EFFECTS OF RESPONSE TYPE ON PIGEONS' SENSITIVITY TO VARIATION IN REINFORCER AMOUNT AND REINFORCER DELAY

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Twelve pigeons, divided into two groups, responded on concurrent nonindependent variable-interval schedules to obtain access to grain by either pecking keys or pressing treadles. Either the amount of grain or the delay to the receipt of grain was varied in separate conditions to determine the sensitivity of relative responding to variation in reinforcer amount (s_A), the sensitivity to variation in reinforcer delay (s_D), and s_A/s_D, a measure related to self-control. There were no significant differences between the two groups in the values of s_A, s_D, and s_A/s_D. These results suggest that the values of s_A, s_D, and s_A/s_D for pigeons may be similar across these two types of responses.

Key words: choice, self-control, reinforcer delay, generalized matching law, key peck, treadle press, pigeons

Self-control has been defined as the choice of a larger, more delayed reinforcer over a smaller, less delayed reinforcer, and impulsiveness has been defined as the opposite choice (Ainslie, 1974; Grosch & Neuringer, 1981; Logue, 1988; Rachlin & Green, 1972). One model that has been successfully used to describe much data from self-control paradigms is the generalized matching law (e.g., Chavarro & Logue, 1988; Chelonis, King, Logue, & Tobin, 1994; Logue, 1988; Logue, Rodriguez, Peña-Correal, & Mauro, 1984). According to the generalized matching law, subjects match their relative rates of responding on two response alternatives (e.g., left and right response alternatives) to power functions of the relative amounts and delays of reinforcement that are available from the two alternatives. This model can be employed to assess subjects' sensitivity to variation in reinforcer amount and reinforcer delay (Baum, 1974; Logue et al., 1984).

Expressed mathematically, the generalized matching law for self-control paradigms can be stated:

$$\left(\frac{B_L}{B_R}\right) = k\left(\frac{A_L}{A_R}\right)^{s_A}\left(\frac{D_R}{D_L}\right)^{s_D}. \qquad (1)$$

In this equation, B_L and B_R represent choices of the left and right alternatives, respectively; k represents a response bias to choose the left alternative (when k is greater than 1) or the right alternative (when k is less than 1); A_L and D_L represent the amount and delay, respectively, of a reinforcer received following a choice of the left alternative; and A_R and D_R represent the amount and delay, respectively, of a reinforcer received following a choice of the right alternative. Finally, s_A and s_D represent the subject's sensitivity to variation in reinforcer amount and reinforcer delay, respectively. If s_A is greater than s_D, given a particular combination of A_L/A_R and D_R/D_L, a subject is more likely to show self-control than if s_A is less than s_D.

Different species tend to show different sensitivities to variation in reinforcer amount and reinforcer delay (Tobin & Logue, 1994; Tobin, Logue, Chelonis, Ackerman, & May, 1996). Pigeons, for example, tend to have values of s_A/s_D that are close to 1 (Chavarro & Logue, 1988; Logue et al., 1984; Rodriguez & Logue, 1986). In general, pigeons tend to show less self-control than do the other species that have been tested (Tobin & Logue, 1994; Tobin et al., 1996).

All of the previous research that has examined self-control in pigeons has used key pecking as the response, regardless of whether self-control was measured using discrete-trials procedures (e.g., Green, Fisher, Perlow,

& Sherman, 1981; Logue, Chavarro, Rachlin, & Reeder, 1988; Mazur & Logue, 1978) or concurrent variable-interval schedules (e.g., Chavarro & Logue, 1988; Logue et al., 1984). This uniformity might limit the generality of the pigeon self-control laboratory data because pigeons make many responses other than key pecking, both inside and outside of the laboratory. Furthermore, for several reasons, the choice of key pecking as the response used to examine pigeons' self-control may contribute to pigeons' tendency not to demonstrate self-control, possibly by increasing their sensitivity to variation in reinforcer delay or by decreasing their sensitivity to variation in reinforcer amount.

