Multimodal distributions of pigeon's reaction time*

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Four pigeons were trained to peck at one disk when presented with white noise at one of five levels $\geqslant$ 76 dB SPL and to peck at another disk when presented with white noise at one of five levels $\leqslant$ 72 dB SPL. The distributions of reaction time indicate that, in this situation, the pigeons emit several discrete types of responses, each with its own characteristic speed of execution. Differential reinforcement of short reaction times affects the proportions of the response-type mixture, but not the characteristic speed of each response.

The purpose of this paper is to describe some rather unusual distributions of reaction time found in the course of experiments dealing with the choice behavior of pigeons. In these experiments. four White Carneaux pigeons were trained to peck at three translucent disks, located in a test chamber that also contained a loudspeaker and a device for presenting food. Training sessions were divided into a series of trials separated from each other by intervals ranging from 10 to 35 sec. The disks were mounted at the approximate height of the pigeon's head and were separated from each other by about 8 cm. At the beginning of a trial. the center disk was illuminated. When the pigeon pecked at this disk, white noise was presented at one of 10 levels, ranging from 54 to 90 dB re 0.0002 dyne/cm^2. At the same time. the center disk went dark and the two side disks were illuminated. A subsequent peck at either of the side disks ended the trial by causing the illumination of the disks and the auditory stimulus to go off. In addition. if the response was to the disk the E had defined as correct. it was followed by reinforcement. a 2.5-sec period of access to a tray of mixed grain. A peck at one of the disks was reinforced only if it occurred in the presence of a sound intensity less than or equal to 72 dB. and a peck at the alternate disk was reinforced only if it occurred in the presence of an intensity level greater than or equal to 76 dB. The 10 levels of sound intensity were presented in random order.

The time elapsed from the peck at the center disk. which turned on the sound. to the peck at one of the choice keys will be called the reaction time (RT). Figure 1 shows frequency distributions of RT for one of the birds. separately for responses to each of the two choice disks and each of the 10 levels of sound intensity. These distributions are based on the results of 170 daily sessions (80 trials per day) and represent only measurements made after the discriminative performance of the pigeons had attained a final steady level. This report is primarily concerned with the fact that the distributions appear to be made up of several discrete subdistributions. The RTs of the other birds also

fell into such easily identifiable subdistributions. though the number of these subdistributions varied from bird to bird (from 2 to 5). Also. the RT values at which the peaks and valleys occurred differed from bird to bird.

Naturally, our first reaction to these distributions was to begin an intensive search for apparatus artifacts. but none were found. The outcome of a subsequent search for possible explanations and controlling variables is summarized below.

(1) The several subdistributions might be associated with easily distinguishable behavior patterns. For example. it might be that the birds typically peck at the side disk a number of times before striking it hard enough to trip the microswitch that stops the clock. and that this number varied from trial to trial. Or one might imagine that the birds swing their heads from side to side a variable number of times in overt vascillation. However. careful observation of the birds lent no support to such notions. There were no obvious discrete features of behavior that could be related to the various subdistributions.

(2) It might be that the several subdistributions reflect systematic changes in RT during the course of each daily session. For example. it might be that the birds respond very quickly at the beginning of each session and then. perhaps because of fatigue. shift to progressively slower modes of responding. To check on this possibility. the results from each daily session (80 trials) were divided into eight blocks of 10 successive trials. and RT distributions were prepared separately for each of the eight blocks. Each of the resulting distributions had the same appearance as those shown in Fig. 1. with no indication of systematic change during the course of a session.

A similar possibility is that the birds respond with different characteristic speeds on different days. in which case the different distributions could represent results obtained on "slow days." "fast days." etc. This possibility is somewhat more difficult to examine because the distributions obtained on any single day are very irregular due to the small number of responses on which they are based. Still. visual examination of the distributions obtained on very many different days left no doubt that the distributions obtained on single days were also multimodal.

(3) After the completion of the main experiment. further measurements were made with the duration of the interval between trials adjusted to a fixed value of 10 sec. This was done to check on the possibility that the RT obtained on a given trial might be related to the length of the preceding intertrial interval. However. the disbributions obtained with the fixed intertrial interval procedure did not differ in any way from those obtained with the previous procedure.

