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DISCRIMINABILITY OF FIXED-RATIO SCHEDULES FOR PIGEONS: EFFECTS OF ABSOLUTE RATIO SIZE[1]

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In a discrete-trial choice situation, 12 pigeons were trained to discriminate which of two different fixed ratios they had completed. Psychometric functions were obtained at three ratio requirements (*i.e.*, with the larger ratio set at 10, 20, or 30 responses) by gradually reducing the size of the smaller value. Although different response biases developed across subjects, in each case accuracy decreased systematically with ratio difference regardless of absolute ratio requirements. Above-chance performances were maintained even at relative ratio differences of 10% or less. Estimates of the Weber fraction showed that, in general, discriminability improved with absolute ratio size up to 30 responses, and beyond, when the results of other studies are considered. A similar trend held for rats studied by other investigators in fixed-ratio "counting" tasks at lower requirements. In terms of a signal-detection analysis, performance was similar to that reported for other species and dimensions. Taken together, the results suggest that for this somewhat novel dimension the same psychophysical relations hold as are commonly observed for exteroceptive stimuli.

Most psychophysical fork focuses on the discriminability of familiar exteroceptive stimuli, with reinforcement schedules serving instructional and/or motivational ends when animal subjects are used. Random scheduling of some sort is required to eliminate extraneous sources of stimulus control (Blough, 1966). In other contexts, the schedules themselves are directly studied—usually in terms of their effects upon behavior (*e.g.*, Ferster and Skinner, 1957), less frequently for their discriminability. While temporal cues[2] have received considerable attention in recent years (*e.g.*, Catania, 1970; Elsmore, 1972; Richardson and Loughead, 1974), a parallel interest in response-based dimensions has not arisen despite Rilling and McDiarmid's (1965) original work in the area. Their study, and the one that followed (Pliskoff and Goldiamond, 1966), determined the discriminability of fixed-ratio (FR) schedules for pigeons, using choice procedures analogous to the "yes-no" methods of signal-detection research. Two different-sized ratios were alternated from trial to trial on a "stimulus" key. Subjects were required to complete the scheduled ratio and then to indicate its value by a peck on the appropriate side key, which was reinforced. Pliskoff and Goldiamond found that at relatively small ratio differences (*e.g.*, at FR 42 *versus* 58) their birds made many more errors than did Rilling's subjects at comparable values. The discrepancy is difficult to interpret because only a small number of subjects was tested under each procedure. In any case, both studies provide convincing demonstrations of stimulus control by fixed-ratio size in the region of FR 50. The psychometric functions are similar to those of classical psychophysics. The detectability plots for Rilling's subjects show performance changes consistent with the predictions of the so-called "modern" approaches to signal detectability, which separate the sensory and motivational factors controlling choice behavior (see Green and Swets, 1966).

Comparable results have been obtained in vision (Hodos and Bonbright, 1972; Wright,

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[2] Strictly speaking, the term "temporal cues" describes the stimulus conditions from the experimenter's viewpoint only, in terms of scheduled values (*e.g.*, different durations), without reference to receptor processes, which are unknown.

1972), audition (Clopton, 1972; Irwin and Terman, 1970; Terman, 1970), and taste (Morrison and Norrison, 1966), using choice procedures like Rilling's. In most cases, though, parametric work has not been undertaken. For example, except for Clopton's work with monkeys, little is known about the effects of stimulus level on differential sensitivity. Presumably, the relation is an orderly one that parallels the results obtained from human subjects. The argument seems less convincing, however, when a novel dimension like fixed-ratio difference is involved. As Leckart and Bishop (1967) noted, additional research is needed to determine whether Weber's law applies across a range of values. In any event, discriminability should be measured in the lower regions, where most free-operant work is done. More generally, the data may provide an empirical basis for speculating about the role of response-produced cues in behavioral chains, and thus supplement other approaches to the problem (see Platt and Senkowski, 1970).

The present study was designed to extend Rilling's results to other sets of values to determine the effects of absolute ratio size on fixed-ratio discriminability, using within- and between-group comparisons and a larger number of subjects. Because of continued interest in the application of detection theory to animal psychophysics (*e.g.*, Swets, 1973), the traditional measures of discriminability (difference threshold, Weber fraction, and point of subjective equality) are presented along with a signal-detection analysis of the data.

METHOD

Subjects

Twelve White Carneaux pigeons, ranging in age from 5 to 7 yr, served in the first phase of the experiment. They were maintained at approximately 80% of their free-feeding weights and were tested daily. All were experimentally naive except Bird 323, which had been trained in a similar task several months earlier. Five of the subjects served in the second phase and two of these (Birds 372 and 323) were tested at night under a more flexible weight criterion.