First, pigeons pecking keys might not show self-control due to autoshaped responding on the lit key that delivers the smaller, less delayed reinforcer. Previous research has shown that pigeons are more likely to make autoshaped key pecks on a key associated with a short delay to food than on a key associated with a long delay to food (Poling, Thomas, Hall-Johnson, & Picker, 1985). Therefore, autoshaped key pecks might occur primarily on the impulsive alternative in a self-control paradigm.

Another possible reason for low self-control for food when key pecking is the response is that certain proprioceptive stimuli involved in pecking keys may be similar to stimuli that are related to eating. Key pecks are often very similar to the pecks that pigeons make when they eat (Jenkins & Moore, 1973). Furthermore, both pigeons and humans have been shown to exhibit less self-control for food when food is physically present than when it is absent (Grosch & Neuringer, 1981; Mischel & Ebbesen, 1970). Research has also shown that both pigeons and humans demonstrate more self-control when allowed to perform some task that is unrelated to the reinforcer (Grosch & Neuringer, 1981; Mischel, Ebbesen, & Zeiss, 1972). Together, all of these experiments suggest that the type of stimuli that are present may affect pigeons' self-control for food, and that key pecking may be associated with consummatory stimuli that tend to result in decreased self-control.

The present experiment compared sensitivity to variation in reinforcer amount (s_A) and sensitivity to variation in reinforcer delay (s_D) in pigeons pressing treadles and pecking keys

so as to determine whether or not these measures differ as a function of response type. A procedure was chosen that determined the values of s_A and s_D because once a subject's values of s_A and s_D are known, the subject's self-control can be predicted for a variety of different combinations of absolute values of reinforcer amount and delay. Furthermore, by measuring both s_A and s_D, separate information is obtained concerning the control over behavior by relative reinforcer amount and relative reinforcer delay, information that cannot be obtained using more traditional self-control paradigms.

Based on several considerations, it seemed possible that the values of s_A/s_D for pigeons would be higher with treadle pressing than with key pecking. First, a treadle-pressing procedure might not be as likely to generate autoshaped impulsive responses as would a key-pecking procedure. Several experiments have indicated that autoshaped responses tend not to occur when treadle pressing is the response. For example, LoLordo, McMillan, and Riley (1974) demonstrated that, when the conditioned stimulus was a keylight and Pavlovian conditioning trials were superimposed upon a baseline differential-reinforcement-of-low-rate (DRL) schedule (a schedule in which the subject must respond at a low rate in order to receive reinforcement), pigeons' rate of responding on a key increased but their rate of responding on a treadle decreased. Further, several experimenters have found that pigeons' responding on a DRL schedule is less frequent (resulting in more reinforcement) when treadle pressing is used as the operant than when key pecking is used (Hemmes, 1975; Richardson & Clark, 1976). If a treadle-press procedure is less likely to result in autoshaped responses than is a key-peck procedure, and if autoshaped key pecks are more likely to occur on response alternatives with short delays to reinforcement, then when treadle pressing (vs. key pecking) is the response, there should be fewer choices of the short-delay alternative and the value of s_A/s_D should be higher. Second, the response required for a pigeon to operate a treadle is dissimilar to the pigeon's eating response. Therefore, operating a treadle should not produce consummatory stimuli that are correlated with the reinforcer to the degree that key pecking might. In that case, the pigeons

would choose the short-delay alternative less often, and s_A/s_D would be higher than when key pecking is the response.

METHOD

Subjects

The subjects were 12 experimentally naive White Carneau pigeons randomly assigned to two groups of equal size (the key group and the treadle group). All of the pigeons were maintained at 80% of their free-feeding weights and were given free access to water.

Apparatus

The apparatus for the key group was an experimental chamber 33.5 cm long, 30 cm wide, and 33 cm high. Two translucent Plexiglas response keys, each 2 cm in diameter, were mounted behind circular holes in one wall, 21 cm above the floor, and 12.5 cm apart. Each key could be transilluminated with red, green, or white light and required a force of 0.15 N to operate. A hopper, located 11 cm from the floor and midway between the response keys, allowed access to mixed grain. Located on top of the apparatus were two 6-W white lights and two 7.5-W lights (red and green) that could illuminate the chamber through a Plexiglas-covered hole in the aluminum ceiling.

