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CHOICE BETWEEN RESPONSE RATES[1]

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Three pigeons were required to peck a single key at a higher and a lower rate, corresponding to two classes of shorter and longer concurrently reinforced interresponse times. Food reinforcers arranged by a single variable-interval schedule were randomly allocated to the two reinforced interresponse times. The absolute durations of reinforced interresponse times were varied while the total reinforcements per hour was held constant and the relative duration, *i.e.,* the relative reciprocal, of the shorter reinforcer class was held constant at 0.70. Preference for the higher rate of responding, as measured by the relative frequency of responses terminating interresponse times in the shorter reinforced class, depended on the absolute reinforced response rates. Preference for the higher reinforced rate increased from a level of near-indifference (0.50) at high reinforced response rates, through the matching level (0.70) at intermediate reinforced response rates, to a virtually exclusive preference (>0.90) at low reinforced response rates. These results resemble corresponding preference functions obtained with two-key concurrent-chains schedules and thereby provide another sense in which it may be said that interresponse-time distributions from interval schedules estimate preference functions for the component response rates corresponding to different classes of reinforced interresponse times.

In a "paced" variable-interval (VI) schedule, reinforcement is arranged only for responses terminating interresponse times (IRTs) within a specified interval, or class. One way tentatively to view a VI schedule itself is as a compound of numerous paced VI schedules where the component paced schedules correspond to various classes of reinforced IRTs (Shimp, 1967). This view suggests that to understand behavior maintained by VI schedules, it would help to study paced schedules and how paced schedules combine. In a paced VI schedule, the rate at which a subject responds is determined by the class of reinforced IRTs that defines the pacing contingency. If the reinforcement density is sufficiently high, an organism spends virtually all of the time responding at the reinforced rate (Shimp, 1967). One can also arrange a paced VI with two concurrent reinforced response rates, *i.e.,* with two pacing contingencies. If the reinforcement density is sufficiently high, a subject spends virtually all of the time responding at the two reinforced rates; part of the time at the lower rate and the rest of the time at the higher rate (Shimp, 1968; Staddon, 1968). The total behavioral output is a mixture of these two reinforced response rates. It is possible to measure a subject's preference for a particular one of two such rates by computing the relative frequency of all responses that terminate IRTs conforming to that rate, *i.e.,* belonging to the corresponding class of reinforced IRTs. This preference measure is formally analogous to preference measures in multi-operanda experiments. But the analogy is more than a formal one: the preference functions obtained in compound paced VI schedules appear to be independent of the number of operanda. Whether the subject is required to respond at different rates on the same operanda, or is required to respond at different rates on different operanda, the resulting preference functions are the same (Moffitt and Shimp, 1971).

Let us review the preference functions obtained to date with compound paced VI schedules. Preference for the higher of two component response rates is a monotonically increasing, negatively accelerated function of the relative reinforcements per hour for that

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rate, *i.e.,* for IRTs in the class of shorter IRTs (Shimp, 1968, 1971; Staddon, 1968; Moffitt and Shimp, 1971). The same preference function appears to describe the effect of magnitude of reinforcement (Shimp, 1968; Moffitt and Shimp, 1971). When both rates are equally reinforced, these preference functions have a value that approximately equals the relative reciprocal of the length of the shorter class of reinforced IRTs (*i.e.,* the reciprocal of the length of the shorter class divided by the sum of the reciprocals of the lengths of each class). And, if one varies this relative reciprocal, while continuing to reinforce both rates equally, one can obtain a matching function: the preference for the higher rate approximately equals the relative reciprocal of the length of the shorter class of reinforced IRTs (Shimp, 1969, 1971; Moffitt and Shimp, 1971). These preference functions depend on the density of reinforcement: preference increases from a level of near indifference at very low reinforcements per hour and reaches an asymptote approximating the matching-to-relative-reciprocal value at 20 or 30 reinforcements per hour (Shimp, 1970). It also has been found that the effects of reinforcement extend farther back in time than the duration of the reinforced IRTs: preference for the higher rate depends on the length of the IRT preceding the reinforced IRT (Shimp, 1973*b*).