(4) The next analysis was done to check on the possibility that the RT obtained on any particular trial
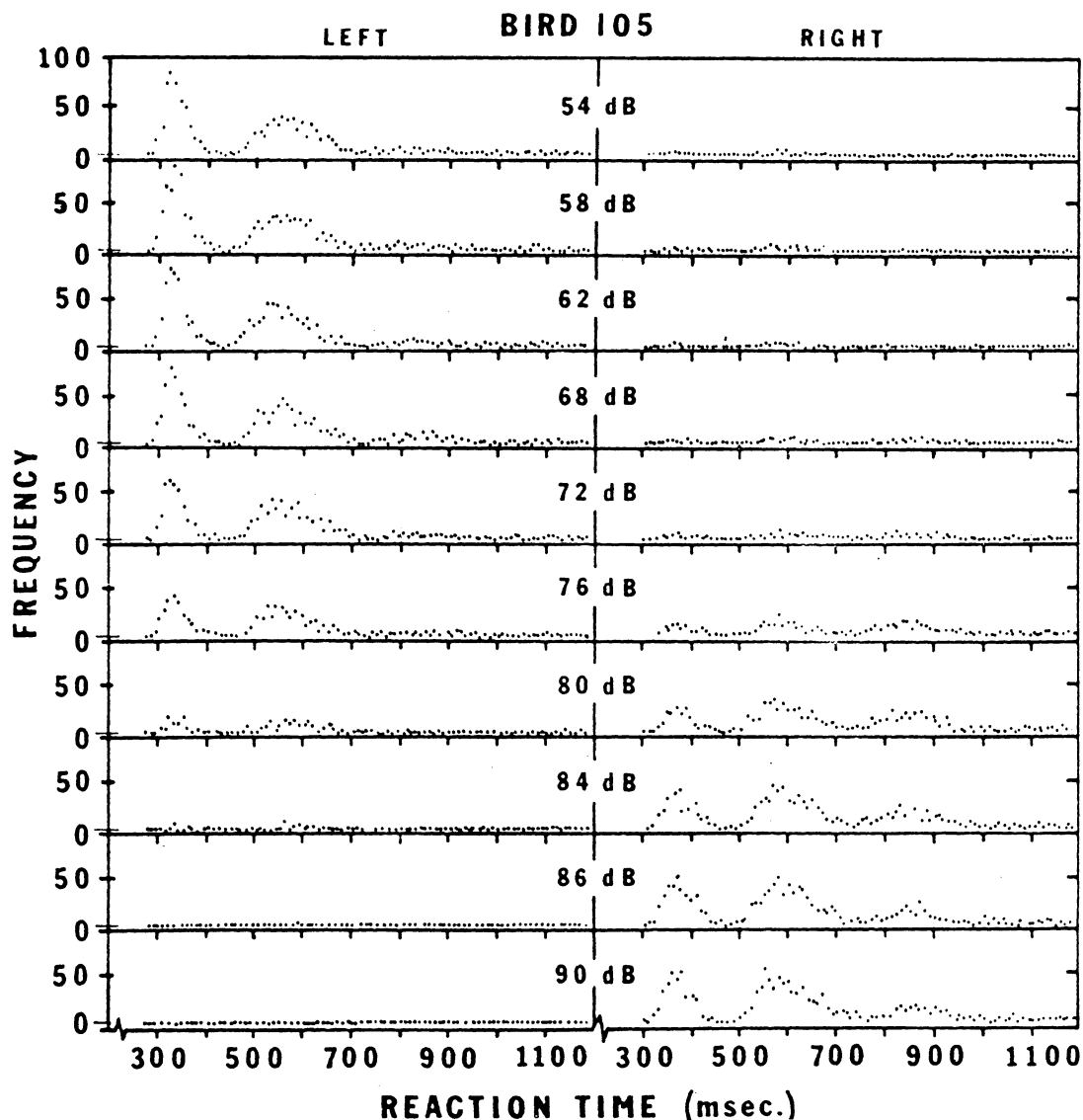
Fig. 1. Frequency distributions of reaction time, truncated at 1,200 msec. Each distribution represents responses in the presence of white noise at the intensity level written in the panel. The left-hand panels show reaction times for responses to the left disk, the right-hand panels show reaction times for responses to the right disk.

might be influenced strongly by some characteristic of the immediately preceding trial. Separate frequency distributions were prepared for trials classified on the basis of several characteristics of the immediately preceding trial. These characteristics were: whether the response on the preceding trial was to the left or right disk, whether it was correct or incorrect, whether the stimulus presented was loud (greater than 76 dB) or soft (less than 72 dB), and whether the RT was short (less than 700 msec) or long (greater than 1,000 msec). The results indicated that the RT on any given trial was not influenced in any way by the characteristics of the preceding one; in particular, no matter how the trials were sorted, the frequency distributions based on these trials had the same multimodal form as the distributions based on all trials.