The apparatus for the treadle group was similar to the one for the key group except that there were two treadles mounted on the front wall. Each stainless steel treadle was mounted directly under each of the response keys, 2 cm above the floor and protruding 8 cm into the chamber. The base of each treadle was a straight rectangular rod, 1 cm wide and 0.5 cm thick, that protruded 5.5 cm into the chamber. Mounted at the end of each rod was a stainless-steel disk (0.3 cm thick) that was 5 cm in diameter. Each treadle required a force of 1.2 N to operate. (See King & McSweeney, 1987, for an example of previous research using similar treadles.)

Each chamber was enclosed in a sound-attenuating box with an air blower that was used for ventilation and that helped to mask extraneous sounds. An IBM®-XT computer, located in another room, using a CONMAN program, controlled the presentation of stimuli and recorded responses.

Procedure

At the beginning of a session, the experimental chamber was illuminated by the white houselight, the left keylight was transilluminated green, and the right keylight was transilluminated red (the choice period). An effective response on an illuminated key for the key group or on a treadle below an illuminated key for the treadle group was followed by a brief click. When the keylights were not illuminated, responses on the keys or treadles had no programmed consequences for either group. Responses on the keys, whether illuminated or not, had no programmed consequences for the treadle group.

Reinforcers were available for effective responses according to a Stubbs and Pliskoff (1969) nonindependent concurrent variable-interval (VI) 30-s VI 30-s schedule. This schedule was constructed using a single VI 15-s schedule with 15 intervals programmed according to the progression suggested by Fleshler and Hoffman (1962). When an interval in this VI schedule had timed out, the VI schedule ceased timing, and a reinforcer was randomly assigned to either the left or right alternative, with the constraints that the pigeon could not receive more than six reinforcers in a row on a given alternative and that, in each session, half of the reinforcers had to be assigned to each response alternative. There was also a 3-s changeover delay (COD); subjects could not obtain a reinforcer for at least 3 s following a change from responding on one key or treadle to responding on the other key or treadle. The purpose of the COD was to ensure that reinforcement did not follow sequences of responses involving both manipulanda (de Villiers, 1977).

Once a reinforcer had been assigned to one of the alternatives and the COD requirement had been satisfied, an effective key peck for the key group or an effective treadle press for the treadle group on that alternative initiated a delay period (time between a choice and reinforcer access). During this period, the keylights and the white houselight were turned off, and the red or green houselight was turned on, depending on whether the red or the green key had been pecked. At the end of the delay period, mixed grain was made available. Following access to the reinforcer, the VI schedule began timing another

Table 1

Number of sessions of exposure to each condition for each subject.

Condition[a]				Subject											
				Key group						Treadle group					
A_L	A_R	D_L	D_R	1	2	3	4	5	6	7	8	9	10	11	12
6	6	6	6	12	13	12	15	13	28	13	13	18	15	19	12
10	2	6	6	28	10	12	13	23	14	11	15	23	15	20	29
6	6	10	2	10	17	12	10	10	12	13	22	19	12	18	10
2	10	6	6	17	17	15	19	14	14	23	13	26	14	22	17
6	6	2	10	12	11	23	13	10	12	16	10	11	10	16	10

[a] A_L, A_R, D_L, and D_R represent the number of seconds of left and right reinforcer access (amount) and reinforcer delay periods, respectively.

interval, the colored houselight was turned off, and the white houselight and the keylights were again lit. Sessions were terminated after 30 reinforcers had been received.

When nonindependent concurrent VI schedules are used, as was the case here, choice behavior tends to be somewhat less sensitive to reinforcer variation than when independent concurrent VI schedules are used (Chavarro & Logue, 1988). Nevertheless, using nonindependent concurrent VI schedules has the advantage of insuring that the subjects are exposed to the contingencies for both left and right responses, and that relative reinforcement rates for both levers remain equal and independent of preference for either alternative. Furthermore, nonindependent concurrent VI schedules have been used successfully to measure preference in previous choice research (e.g., Alsop & Davison, 1986; Davison, 1988; Davison & Smith, 1986; Hanson & Green, 1986; Llewellyn, Iglauer, & Woods, 1976; Stubbs & Pliskoff, 1969; Sumpter, Foster, & Temple, 1995), including self-control research (e.g., Chavarro & Logue, 1988; Chelonis et al., 1994; King & Logue, 1990; Logue, King, Chavarro, & Volpe, 1990; Logue et al., 1984; Rodriguez & Logue, 1986).