Apparatus

The test chamber for Phase 1 was a home-made model containing a three-key response panel manufactured by Lehigh Valley Electronics. Another chamber of the same design was used in Phase 2. The keys, which could be illuminated by white light, were located 23.2 cm above the chamber floor. A minimum force of about 0.2 N (20 g) and an excursion of 1 mm was required to operate them. Experimental contingencies were controlled by predetermining counters (Sodeco, model TCeF4PE.25), plus a system of relays, switches and timers, all of which were located in another room.

Procedure

Phase 1. The subjects were assigned to different groups, as follows: four birds were tested with the larger ratio set at FR 10, three birds at FR 20, and five at FR 30. After the birds had been adapted to the chamber, a preliminary training procedure similar to Rilling's (1967) was used to establish center- and side-key responding. After five days of training, the discrimination task was introduced. A fixed number of pecks on the center key, when lit, darkened it and illuminated both side keys; a peck on either side key darkened both and produced either reinforcement or blackout, depending upon the size of the preceding ratio. On small ratio trials (*e.g.*, after FR 2), a left-key peck was considered "correct" and produced grain; a right-key peck was "incorrect" and turned off the house-light for 3 sec. The contingencies were reversed on large ratio trials (*e.g.*, after FR 10). The next trial did not begin until a minimum of 11 sec had elapsed with no center-key responding. The two ratio values were scheduled equally often in a session according to a quasi-random sequence that restricted the run length of each value to a maximum of five.

A descending series of test values was used, beginning at a relatively large ratio difference and continuing until the difference had been reduced to 10% of the larger value. After one set of values had been tested, the smaller ratio was increased by one or two responses to permit testing at another (smaller) difference. At first, increases were delayed until the performance of all birds in a group had stabilized for 500 trials. Later, increases were made on an individual basis to accommodate those subjects that stabilized slowly and/or missed sessions because they were overweight; in addition, sample size was increased to 1000 trials and the criterion made more stringent—accuracy levels over the last 500 trials had to fall within five points of the mean. Occasionally, the series direction was reversed to redetermine a subject's performance at an earlier set of values. At the end of Phase 1, three birds were tested at the point of physical equality (*e.g.*, FR 10 *versus* 10) to rule out the possibility that cues from the scheduling apparatus or other extraneous sources affected the results.

The top half of Table 1 summarizes the procedures, subject by subject, according to group, to indicate exactly the range of ratio values tested and to highlight differences in treatment among subjects. For example, Bird 323 was exposed to nine different ratio sets, one at a time, beginning at FR 12 *versus* 30 and ending at FR 30 *versus* 30. Because its session length was twice that of the other subjects, probabilistic reinforcement was used—*i.e.*, 50% of its correct choices were randomly reinforced with grain; all incorrect choices produced blackout. Bird 368 completed fewer sets because it fell behind schedule early in testing when it was slow to make criterion. Bird 367 injured its beak at FR 14 *versus* 20 and could not be reconditioned. While most subjects could be maintained on weight using 2.5 sec of access to grain as reinforcement, a few (Birds 361, 368, 323) required somewhat lower values.

Table 1

Summary of Test Conditions in Phases 1 and 2

Bird No.	*Larger Ratio*	*Smaller Ratios*	*Trials per Day*	*Total No. of Sets*
		PHASE 1		
5	FR 10	FR 2-9	100	8
361	FR 10	FR 2-9	100	8
362 (1)	FR 10	FR 2-10	100	9
363	FR 10	FR 2-9	100	8
364 (1)	FR 20	FR 6-20	100	9
366	FR 20	FR 6-18	100	8
367	FR 20	FR 6-13	100	5
368	FR 30	FR 9-23	100	8
370 (1)	FR 30	FR 9-27	100	10
371	FR 30	FR 9-27	100	10
372 (1)	FR 30	FR 9-27	100	10
323 (1)	FR 30	FR 12-30	200	9
		PHASE 2		
362 (3)	FR 10	FR 2-7	300-400	6
364 (2)	FR 10	FR 2-9	200-400	8
370 (2)	FR 10	FR 2-6	200-400	5
372 (2)	FR 10	FR 5-8	400	4
362 (2)	FR 30	FR 9-25	200-400	9
364 (3)	FR 30	FR 13-25	300-400	7
372 (3)	FR 30	FR 17-25	400	5
323 (2)	FR 30	FR 20-26	400	4

NOTE.—Test order for subjects serving in both phases of the study is shown in parentheses.