(5) In discussion of the RTs of human Ss, it has sometimes been suggested that very short RTs may reflect "fast guesses" rather than choices based on the stimuli presented (Ollman, 1966; Yellot, 1967). To check on this and similar possibilities, the variation of choice probability with stimulus intensity was examined separately for each of the response classes defined by the subdistributions. The results for Bird 105 are shown in Fig. 2. Each curve is based on only those responses that occurred within the time limits written in the figure. Thus, one curve is based primarily on the responses from the first subdistribution, another primarily on responses from the second subdistribution, and so on. If the Ss were guessing on all trials, i.e., if their responses were independent of stimulus intensity, the function would be a horizontal line. If it is assumed that the Ss guess on a constant proportion of all trials, and that on the remaining trials they choose responses on the basis of stimulus intensity, then the proportion of trials on which the selection of the response is governed by the

auditory stimuli [this proportion will be called p(A)]. is given by the difference between the upper and lower asymptotes of the sigmoidal choice curves shown in Fig. 2 (cf. Heinemann. Avin. Sullivan. & Chase. 1969). It can be seen that the values of p(A) are virtually identical for three curves. Simple analyses of variance done on the p(A) values derived from the curves of all the birds yielded no statistically significant differences. Thus. the degree to which the pigeons' choices are controlled by the auditory stimuli does not vary with the RT.

(6) Choice curves such as those shown in Fig. 2 are consistent with a simple model based on the theory of signal recognition. This model assumes that the sensory effect produced by a given stimulus varies from trial to trial. and that the distribution of the sensory effects is normal. The distributions produced by repeated presentations of different stimulus intensities are assumed to have different means but the same variance. If the S chooses one response when the sensory effect falls below some criterion value. and chooses the alternate response when the sensory effect exceeds this criterion value. then choice curves of the general form shown in Fig. 2 will be obtained (Heinemann et al. 1969; Boneau & Cole. 1967).

A number of models based on signal recognition theory have also been proposed for choice reaction time (cf. Laming. 1968). Within this framework. a model that has some of the properties needed to account for the multimodal RT distributions could be constructed on the following assumptions: (a) Though the auditory stimulus is presented continuously. the pigeon bases its decision on one or more short discrete observations of the sensory inflow. (b) The rule for response selection is based on two criteria or cutoff points that divide the continuum of sensory effects into three regions to be called "soft." "medium." and "loud." If the first observation taken is "soft" or "loud." the appropriate response is made immediately. but if it falls into the "medium" region. another observation is made. Additional observations are made until one that falls into the "soft" or "loud" regions is encountered. The RT is assumed to reflect the number of observations made prior to a response. This sort of model leads to the expectation that RTs to stimuli in the middle of the intensity range will be longer than RTs to stimuli at the ends of the range. To check on this matter. the mean RTs for responses made in the presence of each of the 10 stimuli were computed. separately for each disk. The mean RTs did not vary in any consistent way with stimulus intensity: in particular. for none of the birds was there the slightest indication that RTs are largest in the middle of the stimulus range.

(7) In the experiments described above. every correct response was reinforced. In a further experiment with the same birds. correct responses were reinforced only if the RT was less than 800 msec. This procedure resulted in a large decrease in the mean RT. However. the procedure did not cause a shift in the modes of the various subdistributions. Rather. the change in the mean
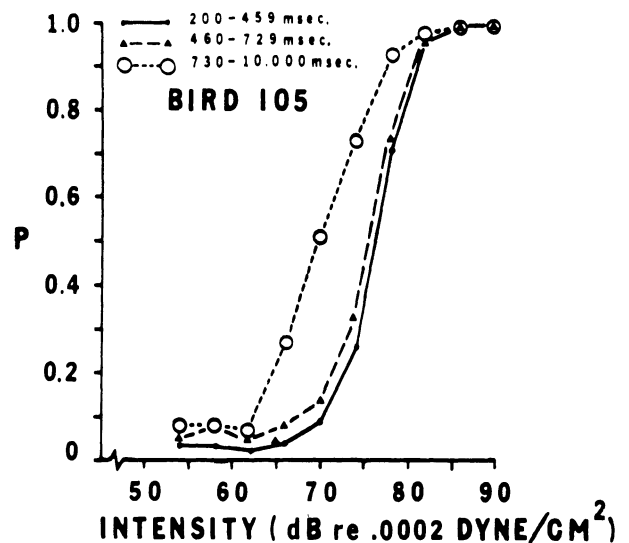

Fig. 2. Proportion (P) of responses to the disk defined as correct for the five high-intensity stimuli, as a function of stimulus intensity. Each curve is based on responses executed within the time limits indicated in the key. Based on the results shown in Fig. 1.

value of RT was produced by a change in the relative number of responses in each of the subdistributions. In other words. the pigeons now made relatively more of the faster responses.

(8) In a further experiment. a different group of pigeons were trained simply to peck at the center disk and then at one of the side disks (always the same side). Reinforcement was presented immediately following the completion of this two-peck sequence. No sounds or other discriminative stimuli were presented. thus no decision was required. The RT distributions obtained in this experiment were also multimodal, suggesting very strongly that the multimodal form of the frequency distributions does not reflect a characteristic of an underlying decision process.

In summary. the principal results of these experiments indicate that with respect to RT. the pecking responses of pigeons do not form a continuous repertoire but fall into a few discrete classes. Differential reinforcement of short RTs affects the relative frequency with which responses belonging to the different classes occur. but not the modal RT values that define the classes.

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