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TIME-ALLOCATION, MATCHING, AND CONTRAST[1]

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A variable-interval schedule arranged food reinforcement for key pecking by pigeons on a single operandum at two rates, corresponding to two classes of reinforced interresponse times ranging from 1.5 to 2.5 sec and from 3.5 to 4.5 sec. The scheduled reinforcement rate for the higher component response rate was constant and equivalent to that of a variable-interval 4-min schedule. The scheduled reinforcement rate for the lower component response rate varied from zero to over 100 per hour. The number of occurrences of the constant component response rate varied inversely with the reinforcement rate for the variable component. This result, by definition a concurrent reinforcement interaction, or contrast, was the combined effect of two time-allocation functions, which together determine mean response rate: the time allocated to both component rates as a function of the total reinforcement rate, and the time allocated to a particular component rate as a function of the percentage of reinforcements for that component. The present experiment reveals a further parallel between the controlling relations for free responding on a single operandum and those for choice between two operanda; in each case, a concurrent reinforcement interaction can be found that corresponds to matching.

In a concurrent variable-interval variable-interval (*conc* VI VI) schedule, response rate in one component with a constant reinforcement rate varies inversely with the reinforcement rate for the other component (Catania, 1963; Rachlin and Baum, 1969, 1972). This phenomenon is by definition a concurrent reinforcement interaction, or contrast. The present experiment was designed to see if such an interaction obtains when the reinforced component behaviors are two different response rates corresponding to two classes of reinforced interresponse times (IRTs). For this purpose, the present experiment used a one-key *conc* VI VI for two classes of reinforced IRTs (Shimp, 1968). Behavior in this context may be partitioned into three classes: responding at either of the two reinforced component response rates, and responding at non-reinforced response rates.

The experiment was designed to determine whether a concurrent reinforcement interaction occurs in this context and also, if it does, whether the effect can be explained in terms of time-allocation functions determining the way a subject partitions its time among these three behavioral categories.

METHOD

Subjects

Two adult White Carneaux pigeons (Birds 1 and 2) and an adult homing pigeon (Bird 3) were maintained at approximately 80% of their free-feeding weights.

Apparatus

The experiment required the use of the center keys in three standard Lehigh Valley Electronics three-key pigeon chambers, which were interfaced to a Digital Equipment Corporation PDP-12 laboratory computer. The computer arranged all experimental conditions and recorded the data for subsequent analysis.

Procedure

The procedure was essentially the same as for previous *conc* VI VI schedules of reinforcement for two rates of responding on a single operandum, *i.e.,* for two classes of reinforced IRTs (Hawkes and Shimp, 1974; Shimp, 1968). A single VI schedule arranged reinforcements randomly in time, and a random process as-

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signed each reinforcement arranged by the VI schedule to one of the two component response rates. An available reinforcement had to be collected before another could be arranged.

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, except for a period of 0.1 sec immediately after each key peck, during which the houselight also was off. This short blackout was intended to provide visual response-feedback. A key peck terminating an IRT in either reinforced class turned off the houselight for 0.1 sec. A non-reinforced key peck terminating an IRT in either reinforced class turned off the keylight and the houselight for 0.1 sec. The intended purpose of these stimuli was simply to shorten the duration of training required in each experimental condition. These stimuli appear to have no effect on preference between reinforced response rates (Hawkes and Shimp, 1974; Moffitt and Shimp, 1971).

Reinforced IRTs. The absolute and relative rates of reinforced responding remained constant: throughout the experiment the shorter and longer reinforced IRTs extended from 1.5 to 2.5 sec and from 3.5 to 4.5 sec, respectively.

Frequency of reinforcement. A variable-interval schedule arranged a reinforcement (2.0-sec access to mixed grain) with probability p every 1.0 sec. Table 1 shows the values of p for each condition. The VI schedule stopped during reinforcement and whenever a subject paused longer than the upper bound of the longer IRT, *i.e.,* whenever its momentary response rate was lower than the lowest reinforced response rate. This contingency was intended to prevent the reinforcement of an IRT following a long pause: the duration of the IRT preceding reinforced IRTs can affect both mean response rate and temporal patterning of responding (Shimp, 1973). Reinforcements arranged by the VI schedule were partitioned between the two component response rates with probabilities shown in Columns 3 and 4 of Table 1. The values for the total and relative reinforcement frequencies were devised so that the scheduled reinforcements per hour for the higher reinforced response rate was always approximately that produced by a VI 4-min schedule. (The relative reinforcement frequency for a component response rate is the reinforcement frequency for that component divided by the sum of the reinforcement frequencies for both component response rates.) The scheduled reinforcements per hour for the lower reinforced response rate varied from zero to more than 100.