The major dependent variables were the percentage of correct responses and the percentage of responses to one side key. The latter is a nondirectional measure of response bias that has a maximum value of 1.0 when all responses occur on the same side key and a minimum of 0.5 when responses are distributed equally on both keys (*i.e.*, when no "position preference" exists). Means were computed for criterion data only (*i.e.*, for the last five to 10 days at each ratio difference) after several days of preliminary testing. Comparable data were obtained for three of Rilling's subjects to estimate FR 50 performance levels.[3]

Phase 2. After Phase 1, one or two birds from each group was transferred to other values and/or retested at the same values (see Table 1). The procedure differed from Phase 1 in that: (i) the number of trials was increased to a minimum of 200 per day, depending upon the subject's weight and the time available for testing; (ii) Bird 323 was maintained at 0.5 reinforcement probability while the others were reduced from 1.0 to 0.4; and (iii) except for Bird 370, performance was determined at two sets of values simultaneously by scheduling two different values of the smaller ratio equally often on half of the trials and a single value of the larger ratio on the remaining trials. Because only two response classes were defined, the payoff matrix remained symmetrical in any case. The initial values were chosen to yield about 90% accuracy, and their difference was gradually reduced until responding fell below 75% correct. For example, Bird 364 was tested with ratio values ranging from FR 2, 3 *versus* 10 to FR 8, 9 *versus* 10 before being switched to FR 30 for additional testing. For further details see Hobson (1970). A criterion comparable to the Phase 1 criterion for individual subjects was used to determine when

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[3] The psychometric functions for two of Rilling's subjects have appeared elsewhere (Rilling and McDiarmid, 1965, Figure 1). The remaining data, which are unpublished, were supplied by Rilling in personal communication. Because Bird 4800 was tested twice, its results are treated here as a within-subject replication of the original FR 50 data (see Figure 3).

performance levels had stabilized in Phase 2. The results are based on the last 1000 to 1200 trials completed at each set of values.

RESULTS

Figure 1 shows psychometric functions for each subject in Phase 1, based on the percentage of correct responses at each set of values. Position preference data for the same subjects are also shown (dotted lines) to indicate any shift in the distribution of side-key responses during testing. The abscissa has been scaled in proportion to absolute ratio size so that performances can be compared on the basis of relative ratio differences. The results

