FREQUENCY DISTRIBUTION OF INTERRESPONSE TIMES DURING VI AND VR REINFORCEMENT¹

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A detailed analysis was made of the interresponse times (IRTs) of two rats under both a VI 40-sec and a VR 15-sec schedule. Except for the latency of the first response after a reinforcement, the mean IRTs of all further responses differed little. Similarly, the frequency distributions of the successive IRTs did not vary greatly, but were of no simple form. Sequential dependencies between successive IRTs were small, never accounting for more than 1% of the variance.

Understanding of the relationship between response rate and IRTs suffers from the lack of an adequate theoretical analysis and from insufficient empirical knowledge of the characteristics of IRT distributions. It has been suggested (e.g., Mueller, 1950) that the emission of responses in a wide variety of free-operant situations may be described by a Poisson process. This proposal is attractively simple and potentially very fertile, as Poisson processes lend themselves to numerous extensions and modifications (e.g., McGill, 1963). Interresponse times in a Poisson process are independently and exponentially distributed. Mueller (1950) presents some empirical IRT distributions which can be fitted very well by an exponential distribution. No direct tests of the independence of successive responses are given, however.

Exponential IRT distributions have their mode at the smallest class interval and are monotonically decreasing. In recent years two facts about IRT distributions have been made abundantly clear: (1) IRT distributions are not necessarily monotonically decreasing (e.g., Sidman, 1956; Kelleher, Fry, and Cook, 1959); nor (2) are they always independent (e.g., Wertheim, 1965). Thus, a theory specifying independent and identically distributed IRTs certainly will not be able to account for all or even most of the data.

The present study seeks an empirical analysis of IRT distributions under reinforcement

schedules that should maximize the chances of observing independent and identically distributed IRTs. In the studies mentioned above, where such IRT distributions did not occur, the schedules employed reinforced some IRTs and not others. Under VR and VI schedules, the distribution of reinforcements over IRTs is presumably more nearly equal. Thus, timing behavior might be absent and dependencies between successive responses would be minimized. Conditions can be arranged to obtain stable over-all performance, thereby increasing the chances that all IRTs, or at least a large subset of them, will be identically distributed. There are no compelling *a priori* reasons to expect a particular form of IRT distribution, such as the exponential distribution.

METHOD

Subjects

Two naive female adult white rats were maintained on 23-hr food deprivation. After the daily experimental sessions they were given free access to wet mash for 1/2 hr in their individual living cages.

Apparatus

The experimental chamber was a standard Grason-Stadler rat box. All programming was done by automatic switching circuits. Responses were recorded on an Esterline-Angus event recorder with a chart speed of 12 in. per min. Interresponse times were measured manually from the session records in 1/2-sec units.

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Procedure

Subjects were given 20-min sessions daily. An initial session with continuous reinforcement was followed by 10 sessions with FR reinforcement, the ratio being gradually increased to nine. During the next three sessions, a VR 9 schedule was employed which, for the following 16 sessions, was increased to VR 15. The ratios used ranged from 3 to 29 and were approximately rectangularly distributed. The values of the ratios were 27, 9, 21, 22, 15, 9, 20, 6, 4, 27, 20, 11, 12, 3, 15, 17, 27, 9, 12, 10, 15, 5, 14, 15, 5, 21, 24, 14, 11, 21, and 24. Recordings were taken on the last eight days of this schedule. After VR training, subjects were shifted to a VI 40-sec schedule. Intervals from 5 sec to 90 sec were used. Again the distribution was approximately rectangular. Reinforcements became available after 30, 47, 50, 32, 72, 57, 5, 17, 37, 59, 62, 30, 25, 5, 45, 35, 50, 45, 90, and 7 sec. After seven practice sessions, 14 recording sessions were given. The first bar press of each session was always reinforced, irrespective of the reinforcement schedule.

RESULTS

IRTs under Variable Interval Reinforcement. Cumulative records of the bar presses of both rats during the 14 recording sessions revealed no conspicuous differences between sessions. Representative records for three sessions of S2 are presented in Fig. 1. The average response rate for both subjects was about 18 responses per min. Performance appeared to be stable throughout the 20-min sessions. Thus, in all further analyses the data from all sessions have been pooled.