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

A prerequisite for the meaningful decomposition of behavior maintained by the present schedule of reinforcement into higher and lower component response rates is a bimodal

Table 1

Experimental Conditions

Condition Number	*Number of Days*	*Relative Rate of Reinforcement*		*Probability of Arranging a Reinforcement Every 1 Sec*	*Equivalent VI Schedule (min)*	
		Shorter IRT	*Longer IRT*		*Shorter IRT*	*Longer IRT*
1	49	0.50	0.50	0.008	4.0	4.0
2	29	1.00	0.00	0.004	4.0	EXT
3	39	0.80	0.20	0.005	4.0	16.0
4	23	0.67	0.33	0.006	4.0	8.0
5	16	0.50	0.50	0.008	4.0	4.0
6	16	0.20	0.80	0.021	4.0	1.0
7	13	0.33	0.67	0.013	4.0	2.0
8	22	0.11	0.89	0.037	4.0	0.5
9	16	1.00	0.00	0.004	4.0	EXT

distribution of IRTs, with the locations of the two sub-distributions corresponding to the two classes of reinforced IRTs. The experimental and statistical methods employed to establish such bimodal distributions in the present experiment were the same as in the previous experiments using the same *conc* VI VI schedule for two classes of IRTs (Hawkes and Shimp, 1974; Shimp, 1968, 1969, 1970, 1971, 1973). As in previous experiments, a fairly large number of responses terminated IRTs slightly shorter than the lower bounds of the classes of reinforced IRTs (Hawkes and Shimp, 1974; Shimp, 1968, 1970). Consequently, the data analysis was performed with "obtained" classes of IRTs. That is, we looked at the IRT distributions and determined "obtained" classes, which were very similar to the reinforced classes except that they typically also contained IRTs slightly shorter than those in the reinforced classes. (IRT distributions representative of those obtained in the present experiment have been portrayed before. See Shimp, 1968, 1970.) If one excludes IRTs terminated by responses occurring within 0.1 sec after the end of the response-feedback blackout, the per cent of all responses that terminated IRTs in the "obtained" IRT distributions, averaged over the last two days of each condition, was 98, 97, and 98, for Birds 1, 2, and 3, respectively. The data were analyzed in terms both of these obtained classes and the reinforced classes. The two analyses were only trivially different, and were identical with respect to the conclusions described below. To conserve space, we present here only the analysis in terms of obtained classes. The end-product of this preliminary decomposition of behavior into two component behaviors is given by Table 2, which gives the number of responses terminating shorter and longer IRTs on each of the last two sessions of each condition.

Figure 1 shows how a subject partitioned time between classes of reinforced and nonreinforced behaviors as a function of total reinforcement density. It shows the "per-cent-time-spent-responding" as a function of the total obtained reinforcements per hour. Per-cent-time-spent-responding measures the per cent of the time a subject allocates to reinforced classes of behaviors and equals the following ratio:

$$\text{Per-cent-time-spent-responding} = \frac{(f_s \times l_s) + (f_l \times l_l)}{T}$$

Table 2

Number of responses and reinforcements for the shorter and longer classes of interresponse times on each of the last two days of each condition.

Condition Number	Interresponse Times						Reinforcements					
	Shorter			*Longer*			*Shorter*			*Longer*		
	Bird 1	*Bird 2*	*Bird 3*	*Bird 1*	*Bird 2*	*Bird 3*	*Bird 1*	*Bird 2*	*Bird 3*	*Bird 1*	*Bird 2*	*Bird 3*
1	503	1047	1052	505	328	485	5	12	7	11	4	8
	606	828	1159	638	440	415	18	9	12	15	6	5
2	1723	1221	1911	59	1	13	10	4	11	0	0	0
	1602	1251	1983	75	11	36	5	4	13	0	0	0
3	95	1798	1747	403	115	217	15	7	8	3	5	3
	1003	1630	1700	400	222	207	9	7	9	4	2	4
4	1010	998	1190	377	217	468	9	12	12	4	5	8
	1050	980	1305	378	230	405	11	9	17	4	4	10
5	521	837	1036	624	362	555	8	14	14	23	10	10
	683	881	849	565	373	600	9	12	11	9	17	19
6	310	415	526	734	659	695	7	13	17	53	45	45
	340	424	420	767	662	741	8	12	13	38	41	44
7	553	677	767	686	462	538	13	13	18	26	28	25
	535	659	618	695	511	619	14	13	9	30	29	35
8	169	266	166	784	715	829	11	8	12	114	104	97
	190	220	175	790	716	834	16	11	7	74	92	83
9	1197	678	1770	170	139	50	14	8	15	0	0	0
	1414	585	1557	132	131	86	8	7	14	0	0	0