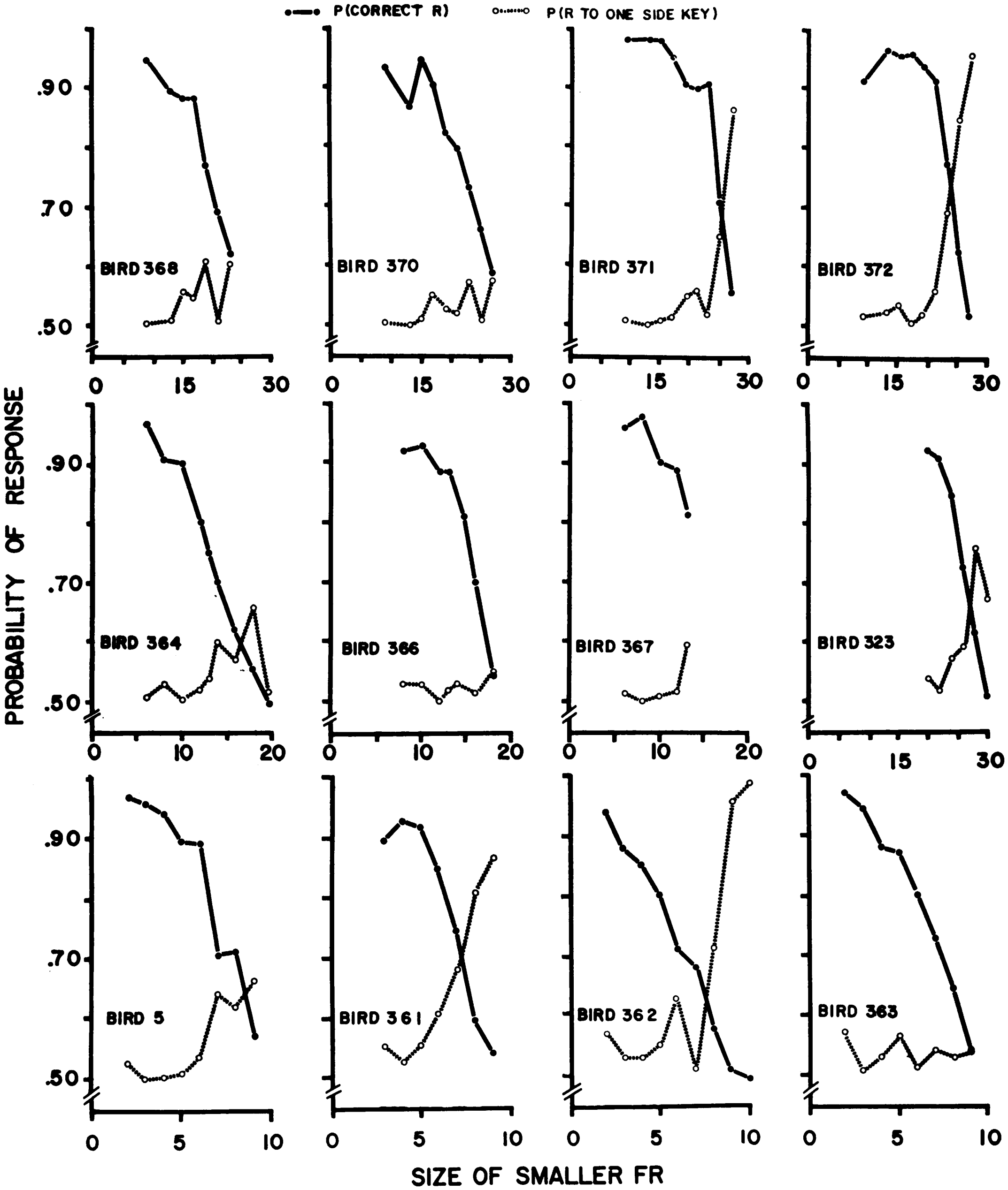

Fig. 1. Psychometric functions and position preferences for individual subjects in Phase 1, based on the means for the last 500 to 1000 trials of testing. See text for further details.

from Phase 2 are plotted in the same way in Figure 2. For Birds 362, 372, and 323, Figure 2 repeats the psychometric functions from Phase 1, to illustrate reliability. The data show that subjects performed similarly, under a somewhat different set of test conditions, when transferred to new ratio levels and/or returned to the original values. As ratio difference reduced accuracy levels, most subjects began choosing one of the two side keys more frequently than chance (*i.e,* on more than 50% of the trials), but preference varied considerably from subject to subject and at different points in the test series. In any case, the psychometric functions showed good stimulus control by fixed-ratio size regardless of preference. Only two subjects failed to maintain above-chance accuracy levels at the smallest difference. In other words, the dimension was a discriminable one for pigeons even when the difference was reduced to 10% of the larger value. The performance of Bird 323 at FR 28 *versus* 30 indicates that for the "best" subjects, the difference must be reduced beyond that point before chance levels are obtained. Whatever the limits, the psychometric functions for most subjects appeared somewhat steeper at FR 30 than FR 10, which suggests that discriminability in terms of relative ratio differences improved with absolute ratio size. For example, compare the results for Bird 364 at FR 7 *versus* 10 to those at FR 14 *versus* 20 and FR 21 *versus* 30.

To estimate the effects of absolute ratio size more exactly, the psychometric functions were replotted on normalized ordinates and a straight line fit by eye to the data within the range of decreasing accuracy levels. The curve