The present experiment was designed to explore the boundary conditions for the matching-to-the-relative-reciprocal phenomenon. In the previous experiments in which this phenomenon was obtained, the absolute response rates varied within a rather restricted range (Shimp, 1969, 1971; Moffitt and Shimp, 1971). Some evidence suggests that preference depends on the absolute rates, as well as on the relative rates. In a more complex compound paced VI, one in which there were 10 instead of two reinforced classes of IRTs, Shimp (1973*a*) found that preference for a particular component response rate depended on the absolute rates of responding. Preference was different when the 10 classes ranged in 0.05-sec intervals from 0.1 to 0.6 sec than when they ranged in 0.50-sec intervals from 1.0 to 6.0 sec. Also, in an unpublished experiment, the present authors found that preference relations in a compound paced VI with three reinforced response rates depended on the absolute response rates. The present experiment was designed to study the effect on preference for one of two concurrently reinforced response rates of variations in the absolute key-pecking requirements, while the relative requirements were constant.

METHOD

Subjects

Three adult White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights.

Apparatus

Three standard Lehigh Valley Electronics three-key experimental chambers for pigeons were interfaced to a Digital Equipment Corporation PDP-12 laboratory computer. Only the center keys in the chambers were used. The computer arranged stimuli and reinforcements and recorded data on magnetic tape for subsequent analysis. White noise helped to mask extraneous sounds.

Procedure

The procedure was basically the same as that of previous experiments in which two rates of pecking a single operandum were concurrently reinforced (Shimp, 1968, 1969, 1970, 1971, 1973*b*). A single VI schedule arranged a distribution of interreinforcement intervals, and each reinforcement arranged by the VI schedule was randomly assigned to one of two classes of reinforced IRTs. The schedule was a kind of synthetic concurrent schedule of reinforcement for two classes of IRTs (see Menlove, Moffitt, and Shimp, 1973).

Total reinforcements per hour. A random-interval schedule arranged a reinforcement with probability 0.05 every 3 sec. This schedule stopped timing during reinforcement and whenever a subject paused longer than the upper bound of the longer reinforced IRT. The average scheduled inter-reinforcement interval was approximately 60 sec. The number of reinforcements actually obtained was well above a rate of 30 per hour, except in Conditions 3 and 5, where the rate was slightly less. Reinforcement was 2.0-sec access to mixed grain. Except for a light over the food hopper, the chamber was dark during reinforcement.

Relative reinforcements per hour. The two classes of IRTs were randomly reinforced: the probability of reinforcement for the shorter

IRT was constant and was independent of which IRT was previously reinforced. There were no restrictions on the sequence of reinforced IRTs. The scheduled relative reinforcements per hour for the higher reinforced response rate was 0.5 throughout the experiment: *i.e.,* half the reinforcements were scheduled for the higher and half for the lower reinforced response rate.

Discriminative stimuli. Each key peck initiated a sequence of visual stimuli. The houselight was off and the keylight was on whenever reinforcement was potentially available, *i.e.,* whenever the time since the last response fell in either class of reinforced IRTs. The houselight was on and the keylight was off at all other times since the last response. A key peck terminating an IRT in neither reinforced class had no visual consequence: the houselight remained on and the keylight remained off. A non-reinforced key peck at a time when reinforcement was potentially available had the visual consequence that the keylight went out and the houselight came on. The sequence of visual stimuli did not depend in any way on whether the VI programmer had or had not arranged a reinforcement. Neither did it depend on whether the next reinforced IRT was to be the shorter or the longer IRT. In short, reinforcements were not signalled in any way.

The purpose of the discriminative stimuli in the present experiment was to shorten the time required by a subject in each condition to reach a level of steady state behavior. Our experience in conducting similar experiments suggested that steady state behavior is achieved more quickly when the two reinforced response rates are correlated with visual discriminative stimuli. Here, the same stimuli were correlated with both reinforced response rates and served only to distinguish these rates from non-reinforced rates, not to distinguish one reinforced rate from the other. Previous experiments in the present series have indicated that discriminative stimuli such as those used here tend to sharpen the two IRT distributions so that their modes are more clearly defined and tend to fall nearer the lower bounds of the corresponding classes of reinforced IRTs, but that the stimuli have no discernible effect on the relative frequencies of occurrence of IRTs in the two distributions (Moffitt and Shimp, 1971). Thus, one may employ discriminative stimuli for the present purpose of more quickly reaching steady state behavior without thereby also affecting preference between IRT distributions.