where f_s and f_l are the frequencies of shorter and longer IRTs, l_s and l_l are the lengths of the shorter and longer IRTs, and T is the duration of the session, minus time during which the food hopper was operated. The length of an IRT was set equal to its lower bound, rather than its midpoint, because of a positive skewness in IRT distributions (Shimp, 1967). Figure 1 shows the results for the last two days of each condition. The curves, especially those for Birds 1 and 3, are approximately flat for reinforcements per hour greater than 20 or 30 and approach an asymptote approximating 90%. At the other end of the curves, the time allocated to reinforced behaviors clearly can be seen to begin to descend only for reinforcement rates less than 20 per hour. This result agrees well with corresponding curves from previous experiments in which total reinforcement rate varied and relative reinforcement rates were held constant (Shimp, 1970, 1974). Observe that Figure 1 is *not* a response-rate

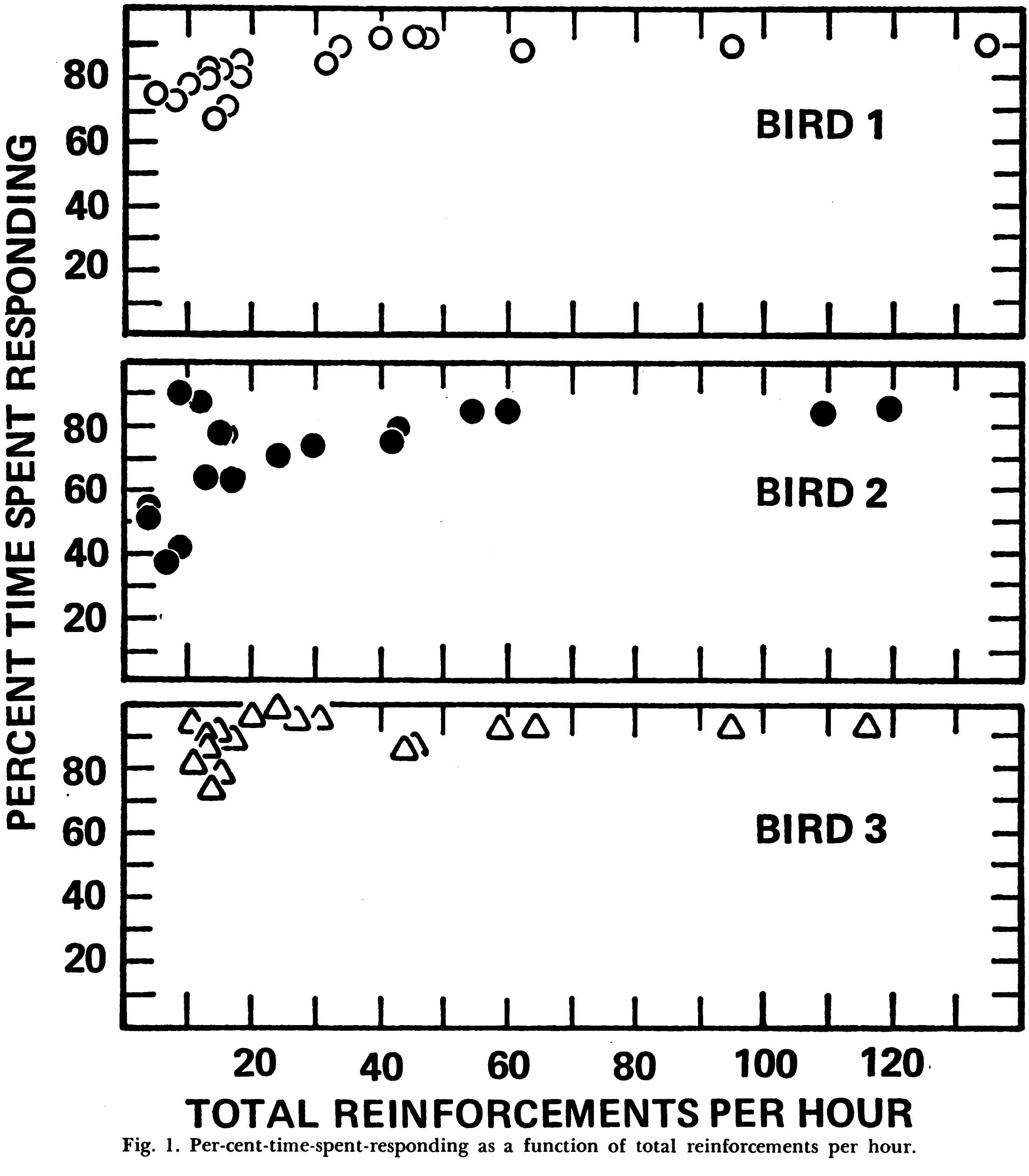

Fig. 1. Per-cent-time-spent-responding as a function of total reinforcements per hour.

function estimating the strengthening effects of reinforcement. As will be shown below, a mean response-rate function badly confounds the effects of total and relative reinforcements per hour.

Figure 2 shows how a subject partitioned its responding between the two reinforced components. Figure 2 shows the relative frequency of responses at the higher response rate, *i.e.,* responses terminating shorter IRTs, as a function of the relative reinforcements per hour for the higher response rate. The relative frequency of shorter IRTs equals the number of shorter IRTs divided by the total number of shorter and longer IRTs, and the relative reinforcements per hour for shorter IRTs equals the number of reinforcements for shorter IRTs divided by the total number of reinforcements. Figure 2 shows these results for the last two days of each condition. The way in which a subject distributed its responding between the higher and lower reinforced response rates roughly conformed to time-allocation matching. That is, the per cent of the time-spent-responding that a subject allocated to the shorter component, *i.e.,* the higher component response rate, approximately equalled the relative reinforcement per hour for that component. This relation can be expressed algebraically as

$$\frac{T_i}{\sum\limits_j T_j} = \frac{R_i}{\sum\limits_j R_j},$$