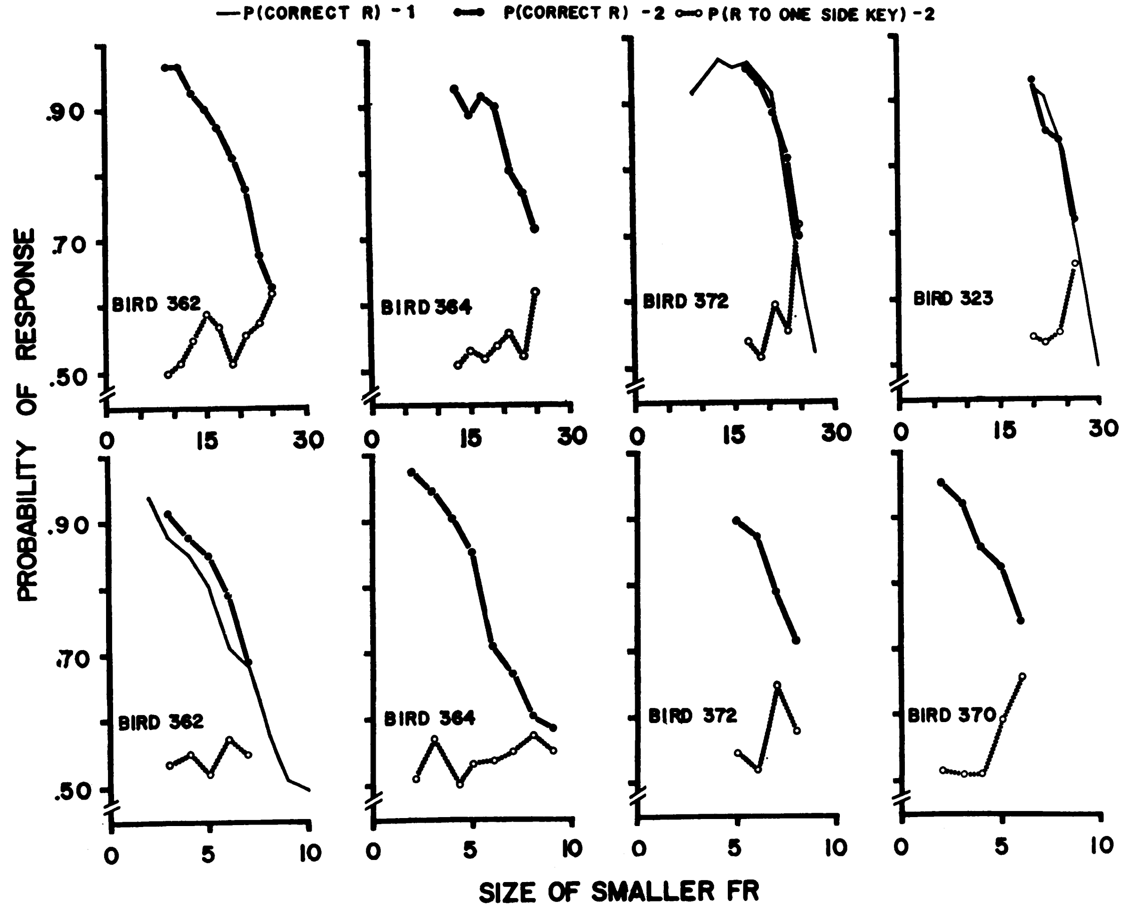

Fig. 2. Psychometric functions and position preferences for subjects serving in both phases, based on the means for the last 1000 to 1200 trials of testing. The key at the top indicates whether the functions were obtained in Phase 1 or 2 of the experiment. See text for further details.

Table 2

Estimates of discriminability at different ratio levels, determined from the psychometric functions in Figures 1 and 2 after a *z*-score transform of the ordinate values.

Bird No.	*Larger Ratio*	*Slope*	*50% Point*	*At 1σ Unit*		*At the 75% pt.*	
				ΔI	*ΔI/I*	*ΔI*	*ΔI/I*
Phase 1							
5	FR 10	−0.31	9.4	3.2	0.34	2.8	0.28
361	FR 10	−0.36	9.0	2.8	0.32	2.9	0.29
362	FR 10	−0.20	9.2	5.1	0.55	4.2	0.42
363	FR 10	−0.23	9.6	4.3	0.45	3.3	0.33
364	FR 20	−0.26	19.0	7.9	0.42	6.3	0.32
366	FR 20	−0.37	19.0	5.4	0.29	4.8	0.24
368	FR 30	−0.32	25.7	8.7	0.34	10.4	0.35
370	FR 30	−0.31	28.8	9.6	0.33	7.9	0.26
371	FR 30	−0.53	28.2	5.6	0.20	5.7	0.19
372	FR 30	−0.64	27.0	4.5	0.17	6.1	0.20
323	FR 30	−0.48	29.7	6.3	0.21	4.7	0.16
Phase 2							
362	FR 10	−0.23	9.2	4.4	0.48	3.7	0.37
364	FR 10	−0.23	9.3	4.4	0.47	3.7	0.37
370	FR 10	−0.24	8.5	4.1	0.47	4.2	0.42
372	FR 10	−0.26	10.1	3.8	0.38	2.5	0.25
362	FR 30	−0.30	28.0	10.0	0.36	8.6	0.29
364	FR 30	−0.28	30.6	11.0	0.36	6.7	0.22
372	FR 30	−0.53	27.9	5.6	0.20	6.0	0.20
323	FR 30	−0.45	30.0	6.6	0.22	4.7	0.16
Rilling							
4800	FR 50	−0.53	48.5	9.5	0.20	6.5	0.13
5488	FR 50	−0.56	49.0	9.0	0.18	7.5	0.15
4860	FR 50	−0.44	49.0	11.5	0.23	9.0	0.18
4800	FR 50	−0.45	46.0	11.0	0.24	11.5	0.23

was extrapolated to determine the abscissa value corresponding to chance performance (*i.e.*, the point of subjective equality or PSE). Data points falling above 92 to 93% and those obtained at zero stimulus difference were not included in the fit. The parameters of the normalized functions are shown in Table 2 for individual subjects, along with the difference thresholds (ΔI) and Weber fractions (ΔI/I) determined from the functions. Comparable estimates for Rilling's birds are also shown.

Traditionally, the slope of the psychometric function has been interpreted as an index of discriminability, a steeper one indicating finer resolution of stimulus differences. When a relative abscissa scale is used, the slope of the function is inversely proportional to ΔI/I and indicates the extent to which Weber's law (ΔI/I = k) holds across a range of values. The fact that an increase in slope was observed here from FR 10 to FR 30 and beyond, when Rilling's data are included (see Table 2), indicates that a strict version of the law does not hold in this region. This result is equivalent to demonstrating that ΔI/I decreased with increases in absolute ratio size, a trend shown in Figure 3. The Weber fractions in the top half of the figure were determined from the slopes of the psychometric functions by measuring the standard deviations of the functions relative to their 50% points. Those in the bottom half of Figure 3 were calculated in another way: the ratio difference required to maintain choice behavior at 75% correct was determined from the normalized functions and divided by the size of the larger ratio to determine ΔI/I according to a constant response criterion.