Experimental conditions. The independent variable in the present experiment consisted of the absolute reinforced rates of responding. While the absolute reinforced rates were varied in the manner shown in Table 1, the relative rates of reinforced responding remained approximately constant. That is, if we let $t_{i,1}$ and $t_{i,2}$ be the lower and upper bounds of the i^{th} class of reinforced IRTs, then the relative reciprocal of the shorter class of reinforced IRTs, *i.e.,*

$$\frac{\frac{1}{t_{1,1}} + \frac{1}{t_{1,2}}}{\frac{1}{t_{1,1}} + \frac{1}{t_{1,2}} + \frac{1}{t_{2,1}} + \frac{1}{t_{2,2}}}$$

was always approximately 0.70.

Table 1

Experimental Conditions

Condition Number	*Number of Sessions*	*Limits for the Classes of Reinforced Interresponse Times (sec)*		*Relative Reciprocal of the Shorter Class*
		Shorter Class	*Longer Class*	
1	38	1.50, 2.50	4.00, 5.00	0.70
2	62	0.40, 0.70	1.10, 1.60	0.72
3	31	8.00, 9.50	19.00, 20.00	0.69
4	23	1.50, 2.50	4.00, 5.00	0.70
5	17	5.00, 6.00	12.50, 13.50	0.70
6	18	0.25, 0.60	0.80, 1.10	0.71
7	17	3.00, 4.00	7.50, 8.50	0.70
8	12	2.00, 3.00	5.20, 6.20	0.70
9	23	2.50, 3.50	6.30, 7.30	0.70
10	27	0.40, 0.70	1.10, 1.60	0.72
11	39	0.40, 0.90	1.10, 1.60	0.70
12	23	4.00, 5.00	9.90, 10.90	0.70

Other procedural details. Experimental sessions lasted 1 hr and were conducted six days a week. Experimental conditions were terminated when the relative frequency of shorter IRTs appeared stable for at least three or four days for all three subjects.

RESULTS

Bimodality of the IRT distributions in the present experiment was a prerequisite for the decomposition of behavior into two distinct components corresponding to the two classes of reinforced IRTs. The IRT distributions were regularly monitored and were found to be appropriately bimodal for each bird in each condition. It has been found in previous, similar experiments that a sizable percentage of the total number of responses are those terminating IRTs just shorter than the lower bounds of the classes of reinforced IRTs (Shimp, 1968, 1970). Such also was the case here. Consequently, the data analysis was performed using "obtained" classes of IRTs. That is, we graphically examined the IRT distributions and determined the "obtained" classes of IRTs. The obtained classes typically contained IRTs shorter than those in the reinforced classes, but of course also typically overlapped the reinforced classes to a great extent. If one excludes some extremely short IRTs terminated by responses occurring immediately after the end of a response-feedback blackout and largely insensitive to schedule contingencies (Shimp, 1973*a*), the per cent of all responses that terminated IRTs in the "obtained" IRT distributions, averaged over the last two days of each condition, was 96, 92, and 94 for Birds 1, 2, and 3, respectively. The outcomes of the two analyses, one with frequencies of IRTs in the reinforced classes, and one with frequencies of IRTs in the "obtained" classes, were identical in terms of the conclusions described below, and differed only in a few minor details. This equivalence has obtained also in the previous experiments in this series. In order to prevent the data analysis from becoming unnecessarily long, we restrict the following analysis to those IRTs that fell within the reinforced classes. Table 2 shows

Table 2

Number of responses terminating IRTs in the two reinforced classes on each of the last two days of each condition.

Condition Number	*Number of Shorter IRTs*			*Number of Longer IRTs*		
	Bird 1	*Bird 2*	*Bird 3*	*Bird 1*	*Bird 2*	*Bird 3*
1	508	772	684	433	302	441
	587	713	591	372	264	489
2	893	794	757	1279	439	1202
	755	463	919	1314	278	1139
3	343	284	348	25	18	21
	166	240	318	11	27	31
4	819	599	726	365	265	440
	725	358	656	440	180	426
5	202	402	381	40	40	60
	177	371	331	28	40	65
6	1438	2036	1359	1648	1220	901
	1783	2162	1338	1732	1178	930
7	544	567	445	145	94	148
	515	523	426	162	99	152
8	612	557	566	316	253	284
	588	609	556	313	254	297
9	381	479	421	286	120	281
	431	327	446	286	82	253
10	647	701	1362	1264	973	1144
	632	630	1276	1256	863	1063
11	756	2317	1246	933	831	1133
	719	1383	1139	825	945	1163
12	297	446	363	176	66	140
	320	435	383	134	29	102

the frequencies of these IRTs for each experimental condition.