Although the over-all response rate during a session was stable, it is still possible that systematic differences might exist between the response rates before and after a reinforcement. Therefore, the average latency of the first bar press after each reinforcement was calculated as well as the IRTs between the first and second responses and all successive response pairs. The mean IRTs are presented in Fig. 2. Ninety-nine per cent confidence intervals for the means are also shown. The confidence intervals become wider as the distance from the last reinforcement increases, since the data points are based upon fewer and fewer scores.

Fig. 1. Samples of cumulative records for VI 40 sec (S2 for sessions 4, 6, and 13) and VR 15 (S1 for sessions 3, 5, and 7).

Fig. 2. Mean IRTs under the VI schedule as a function of the number of responses after reinforcement with 99% confidence intervals for means around the grand mean.

Disregarding the first response time, which is, properly speaking, a latency, the mean IRTs appear to be quite constant. The decrease observed for S1 remains within the confidence limits. A test for the predominance of downward changes relative to the oscillations about the trend does not allow the rejection of the null hypothesis for either subject (Wallis and Roberts, 1957, p. 573).

In order to test the independence of successive responses, all IRTs were categorized into scores above and below the median. Then, the frequency was determined with which a score above the median was followed by a score above the median, as well as the number of times it was followed by scores below the median. Similar calculations were made for the scores below the median. Thus, a 2×2 contingency table was obtained separately for each rat. These tables reveal a slight tendency for IRTs to cluster: for S1 the probability of a short IRT following a short IRT was .52; the probability of a short IRT after a long IRT was only .46. The corresponding values for S2 were .46 and .39. A test of the equality of these proportions resulted in chi-square values of 20.18 and 32.05, with Ns of 5556 and 6771 for S1 and S2, respectively. Both of these values are highly significant. However, the fact that the hypothesis of no dependence can be rejected is, in itself, not very informative. The test is based upon a large number of observations and hence is extremely powerful and likely to detect minute deviations. An index of the strength of the relationship between successive responses is provided by the ϕ coefficient, the correlation coefficient for two dichotomous variables. Since $\phi^2 = \chi^2/N$, the amount of non-independence present is extremely small. $\phi^2 = .0037$ and $.0047$ for the two subjects; on each trial less than half of one per cent of the variance can thus be accounted for by regression on the preceding trial.

Every mean IRT in Fig. 2 is associated with an IRT distribution. A chi-square test can be used to ascertain if the frequency distributions of the successive responses may be regarded as identical. After choosing seven categories for the time values, a chi square of 159.53 for 126 df was obtained for S1, which is not significant at the .01 level. A different categorization into six classes (105 df) for S2 resulted in a chi square of 155.04, which is

significant at the .01 level. However, even in the latter case the differences observed were small in absolute value. As an index of the amount of the observed differences, Cramer's statistic ϕ' was computed and found to be .070. $\phi' = \phi/\sqrt{L-1}$ where $L = \min$ (rows, columns), but it can no longer be interpreted in terms of variance reduction (Hays, 1963, p. 606).

Interresponse time distributions averaged over all responses are presented in Fig. 3 for each rat. Obviously neither one of these is exponential: both distributions have a much longer tail than exponential distributions. The rather complex character of the present IRT distributions becomes more apparent in Fig. 4 where conditional distributions were plotted. For both subjects, the conditional probability of a bar press at time t , given that no bar press has occurred up to time t , first increases to a maximum at about $1\frac{1}{2}$ sec and then gradually decreases.

IRTs under Variable Ratio Reinforcement. The data obtained under the VR schedule were analyzed in exactly the same manner as in the previous section.

Response rates were again found to be remarkably constant, both within and between sessions. The data could therefore be pooled over sessions. Examples of the cumulative

Fig. 3. Frequency distribution of all IRTs under the VI schedule.