As indicated above, only responses on the Plexiglas keys were ever effective for subjects in the key group, and only responses on the treadles were ever effective for subjects in the treadle group. This between-subjects design was used to insure that the measures of sensitivity to reinforcer amount and sensitivity to reinforcer delay were not affected by lengthy prior experience with the alternative type of response manipulandum or by lengthy prior experience with the reinforcer contingencies. This sort of prior experience has been shown to affect measures of sensitivity to reinforcer amount and reinforcer delay (e.g., Logue et al., 1984).

Table 1 shows the order of the conditions used and the number of sessions that each subject was exposed to each condition. Three different ratios of amount and three different ratios of delay were used to determine the sensitivity of response ratios to variation in reinforcer amount (s_A) and to variation in reinforcer delay (s_D). Only five conditions were necessary in the present research because, in the first condition shown in Table 1, the amounts and delays were equal for each alternative and, therefore, that condition could be used as a point in the determination of both s_A and s_D. The use of only three may be justified because the conditions used in the present research were identical to those used in many other self-control experiments from this laboratory that have assessed sensitivity to variation in reinforcer amount and reinforcer delay (e.g., Chavarro & Logue, 1988; Logue et al., 1984, 1990). Conditions were changed for an individual subject when that subject had satisfied certain stability criteria. These criteria specified that, first, the subject had to be exposed to a given condition for a minimum of 10 sessions. Also, before a pigeon could be switched to the next condition, the ratio of the number of left responses to the number of right responses for each of the last five consecutive sessions of that condition (i.e., that pigeon's five most recent response ratios) had to be neither higher than the highest response ratio nor lower than the lowest response ratio for that pigeon for all pre-

vious sessions of that condition. In other words, if the pigeon's response ratio for a particular session was outside of the range of its previous ratios for that condition, the pigeon had to remain in that condition for at least five more sessions (assuming that a subsequent response ratio did not again fall outside the range of the ratios for all of the previous sessions for that condition).

RESULTS

All analyses were conducted using the last five (stable) sessions' data from each condition. Effective responses were defined as lit-key pecks (for the key group) or treadle presses when the keys were lit (for the treadle group). The Appendix shows the means and standard errors of the total number of effective left and right responses per session, separately for each subject and each condition.

Table 2 shows the overall response rates on the keys and the treadles during the choice periods (time when the keys were lit), the overall rate of treadle pressing during the delays (when the keys were not lit), and the number of changeover responses, separately for each subject and each condition. The rate of key pecking during the delay was not measured for pigeons in the key group because previous research has found that pigeons tend to make few key pecks during the delays in similar procedures (Chavarro & Logue, 1988).

The data in Table 2 reveal that the overall response rate on the keys for the key group and on the treadles for the treadle group was similar for the two groups, $t(10) = -.503$, $p > .05$, as was the number of changeovers, $t < -0.314$, $p > .05$. Furthermore, the pigeons in the treadle group made few responses on the lit keys during the choice periods. However, these pigeons continued to press the treadles during the delay periods at a rate that was approximately equal to the rate of treadle pressing during the choice periods, $t(5) = .4$, $p > .05$. In addition, during delay periods, the pigeons in the treadle group pressed the treadle at a significantly higher rate than the delay-period key-pecking rate of pigeons responding in similar procedures; see Chavarro and Logue (1988)—mean of 4.0 key pecks per minute of delay time, $SE = 1.2$, $N = 4$; $t(8) = 5.1$, $p < .05$.