where T_i is the time allocated to the i^{th} component, R_i is the number of reinforcements delivered for the i^{th} component, and j ranges over all reinforced components. This matching function in shown in Figure 2 by the curved line. In the previous experiments in which the time-allocation matching function was obtained with concurrent schedules of reinforcement for different response rates, the total reinforcements per hour was held approximately constant (Shimp, 1969, 1973). Figure 2 extends the matching phenomenon to the case in which relative reinforcements per hour and total reinforcements per hour both vary. However, it is known that relative time allocation between components deviates from matching in the direction of indifference as the total reinforcement rate approaches zero (Shimp, 1970, 1974). In the present experiment, the total reinforcement density was lowest when the relative reinforcement frequency for the shorter component was highest. And one can see in Figure 2 that there was at that point some undershooting of the matching value.

Figures 1 and 2 together show that as the reinforcements per hour for the longer component increase, more time was allocated to the reinforced behaviors, but also, the percentage of time-spent-responding allocated to the shorter component decreased. These two functions have opposite implications for the way in which the rate of occurrence of the shorter component depended on the reinforcement rate for the longer component; an increase in the time-spent-responding could be offset by a decrease in the percentage of the time-spent-responding that was allocated to the shorter component. Figure 3 shows how these two input-output functions did in fact combine to affect the rate of the shorter component. Figure 3 shows the results for the last two days of each condition. The rate of occurrence of the shorter component decreased as the rate of reinforcement for the longer component increased. Thus, a concurrent reinforcement interaction, or contrast, was obtained. A comparison of Figures 1 and 2 appears to explain why. Over most of its range, Figure 1 is rather flat: there is only a very small increment in time-spent-responding once the total reinforcements per hour exceeds, say, 20. Therefore, it is the time-allocation matching function in Figure 2 that determines the rate of occurrence of the shorter component over most of the range of the function in Figure 3. Briefly stated, the concurrent interaction in Figure 3 is to a large extent determined by time-allocation matching, and for total reinforcements per hour in excess of about 20, Figures 2 and 3 are essentially equivalent: they are different ways of plotting the time-allocation matching function.

