four) and type of stimuli occurring an equal number of times.

The experiment included two sessions. In the first, the subject first learned the task and familiarized himself with the response buttons. There then occurred a block of 40 trials at the 800-msec rhythm followed by another block at the 200-msec rhythm.

After this initial practice, learning was induced through the presentation of four blocks (160 trials) at the 200-msec rhythm and four blocks at the 800-msec rhythm. The subject was allowed a rest between blocks.

The second session began by presenting a practice trial block at 200 msec and another at 800 msec to allow the subject to refamiliarize himself with the experimental situation. The actual experiment followed, with four trial blocks at 200 msec and four trial blocks at 800 msec.

The 10 subjects were psychology students ranging in age from 21 to 32 years old.

RESULTS

A preliminary remark is necessary. In the case of four stimuli, the nature of the fourth stimulus is determined by the other three. The subject can thus begin programming his response as soon as the third stimulus appears (i.e., approximately 400 msec before the signal appears for the 200-msec rhythm and 1,600 msec before the 800-msec rhythm). A four-stimulus situation is not homogeneous with one characterized by uncertainty and choice (i.e., responding to one to three stimulus items). These considerations can be related to those resulting from the Rabbitt et al. (1975) study. The following analyses consider instances of one to three stimuli. Tables will include, however, latencies and durations for four stimulus items, since they offer additional information, particularly regarding response intervals. The number of anticipated responses of those that were too long in occurring comprise less than .8% of the trials. Attention is called to the fact that each subject underwent 40 trials for each number of stimulus items. The results appear as means of the interindividual results for 10 subjects (i.e., they are calculated on the basis of 400 responses).

Table 1 gives the percentage of successful trials (exact number and order), the latency means of the first responses, the intervals between successive responses, and the interindividual standard deviation of all responses. The following observation can be made.

Percentage of Exact Responses

At the 200-msec rhythm, this percentage decreased regularly with the number of stimuli. When four stimuli

Table 1
Means and Standard Deviations of Latencies of the First Response (LFR) and of Intervals Between Responses

				Interresponse Interval					
		LFR		1-2		2-3		3-4	
N	P	Mean	SD	Mean	SD	Mean	SD	Mean	SD
				200-msec Speed of Presentation					
1	98.0	634	124						
2	92.0	749	110	156	35				
3	68.0	840	156	194	61	188	50		
4	44.1	857	164	225	88	225	91	181	67
				800-msec Speed of Presentation					
1	99.0	589	87						
2	97.0	657	122	151	30				
3	94.0	760	157	220	111	169	42		
4	88.0	578	136	193	58	213	60	154	32

Note—N = number of stimuli; P = percentage of exact responses.

were presented, the number of correct responses was below 50%. This justifies limiting the stimulus choice to four. At the 800-msec rhythms, there was a very slight decrease in correct responding. The slower rhythm enabled the subject to program a greater number of stimuli more exactly. It is hypothesized that this advantage was due to the fact that at a slower rhythm, the subject had time to verbally encode each stimulus one at a time. Verbalization facilitates the successive organization of the responses, even without the processes of rehearsal coming into play. The double encoding (iconic and verbal) is superior to the simple iconic one, which accounts for all the presently known data.

Latency of the First Response (LFR)

LFR was briefer at the 800-msec rhythm than at the 200-msec rhythm for an equal number of stimuli. This difference was significant ($p < .01$ for two responses and $p < .05$ for three responses).

It is important to note that at each rhythm, latency increased when the number of stimuli increased from one to three. The most likely hypothesis is that this increase is linear, although there remains some uncertainty with only three points. The regression equations are: at 200 msec, $L = 532$ msec $+ 105(n - 1)$ and at 800 msec, $L = 497$ msec $+ 85(n - 1)$.

When the rhythm of presentation decreased, the latencies were smaller and the slopes were more gradual. As in the case of response exactness, this finding can be explained by the fact that the subject has more time to organize his responses without changing the nature of the processes involved, since the values retain the same order. The gradient of the slope's increase was slightly greater than for verbal responses (50 msec). This increase can most likely be explained by the fact that, despite learning, the strictly temporal order of the stimuli and the spatiotemporal organization of the responses are less compatible than a series of letters is with a series of verbal responses.