Figure 3 shows that the two methods of estimating the Weber fraction do not yield identical measures of discriminability. The finding, which is common in human psychophysics, has also been reported for other species (see Terman, 1970). The discrepancy,

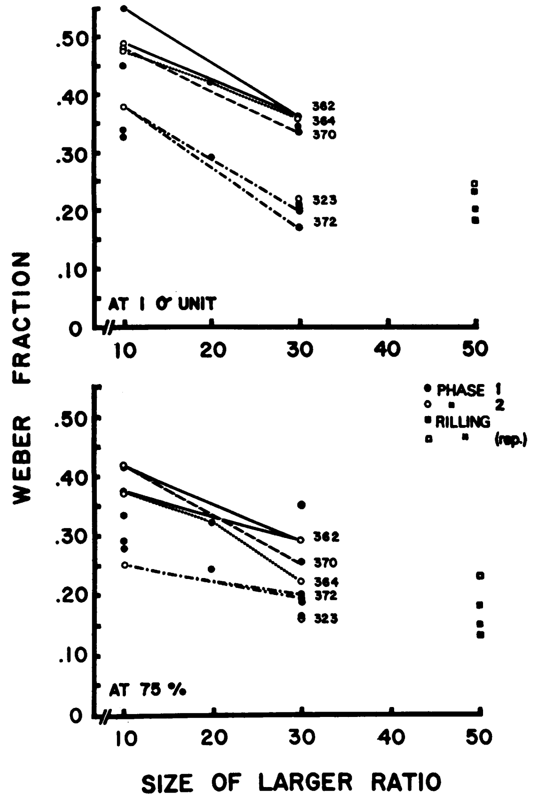

Fig. 3. Weber fraction as a function of absolute ratio size. Estimates in the upper panel are based on the slopes of the psychometric functions in Figures 1 and 2 and those in the lower panel on their 75% points, after a z-score transform of the ordinate values. Straight lines connect data from the same subjects at different ratio sizes.

while interesting, is not troublesome here because, although individuals vary and to a different extent depending upon the measure, within-subject estimates show that a decreasing trend in $\Delta I/I$ occurs from FR 10 to FR 30 without exception. The effect of absolute ratio size is clear in either case.

DISCUSSION

The present study extends Rilling and McDiarmid's (1965) findings at FR 50 to lower ratio requirements. The systematic decrease in accuracy levels with ratio difference indicates that, for a wide range of values, response number or some transform of the fixed-ratio dimension can function as a discriminative stimulus for choice behavior. Exactly how is unclear. Rilling's (1967) later work suggested that response time is not involved. Other response dimensions (*e.g.*, force, location, terminal rate) have not yet been examined. Apparently, like Pliskoff and Goldiamond (1966, p. 7), most researchers are "content" to define the stimulus dimension in operational terms until correlational data are obtained. Formally, the procedure is equivalent to a discrimination task involving exteroceptive stimuli. The dimension is physically defined, reliably measured and, from all reports, readily discriminable to a hungry pigeon. This in itself suggests that the operational approach will continue to demonstrate heuristic value. Conceptually, certain difficulties arise because, like time, the fixed-ratio dimension is irreversible in sequence and processed in some unknown way. While characteristics of this sort may require specialized designs, "they do not imply that [performance] must be dealt with in terms other than those used for discriminations along other continua" (Catania, 1970, p. 38). Nor do they necessarily suggest what kind of collateral behavior, if any, is involved. At present, free-operant studies of fixed-ratio responding in rats, it seems, provide our only source of information. For example, Notterman and Mintz (1965, p. 203) showed that "systematic bases for . . . discrimination exist in the peak force, duration and effort of response" for ratios from FR 6 to 24. Future research must determine whether the findings apply to pigeons in a fixed-ratio choice situation.

In any case, the report of gradual decrease in the slope of the psychometric function for a large number of subjects and in different laboratories strengthens Rilling and McDiarmid's (1965, p. 527) conclusion that the "ability to discriminate ratios is a continuous, not an all or none, process." The abrupt transition that Pliskoff and Goldiamond observed at higher values did not occur. What at first seemed like a surprisingly good performance for Rilling's birds at FR 50 turned out to be typical of subjects tested at other ratio requirements. If there is a limit, it must be low, because above-chance performances were maintained at near-zero stimulus differences—a finding reported for other dimensions as well (*e.g.*, Terman and Kling, 1968). Results of this sort, it might be noted, are consistent with the "no-threshold" position of signal-detection theory, although they do not directly test its assumptions. The term "difference threshold" is retained here simply because it provides a useful estimate of sensitivity at intermediate performance levels. The term itself, as Hodos and Bonbright (1972, p. 478) pointed out, "may have little relevance to the underlying psychophysical mechanism". In fact, subsequent work (Hobson, 1970, Experiment 2) showed that signal-detection theory provides a good account of fixed-ratio discriminability when motivational factors are varied. A cut-off, in the classical (high-threshold) sense, does not appear to exist.