The data were then analyzed according to the generalized matching law (Equation 1) to compare the values of sensitivity to variation in reinforcer amount (s_A) and sensitivity to variation in reinforcer delay (s_D) between the key group and the treadle group. The variable A_i, amount of reinforcement, was defined as the period of time that a pigeon had access to the hopper. Hopper-access time explains at least as much variance in pigeons' choices between two alternatives that vary in amount and delay as does time that the pigeon spends with its head in the food hopper, or the amount of food consumed (Logue & Chavarro, 1987). The variable D_i, delay of reinforcement, was defined as the time between an effective key peck and the beginning of programmed access to reinforcement. At delays between 0.75 s and 2.25 s (or longer), pigeons place their heads in the food hopper before the end of the programmed delay, which results in the programmed delay being equal to the actual delay to obtain grain (Logue & Chavarro, 1987).

The values of s_A and s_D were obtained by using Equation 1 separately with the data collected from the three conditions in which relative reinforcer delay was not varied and the three conditions in which relative reinforcer amount was not varied, respectively. When reinforcer amounts are varied and reinforcer delays are set equal to each other (i.e., the first, second, and fourth conditions of the present experiment), the base 10 logarithm of Equation 1 reduces to

$$\log\left(\frac{B_L}{B_R}\right) = \log(k) + s_A\log\left(\frac{A_L}{A_R}\right). \quad (2a)$$

Similarly, when reinforcer delays are varied and reinforcer amounts are set equal to each other (i.e., the first, third, and fifth conditions of the present experiment), the base 10 logarithm of Equation 1 reduces to

$$\log\left(\frac{B_L}{B_R}\right) = \log(k) + s_D\log\left(\frac{D_R}{D_L}\right). \quad (2b)$$

Thus, s_A and s_D are the slopes of the lines fit to the data in logarithmic coordinates when only reinforcer amounts or only reinforcer delays, respectively, are varied.

The top half of Figure 1 shows the results for the pigeons in the key group, and the bottom half shows the results for the pigeons in

Table 2

Means and standard errors for overall response rate (per minute) on the keys and treadles during the choice periods, rate (per minute) of treadle pressing during the delays, and total changeovers for each subject for each condition.

Subject	Condition				Key response rate during choice period	Treadle response rate during choice period	Treadle response rate during delay period	Changeovers
Key group								
1	6	6	6	6	43.1	—	—	75
	10	2	6	6	42.5	—	—	66
	6	6	10	2	47.0	—	—	87
	2	10	6	6	36.8	—	—	74
	6	6	2	10	21.6	—	—	103
	M (SE)				38.2 (4.5)	—	—	81 (6)
2	6	6	6	6	14.4	—	—	52
	10	2	6	6	18.0	—	—	59
	6	6	10	2	9.0	—	—	49
	2	10	6	6	11.3	—	—	46
	6	6	2	10	10.9	—	—	51
	M (SE)				12.7 (1.6)	—	—	52 (5)
3	6	6	6	6	26.6	—	—	63
	10	2	6	6	34.3	—	—	51
	6	6	10	2	24.1	—	—	63
	2	10	6	6	17.2	—	—	47
	6	6	2	10	31.8	—	—	66
	M (SE)				26.8 (3.0)	—	—	58 (4)
4	6	6	6	6	15.7	—	—	150
	10	2	6	6	25.0	—	—	64
	6	6	10	2	27.4	—	—	81
	2	10	6	6	30.4	—	—	54
	6	6	2	10	28.3	—	—	76
	M (SE)				25.4 (2.6)	—	—	85 (17)
5	6	6	6	6	30.2	—	—	69
	10	2	6	6	33.3	—	—	91
	6	6	10	2	29.0	—	—	66
	2	10	6	6	28.5	—	—	65
	6	6	2	10	30.6	—	—	76
	M (SE)				30.3 (0.8)	—	—	74 (5)
6	6	6	6	6	40.4	—	—	54
	10	2	6	6	38.9	—	—	53
	6	6	10	2	35.1	—	—	69
	2	10	6	6	24.6	—	—	59
	6	6	2	10	36.3	—	—	49
	M (SE)				35.1 (2.8)	—	—	53 (5)
Group mean *(SE)*					28.1 (3.7)	—	—	67 (6)
Treadle group								
7	6	6	6	6	0.2	21.7	18.2	66
	10	2	6	6	0.8	18.1	18.5	52
	6	6	10	2	0.1	29.5	19.3	74
	2	10	6	6	2.2	36.6	17.2	78
	6	6	2	10	0.5	29.2	14.3	74
	M (SE)				0.8 (0.4)	27.0 (3.2)	17.5 (0.9)	69 (5)
	6	6	6	6	0.0	19.4	26.9	56
	10	2	6	6	0.0	23.8	23.3	45
	6	6	10	2	0.0	23.8	13.6	57
	2	10	6	6	1.3	20.8	22.9	43
8	6	6	2	10	2.2	29.0	31.2	56
	M (SE)				0.7 (0.5)	23.4 (1.6)	23.6 (2.9)	51 (3)