Figure 4 is provided here as a reminder of the derived nature of the mean response-rate function. Figure 4 shows the total key pecks per minute as a function of the total reinforcements per hour. If the mean rate of key pecking were to measure the strength of a key-pecking operant, this function should increase. Instead, it decreases, except for a very narrow interval near the origin in the panel for Bird 2. Figure 4 emphasizes that mean response rate confounds the effects of the total reinforcement density and the distribution of reinforced

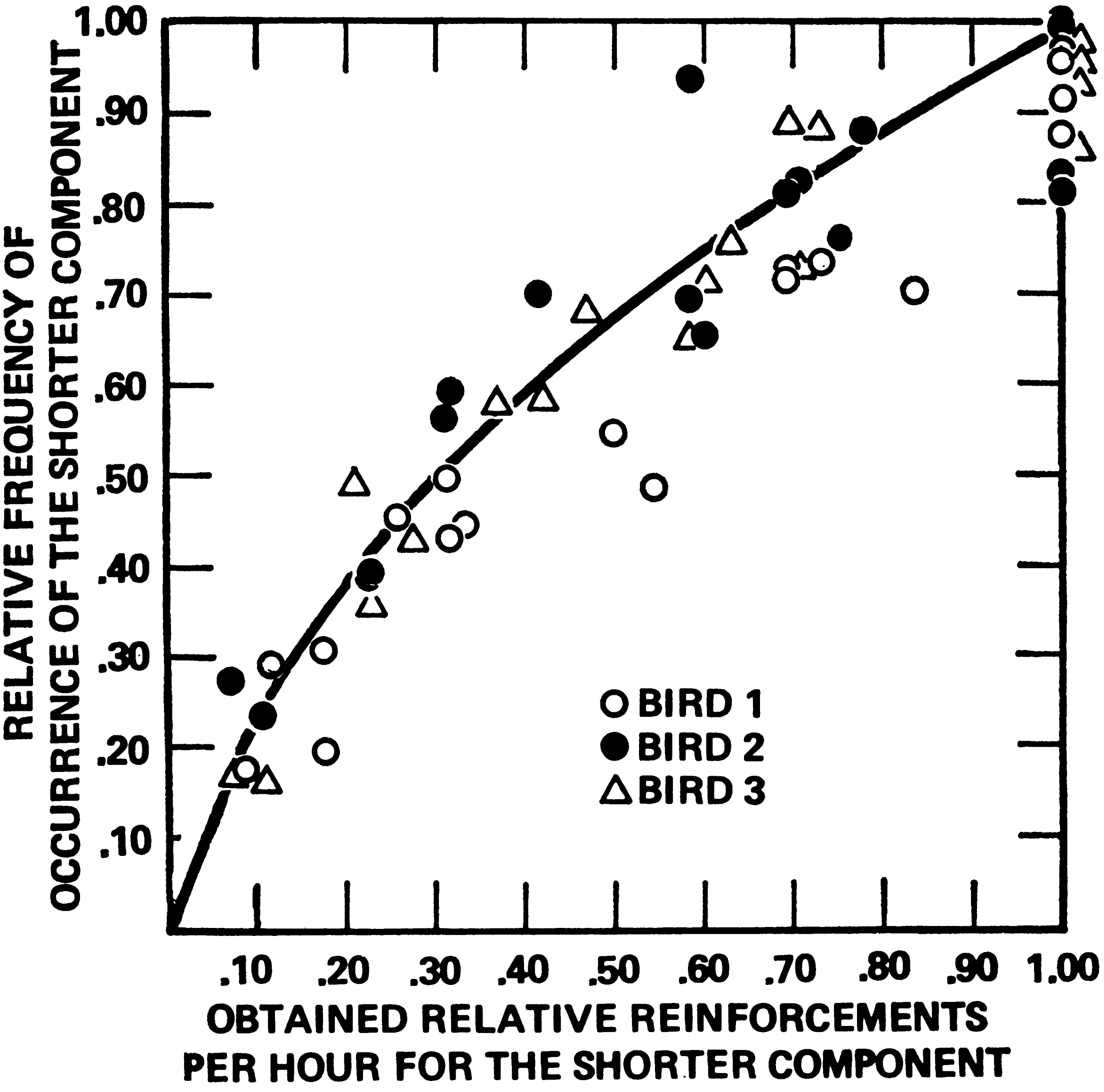

Fig. 2. The relative frequency of occurrence of the shorter component as a function of the obtained relative reinforcements per hour for the shorter component. The curved line represents time-allocation matching.