Similar psychometric functions were obtained from all subjects while side-key preferences varied. This finding suggests that discriminability levels were largely unaffected by the types of response bias that emerged during testing. Some of the subjects with the lowest thresholds, for example, had the strongest biases. For this reason, and because preferences varied across subjects regardless of absolute ratio size, it appears that, over all, no sizeable bias effect exists that might distort the threshold values derived from accuracy levels at different ratio requirements. This suggests in turn that had *d'*, the so-called "bias-free" index of signal detectability been used instead, similar results would have been obtained (see Hobson, 1970, for details). In other words, the effects of absolute ratio size are clear for the range of biases that are encountered here.

Once bias effects are discounted, it is not clear what additional information is to be gained from the analysis. To compute the extent to which *d'* and per cent correct diverge with bias requires certain theoretical assumptions. No doubt, *d'* is the more appropriate measure, but, strictly speaking, its advantages cannot be determined for the fixed-ratio dimension or any other until within-subject estimates are obtained under several biasing conditions to demonstrate invariance. In practice, this is rarely done when psychometric functions are determined, in which case probability measures like those in Figures 1 and 2 may be preferred. At least, the measures represent the subject's behavior directly, while *d'* is, after all, a relatively abstract statistic. The signal-detection approach may prove useful in other ways, because it focuses attention on conditional response probabilities rather than aggregate measures. Figure 4 illustrates this approach. It shows the probabilities of correctly detecting the larger ratio and of falsely reporting the smaller ratio for four different subjects. In signal-detection jargon, the functions are known as "isobias contours" because they describe performance as stimulus intensity (or difference) decreases while biasing parameters (*e.g.*, reinforcement conditions, stimulus probabilities) are held constant.

Figure 4 shows that whatever preferences arose, it can hardly be said that response biases developed willy-nilly as sensitivity decreased. Consistent patterns of responding emerged, much like those seen with human observers. The results for Hodos and Bonbright's subjects provide a recent example, in an animal study of comparable size and design. The contours in Figure 4 are representative, in the sense that they illustrate the variety of biases that emerged during testing. No one is typical of more than two or three of the subjects studied. The results for Bird 364 are shown to suggest that while some contours may defy simple description, extreme shifts in bias from one side to the other rarely occur. The contours for the other unbiased subjects, not shown here, were more regular, remaining close to the minor diagonal of the unit square as sensitivity decreased. The biased subjects developed systematic patterns of a different sort. Bird 361, for example, appears to have distributed its errors according to a constant error-ratio criterion that favored detections of the smaller stimulus value (see Terman, 1970). Bird 362's contours look much like one of Rilling and McDiarmid's subjects. A comparison of its performance with that of Bird 372 indicates that differences in choice behavior may emerge that are obscured by conventional plots (*i.e.*, by aggregate measures like those in Figures 1 and 2). The plots emphasize increasing side-key preferences only; they do not in any obvious way suggest that the subjects adopted different decision criteria as their task became more difficult. On this basis, then, isobias contours appear to offer a finer-grained analysis of choice behavior than traditional measures of psychophysical performance.

The results for Phase 2 indicate that the psychometric functions are reliable when redetermined under somewhat different conditions and after long-term intervening training at other ratio sizes. We have, then, no reason