Latencies decreased in the case of four responses. If the last response appeared on the same continuum as the other three, the latency would be 954 msec (instead of 857) for the 200-msec rhythm and 839 msec (instead of 578) for the 800-msec rhythm.

IRI

In presenting the IRI data, intervals for which there were four responses will be considered, since except for the initial one (LFR), response latencies appeared to be homogeneous in all situations.

(1) At a given level (e.g., between the first and second responses), IRIs increased slightly as a function of the number of responses. They followed the same law as that of initial response latency, but they were characterized by a much more gradual slope: 34 msec at the 200-msec rhythm and 21 msec for the 800-msec rhythm.

(2) For a given number of responses, the IRIs decreased from the beginning to the end of the responses. The duration of the last IRIs was close to that of a simple RT and exhibited the least amount of variability.

(3) The IRIs were noticeably shorter with motor responses than with verbal ones (450 msec).

We will try to explain this difference in the discussion.

DISCUSSION

In this section, two aspects of the previously stated question will be considered.

LFR

Motor responses follow the same laws as verbal responses. Latency of the first response increases linearly with the number of stimulus-response elements, since we consider here only instances in which the number and order of the responses correspond exactly with those of the stimuli.

Motor responses, however, yield a steeper slope, this finding can be explained by a lesser compatibility between the stimulus system and the response system. Despite the learning of a code, this system is certainly less automatic than the system that relates graphemes and phonemes as letters of the alphabet. The value of the slope corresponds to the time necessary to scan each of the perceived items that subsequently enter very short-term memory store. In keeping with Sternberg's (1975) hypotheses on memory and visual search, the search process of the initial response can be considered exhaustive.

The shortest duration of these latencies is greater for verbal responses (approximately 700 msec) than for motor responses (approximately 500 msec), as measured by the intercepts of the equations. This difference seems to correspond to that between the preparation of a verbal response and a motor response, which also results in a difference in IRI duration. In addition, the minimum latency measured by the intercept value hardly varies at all, with the speed of presentation (532 at 200 msec, 497 at 800 msec). First initial responses vary as a function of the number of responses, but the slope is more gradual at the 800-msec rhythm (85 msec) than at the 200-msec rhythm (105 msec). The possibility of verbalizing the stimuli one by one during their presentation has a slight influence on the programming duration of the first response. This influence is even greater on the accuracy of successive responses.

Duration of the IRIs

It was found in 1978 that a verbal recall of stimuli in their correct order of presentation led to IRIs that approached

450 msec in value. This finding was interpreted so as to show that all the responses were initially available and that the intervals were dependent only on the duration required for enunciation of the response. The results from motor responses enable another interpretation of this phenomenon. Motor response IRIs are much shorter and are unequal among themselves. At a given level, IRIs increase with the number of responses. The slope of the interval between the first and second response is 34 msec at the 200-msec rhythm and 21 msec at the 800-msec rhythm. In addition, for a given number of responses, the IRIs become shorter and shorter as the last response is approached; this latency is close to that of a simple RT. Everything occurs as if, following each response, the search duration of the subsequent response decreases with the remaining number of responses.

At first, it was thought that the processes involved in verbal responses could be conceived of as identical to those involved in motor responses. The stability of the IRIs with verbal responses could have been explained by the difficulty in going faster. But Teichner (1979) has found with motor responses the same results found by the present author with verbal responses. When Teichner used six pushbuttons, the IRIs had about the same durations, regardless of the number of stimuli or responses. There was only an increase of approximately 150 msec that accompanied an increase in responses (two to four) when using a panel of about nine possible responses.

There were two differences between the situation of Teichner (1979) and the present one. First, in Teichner's experiments, the presentation of the stimuli was brief and simultaneous. Second, there was in one case six labeled responses and nine in the other; in other words, there was greater uncertainty in the number of possible responses (and also in the number of possible stimuli). There was also a greater amount of uncertainty in our previous experiments, since they utilized 20 letters as possible stimuli and responses.

In conclusion, it seems when the subject begins to respond, all the responses are elaborate; for each response, however, the subject needs a certain amount of time, which depends on the uncertainty of the responses, and to a lesser extent, on the effectors. Motor responses may be quicker than verbal ones in some cases.

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