Thus, one may say that a subject in the present experiment part of the time pecked the key at one rate and some fraction of the rest of the time pecked the key at another rate, and that the two rates corresponded closely to those determined by the pacing contingencies of the schedule.

We must now ask how one may measure the degree to which a subject chose, or preferred, to respond at a particular rate. We may simply compute the percentage of IRTs, of all those IRTs that fell within either reinforced class, that were in the shorter class. This percentage estimates the percentage of IRTs conforming to the higher reinforced response rate. We wish to plot this estimate of preference for the higher reinforced response rate against the absolute rate of reinforced responding. The latter can be measured in any of a number of ways. As the lower bound of either class of reinforced IRTs decreases, response rate increases. Thus, we can arbitrarily pick the lower bound of the class of shorter reinforced IRTs to be the index of the absolute reinforced response rate.

Figure 1 shows preference as a function of the absolute reinforced response requirement. For the highest response rates, the average preference was close to the level of indifference, 0.50. For lower response rates, preference for the higher response rate increased, passing through the matching-to-the-relative-reciprocal value somewhere between values of 1.5 and 4.0 sec on the X axis. Preference continued to increase for still lower response rates until it exceeded 0.90 for the lowest rates. In general, the preference function appears to be monotonically increasing and negatively accelerated.

DISCUSSION

In previous experiments, preference for the higher of two concurrently reinforced response

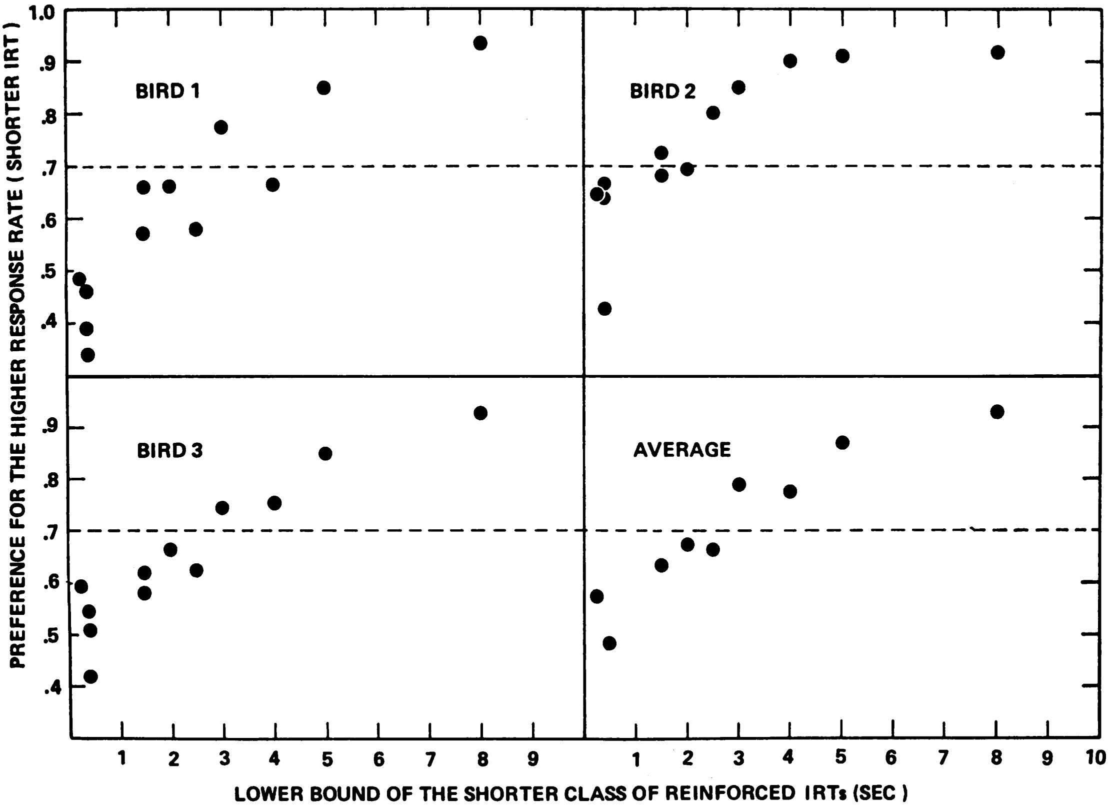

Fig. 1. The number of responses in the shorter class of reinforced IRTs divided by the total number of responses in either the shorter or longer classes of IRTs, *i.e.*, the percentage of shorter IRTs, plotted against the lower bound of the shorter class of reinforced IRTs. (Means over the last two days of each condition.)