IRTs, and that it may be derived from separate functions corresponding to these two variables, such as the functions in Figures 1 and 2. That is to say, the mean response-rate function in Figure 4 decreases because a subject allocates more time to the lower component rate (the longer IRT) in accordance with time-allocation matching, not because the strength of a key-pecking operant decreases. There were two operants in the present experiment, corresponding to two specific reinforced rates of key pecking. Despite the fact that there was but a single operandum, and that a cumulative record of performance here would have revealed only a straight line, there was no single operant, such as key pecking, the rate of which meaningfully corresponded to the absolute or relative strength of any behavior.

DISCUSSION

A concurrent reinforcement interaction, or contrast, was obtained and appeared to result from the combined effects of two time-allocation functions corresponding to the total and relative reinforcement rates. The present interaction does not require us to assume that a given reinforcement input has different effects

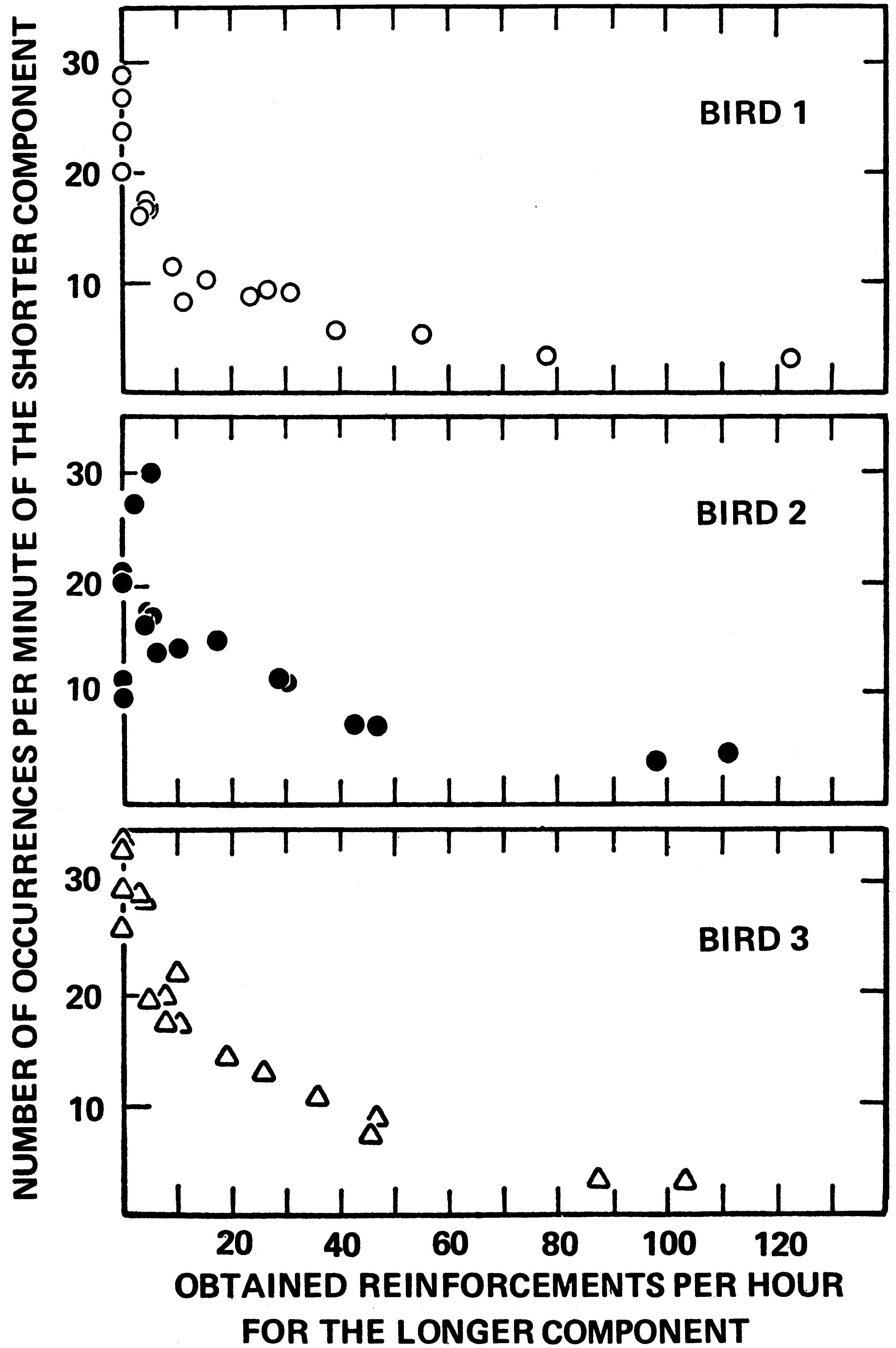

Fig. 3. The number of occurrences per minute of the shorter component as a function of the obtained reinforcements per hour for the longer component. Each panel reveals a concurrent reinforcement interaction function.

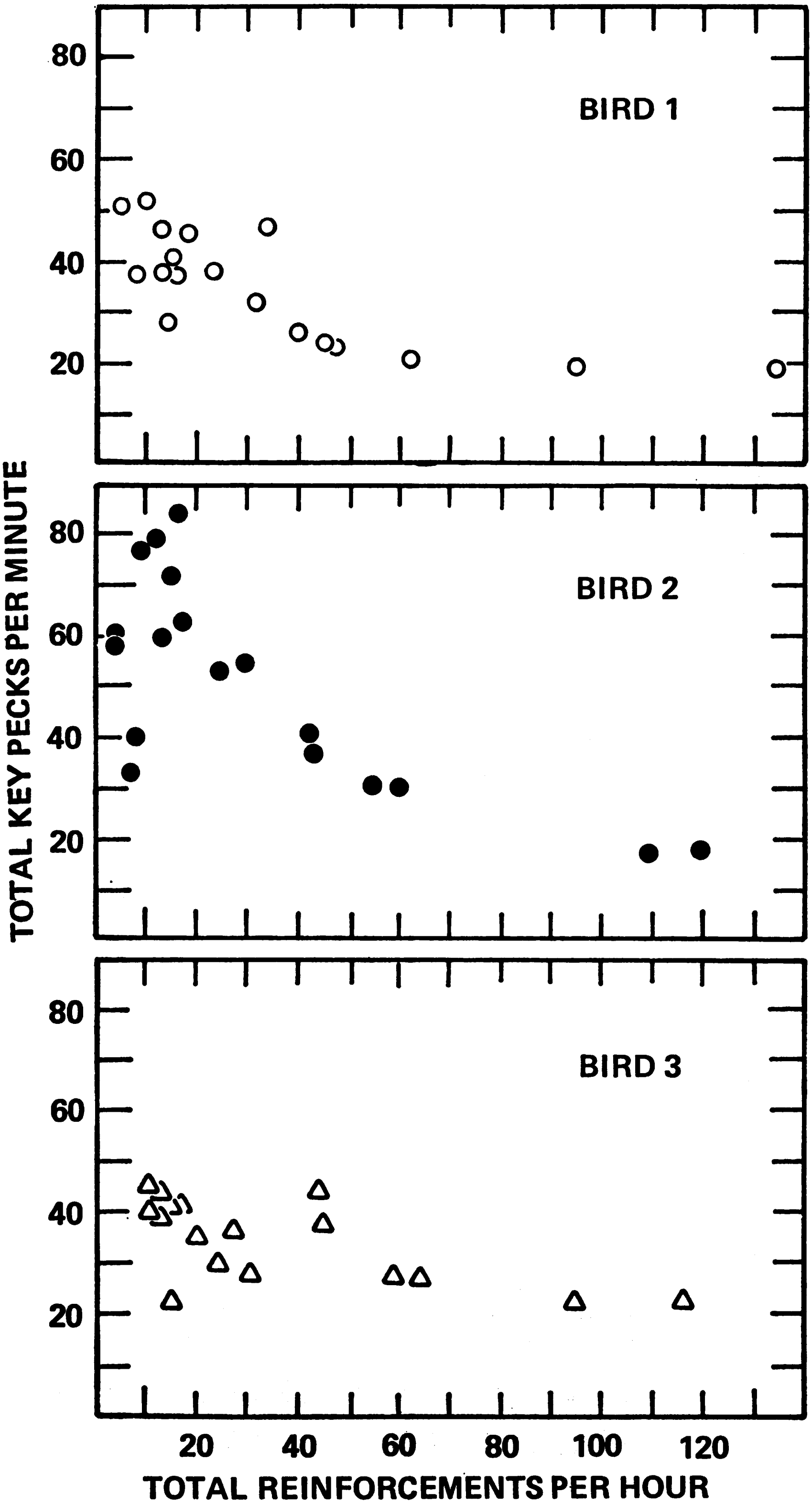

Fig. 4. Total responses per minute as a function of total reinforcements per hour.