Fig. 4. Conditional distribution of IRTs under the VI schedule.

records of S1 are shown in Fig. 1. Response rates per min were about 70 and 40 for S1 and S2, respectively. Figure 5 shows the mean IRTs as a function of the number of responses since the last reinforcement. Both subjects exhibited a stronger warm-up effect than in VI perform-

Fig. 5. Mean IRTs under the VR schedule as a function of the number of responses after reinforcement with 99% confidence intervals for means around the grand mean.

ance: mean IRTs decreased for the first five responses. After that, mean IRTs remained constant for S1 but began to increase steadily for S2. This increase is statistically significant, while the data for S1 did not show a significant predominance of change in any direction.

As for the independence of successive responses, the results are very much like those obtained under the VI schedule. The null hypothesis of no dependence is rejected in both cases due to the power of the chi-square test ($\chi^2 = 32.66$ and 52.13 for S1 and S2, respectively), but the detected dependence is too small to be of much concern. The proportion of variance accounted for by looking at preceding IRTs is .0054 and .0116 for the two subjects.

Over-all IRT distributions are shown in Fig. 6. Only IRTs following the fourth response after each reinforcement were included, since only these were judged to be homogenous enough to permit averaging. Figure 5 shows that the early IRTs are decidedly different from the later IRTs. Differences among the distributions of successive IRTs were statistically significant ($\chi^2 = 81.65$, 30 df and $\chi^2 = 106.86$, 45 df for S1 and S2, respectively).

Fig. 6. Frequency distributions of IRTs under the VR schedule.

The size of the differences was again quite small, ϕ' being merely .076 for S1 and .089 for S2.

The conditional IRT distributions (Fig. 7) did not show the initial increase obtained previously with a VI schedule. Figure 7 is based upon the same data as the frequency distribution in Fig. 6 and is therefore unaffected by the strong warm-up effect after reinforcements.

DISCUSSION

A description of successive IRTs as independently and identically distributed random variables would provide a good approximation to the present VI data. After the first response following a reinforcement, the IRT distributions were reasonably stable, although a slight trend toward shorter IRTs can be detected. Dependencies among responses existed, in that IRTs of similar length tended to cluster, but the proportion of variance which can thus be accounted for is extremely small. Under a VR reinforcement procedure the situation was slightly more complicated, as the mean IRTs were generally less stable,

especially immediately after a reinforcement. However, dependencies among successive responses were again found to be very small.

The conditional distribution of IRTs (Fig. 4) is quite similar to earlier results reported by Anger (1956) with a 5-min VI schedule for practiced subjects. Only one of Anger's subjects showed the initial increase in the conditional response probability that was found in the present case. This discrepancy might be partly due to the differences between schedules, and partly to Anger's use of rather wide response classes as compared with $\frac{1}{2}$ sec here.

Ray and McGill (1964) have shown that the shape of an IRT distribution may depend upon the width of the class interval used. Bimodal distributions of pecking responses in pigeons were observed with class intervals as small as .05 sec. However, even if such bimodality were to be found in rat data, the major results of this paper would not necessarily be affected. Any tempting inferences about a possible mechanism that could generate the observed IRTs would be dependent upon the exact shape of their distribution.

Some of the present findings are of limited generality in some respects. The relative constancy of the mean IRTs after the first response following each reinforcement (Fig. 2) is certainly dependent upon the particular reinforcement schedule employed in this study. This can best be seen by considering a VI schedule in which the various intervals are not equally likely. Fixed-interval reinforcement would be an extreme case of such a schedule. Response rates after the first bar press are no longer constant under such schedules, but subjects adjust their response rates according to the differences in the reinforcement probability at various times. It should be noted, however, that these adjustments are by no means perfect. In the present case, for instance, the conditional probability of reinforcement at time t , given no reinforcement up to time t , increases steadily with t . Response rates, on the other hand, do not show a corresponding increase after the first bar press but remain constant. The only increase in response rate (concentrated right after the time of the last reinforcement) is due to the large latency of the first response.

Finally, it must be noted that the exposure of the present subjects to each schedule was limited. It is possible that a different pattern

Fig. 7. Conditional distributions of IRTs under the VR schedule.

of results would be obtained with much longer training on each schedule.

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