rates approximately equalled the relative reciprocal of the duration of the class of IRTs defining that rate (Shimp, 1969, 1971; Moffitt and Shimp, 1971). In these previous experiments, the lower bound of the shorter class of IRTs nearly always was in, or very close to, the interval from 1.5 to 2.5 sec. The present results are therefore in general agreement with these previous results, as an approximation to matching also was obtained here for this same interval. However, the present results show that preference for one of two concurrently reinforced response rates depends on the absolute rates of responding. Preference ranges from near indifference at high reinforced response rates to virtually exclusive choice of the relatively higher response rate at low reinforced rates: the higher were both reinforced rates, the less a subject preferred the higher of the two. Approximate matching was obtained only over a highly restricted range of intermediate reinforced response rates. Indeed, the present results confer upon matching the status of an arbitrary special case of the general preference relations.

The present results are in tolerable agreement with preference data obtained from two-key concurrent-chains schedules of reinforcement. Such a schedule consists of two links, an initial link and a terminal link. In the initial link, a subject may respond on either of two available operanda. Reinforcement for responding on an operandum in the initial link consists of access to the terminal-link schedule for that operandum. In the terminal link, there is only one available operandum, responding on which is reinforced by the delivery of food (Duncan and Fantino, 1970). Before comparing these preference data with the present data, let us briefly consider how one might describe the present schedule as a concurrent-chains schedule. Shimp (1968) and Staddon (1968) considered the possibility that a subject in a compound paced VI schedule chose how long to wait before the next key peck. That is, they speculated that perhaps a subject, as soon as it terminated one IRT, chose to engage in either of two behavioral sequences, one of which terminated in a key peck after a time equal to the shorter reinforced IRT and the other of which terminated in a key peck after a time equal to the longer reinforced IRT. There are other ways of interpreting a compound paced VI as a concurrent-chains schedule, but for present purposes it will suffice only to consider this one possible way. According to this possible interpretation of events produced by a compound paced VI, a formal analogy to the conventional concurrent-chains procedure becomes apparent: in both, a choice of one alternative is followed by a corresponding sequence of behaviors that may terminate in reinforcement. After completing one cycle, the subject again chooses and initiates another and so on. We hasten to add that differences as well as similarities between the two procedures spring to one's attention, but many of these differences are only parametric and serve only to place compound paced VI schedules and concurrent-chains schedules at different points along the same dimensions.

In any event, let us tentatively adopt the foregoing analogy and see where it leads. According to the analogy, the concurrent-chains schedule most closely resembling a compound paced VI would have an initial link in which both components were continuous-reinforcement schedules. The terminal links might be very short fixed-interval (FI) or paced schedules of some sort. We are unaware of any data from a concurrent-chains schedule exactly like this. There are, however, data from schedules that one may view as similar. Consider, for example, the following. Killeen (1970), Duncan and Fantino (1970), and MacEwen (1972) employed rather short terminal-link FI schedules, although they employed initial-link VI rather than continuous reinforcement schedules. In each of these experiments, it was found generally that preference for the shorter FI exceeded the matching value. By the present analogy, this is as it should be, for the shorter FI in all three experiments was 4 or 5 sec: from the results in the present Figure 1, we see that this interval is slightly beyond that in which matching is typically obtained. The present analysis suggests that preference for the shorter FI would not exceed the matching value for still shorter FIs, and in fact, with very short FIs, one could expect indifference in concurrent-chains schedules. This prediction seems reasonable, although we are unaware of any data bearing on it.

The present data are in agreement with these concurrent-chains data also to the extent that Duncan and Fantino (1970) and MacEwen (1972) found that preference for the shorter FI increased as the values of the terminal-link FIs increased. As noted previously, the corresponding result also was obtained in the present experiment.

Thus, compound paced VI schedules and some concurrent-chains schedules resemble each other in the way in which the preference functions obtained from both depend on the absolute durations of the "terminal-link" schedules. The terminal links in the present experiment were the two different reinforced rates of responding corresponding to the two classes of reinforced IRTs. Perhaps IRT distributions from interval schedules in general may profitably be viewed as preference functions for component response rates corresponding to different classes of reinforced IRTs.

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