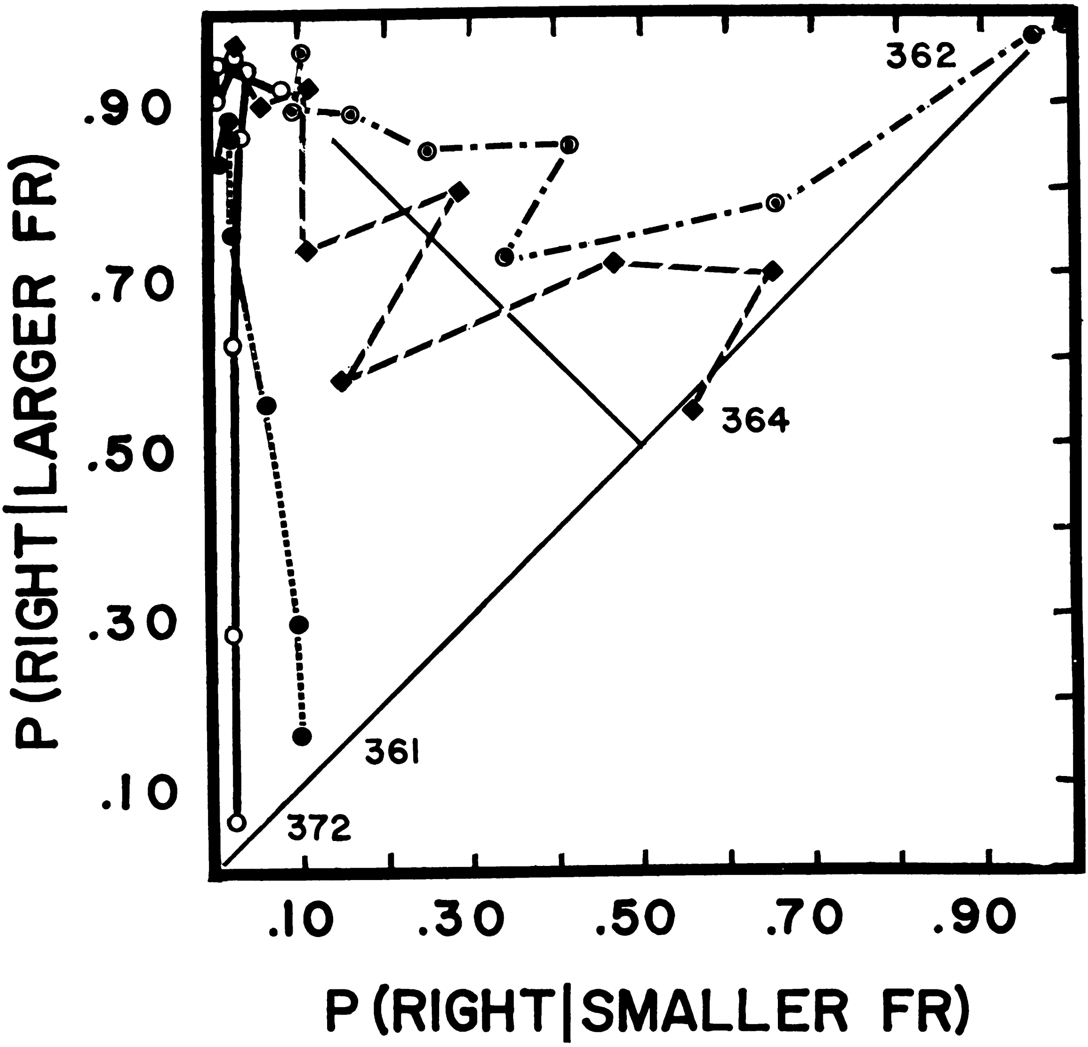

Fig. 4. Some examples of isobias contours for individual subjects in Phase 1. On any given contour, the points represent a subject's median performance at each set of ratio values. The contour for Bird 362, for example, begins at the coordinates 0.95, 0.10 (*i.e.*, its hit and false alarm rates at FR 2 *versus* 10).

to believe that small differences in procedure (*e.g.*, session length, probabilistic reinforcement) were critical here or in Rilling's studies. Taken together, the results suggest that the Weber function levels off in the region of FR 50 (see Figure 3). The conclusion is that, for this dimension, the same systematic relation holds between discriminability and stimulus level as is commonly observed for other sorts of stimuli. Typically, the Weber fraction is constant across the middle range of values, while at the extremes, especially at the lower end, it increases rapidly, which indicates a breakdown in proportionality occurs outside a given region. As for Pliskoff and Goldiamond's results, the relatively poor performance of their subjects at FR 58 may reflect an upturn in the Weber function at large ratio sizes. More likely, it represents a parametric effect of a different sort, one specific to their task, because their procedure, unlike Rilling's, imposed a brief delay between stimulus and response. Also, it did not provide for a gradual reduction in ratio difference. These factors point up the difficulty researchers encounter making between-subject comparisons across different stimulus values when test conditions vary. When entirely different tasks are used—for example, a preference test for concurrent ratios (Leckart and Bishop, 1967)—the same problems arise. If the results from different tasks are to be compared, then parametric data must be obtained. The "count" distributions for Mechner's rats (1957, Appendix II) meet this restriction because they overlap the range of ratio values used in the present study.

Mechner's rats were required to make a minimum number of consecutive responses on one lever before responding on a second lever was reinforced. In effect, the subjects were asked to adjust their run length to a given value without underestimating its size. Thus, the run-length distributions obtained at each value (from FR 4 to FR 16) may be treated like psychophysical judgements in the method of average error in classical psychophysics and the traditional measures derived (see Guilford, 1954). That is, the semi-interquartile range of each distribution can be used to estimate ΔI and its median to determine I. Mechner's data, analyzed in this fashion, show a decreasing trend in $\Delta I/I$ across ratio size for individual subjects with one exception (Rat N4). Platt and Senkowski (1970, Experiment 5) reported a similar trend in recent replication of Mechner's study, using food-tray approach to define run-length termination. The results suggest that at some level, similar processes are involved in fixed-ratio counting as in discrimination and for different species. If not, then, to paraphrase Richardson and Loughead's (1974, p. 128) comments in another context, the functional similarity is all the more remarkable. Researchers should be encouraged to make additional, more direct comparisons across species and procedures. The psychophysics of time might serve as a good working model here for two reasons: (1) conceptually, the same problems arise with time as with number and (2) because time has a much longer history, parametric data are available from several kinds of time-based tasks that invite comparison to their analogues in the fixed-ratio dimension. In any case, whatever the relations between response time and number, an established framework of this sort may offer a set of useful procedures for the less well-known dimension. To mention but one possible application, a two-part chaining procedure, modelled after Reynolds' (1966) temporal version, could be used to obtain simultaneous measures of the emission and discrimination of ratio values for individual subjects.

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