on behavior depending on the total reinforcement context. Neither is there any need to appeal to inhibitory processes: while the present results certainly show that "reinforcers produced by one response reduce the rate of other, concurrently reinforced responses" (Catania, 1973), the notion of inhibition is superfluous to their explanation.

Most of the range of the interaction function obtained here was attributable to a time-allocation matching function. In order to interpret correctly the relation between the obtained concurrent interaction and matching, one must recognize, however, that matching is only a special case of more general time-allocation functions: matching corresponds only to special combinations of reinforcement parameters. Preference for a component response rate in the context of the concurrent paradigm employed here depends on variables that do not enter into the time-allocation matching formula. As we have seen above, absolute rate of reinforcement modulates preference for a component response rate (Shimp, 1970, 1974). Also, absolute component duration affects preference (Hawkes and Shimp, 1974). Finally, preference for a component depends on which sequences of components are reinforced (Shimp, 1973). Together, these previous experiments show that time-allocation matching obtains in the present context only when the shorter component duration is roughly 2.0 sec in duration, the total reinforcement rate is at least 20 reinforcements per hour, and the component preceding reinforced components is usually the shorter one. In summary, these are necessary conditions for time-allocation matching and for the present concurrent interaction function. With different conditions, a different interaction function, one not corresponding to matching, would be obtained.

Previously obtained, two-key concurrent interactions are also equivalent to matching and therefore would only be special cases of more general interactions if matching were a special case in two-key concurrent schedules as it is in one-key concurrent schedules. That is to say, in a two-key *conc* VI VI, response rate in the constant component, *i.e.*, in the component with a constant reinforcement rate, depends on the varying reinforcement rate in the other component, and this dependency can be predicted by assuming that a subject responds at the same rate in both components and allocates a percentage of time to responding in a component that equals the percentage of reinforcements obtained in that component (Catania, 1963; Rachlin and Baum, 1969, 1972; Rachlin, 1973). Thus, the concurrent-interaction function in two-key schedules, as well as in one-key schedules, corresponds to a time-allocation function. However, time-allocation matching may only be a special case in the two-key context, since time allocation appears to depend heavily on the changeover delay (Stubbs and Pliskoff, 1969). While the obtained concurrent interactions corresponding to matching may be only arbitrary special cases, they are the only concurrent-interaction functions that can be accommodated by current theories (Catania, 1973; Herrnstein, 1970; Rachlin, 1973).

Catania (1963) and Rachlin and Baum (1969, 1972) obtained the same concurrent interaction function when reinforcements arranged by the variable component were signalled as when they were not. When reinforcements in the variable component were signalled, a subject allocated nearly all of the time to responding on the constant component: a subject switched to the variable component only after the appearance of the signal. The invariant mean response rate in the constant component across signalled and non-signalled conditions seemed originally to suggest that behavior in the constant component was independent of molecular reinforcement contingencies such as the distribution of reinforced IRTs, since these changed drastically as a function of time allocated to behavior in the other component (Catania, 1962, 1963). However, the rate-constancy phenomenon appears to have limited generality. The rate-constancy phenomenon does not obtain in the context of a one-key *conc* VI VI schedule of reinforcement for two-component response rates (Experiment IV in Shimp, 1971), presumably because the rate-constancy phenomenon depends on a particular combination of molecular reinforcement contingencies that usually are not arranged in the one-key context. Furthermore, Catania (1972) reported data supporting this view that rate-constancy obtains only for a narrow range of changeover delays and absolute and relative component durations.

The present experiment reveals another parallel between the controlling relations for responding on a single operandum and those for choice between two operanda (Hawkes and Shimp, 1974; Shimp, 1968, 1969; Moffitt and Shimp, 1971). Each such parallel supports the view that mean response rate is an average over reinforced component behaviors, *i.e.*, reinforced classes of IRTs. These reinforced component behaviors appear to be controlled by time-allocation functions similar to those that control choice behavior in multi-operanda concurrent paradigms.

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