Table 2

(*Continued*)

Subject	Condition				Key response rate during choice period	Treadle response rate during choice period	Treadle response rate during delay period	Changeovers
	6	6	6	6	0.0	36.1	47.3	79
	10	2	6	6	0.0	43.9	44.0	73
	6	6	10	2	0.02	48.3	17.2	83
	2	10	6	6	0.0	36.5	25.4	58
9	6	6	2	10	0.0	20.0	20.0	54
	M (SE)				0.004 (0.004)	37.0 (4.8)	30.8 (6.2)	70 (6)
	6	6	6	6	0.0	23.8	18.2	67
	10	2	6	6	0.0	27.8	13.5	82
	6	6	10	2	0.0	28.9	15.5	75
	2	10	6	6	0.0	28.8	13.2	74
10	6	6	2	10	0.0	30.6	14.7	83
	M (SE)				0.0 (0.0)	28.0 (1.1)	15.0 (0.9)	72 (4)
	6	6	6	6	0.0	45.3	38.7	83
	10	2	6	6	0.0	41.0	41.5	71
	6	6	10	2	0.0	41.5	32.9	93
	2	10	6	6	0.0	36.9	32.7	97
11	6	6	2	10	0.0	35.9	32.5	79
	M (SE)				0.0 (0.0)	40.1 (1.7)	35.6 (1.8)	85 (5)
	6	6	6	6	0.0	23.6	34.9	79
	10	2	6	6	0.0	30.8	22.5	73
	6	6	10	2	0.0	19.7	21.5	73
	2	10	6	6	0.0	14.4	27.3	52
12	6	6	2	10	0.0	22.7	26.5	75
	M (SE)				0.0 (0.0)	22.2 (2.7)	26.5 (2.4)	70 (5)
Group mean (*SE*)					0.2 (0.2)	29.6 (3.0)	24.8 (3.2)	69 (4)

Note. The dashes indicate that the data were not available for that particular subject.

the treadle group, all plotted using Equations 2a and 2b. The corresponding values of s_A, s_D, s_A/s_D, k, and R^2 (the percentage of variance accounted for) for each subject are shown in Table 3. The fits of the generalized matching law accounted for 92% and 95% of the variance for the key group and the treadle group, respectively (but note that the fits are to only three data points). The values of s_A and s_D are not significantly different for the two groups, $t(10) = -0.87$, $p = .4$; and $t(10) = 1.34$, $p = .2$, respectively. Furthermore, although the only 2 pigeons with values of s_A/s_D less than 1 were in the key group and although the mean value of s_A/s_D was smaller for the key group than for the treadle group, the difference was not significant, $t(10) = -1.0$, $p = .3$.

Table 4 shows the results of additional t tests that compare the values of s_A, s_D, s_A/s_D, and k for the two groups to specific values. These results indicate first that, although the mean values of s_A/s_D are greater than 1 for

both groups, in neither case was the difference significant. Thus, there was little evidence in either group of differential sensitivity to variation in reinforcer amount versus reinforcer delay. Also, for both groups, both s_A and s_D were between 0 and 1. This demonstrates that, consistent with previous research (e.g., Chavarro & Logue, 1988), although the values of s_A and s_D tended to be low, the responding of subjects in both groups was at least somewhat sensitive to variation in both reinforcer amount and reinforcer delay. Finally, the results show that neither group of subjects exhibited a significant response bias, because in neither group was the mean value of k significantly different from 1.

DISCUSSION

The values of s_A (sensitivity to variation in reinforcer amount), s_D (sensitivity to variation in reinforcer delay), and s_A/s_D (a measure re-
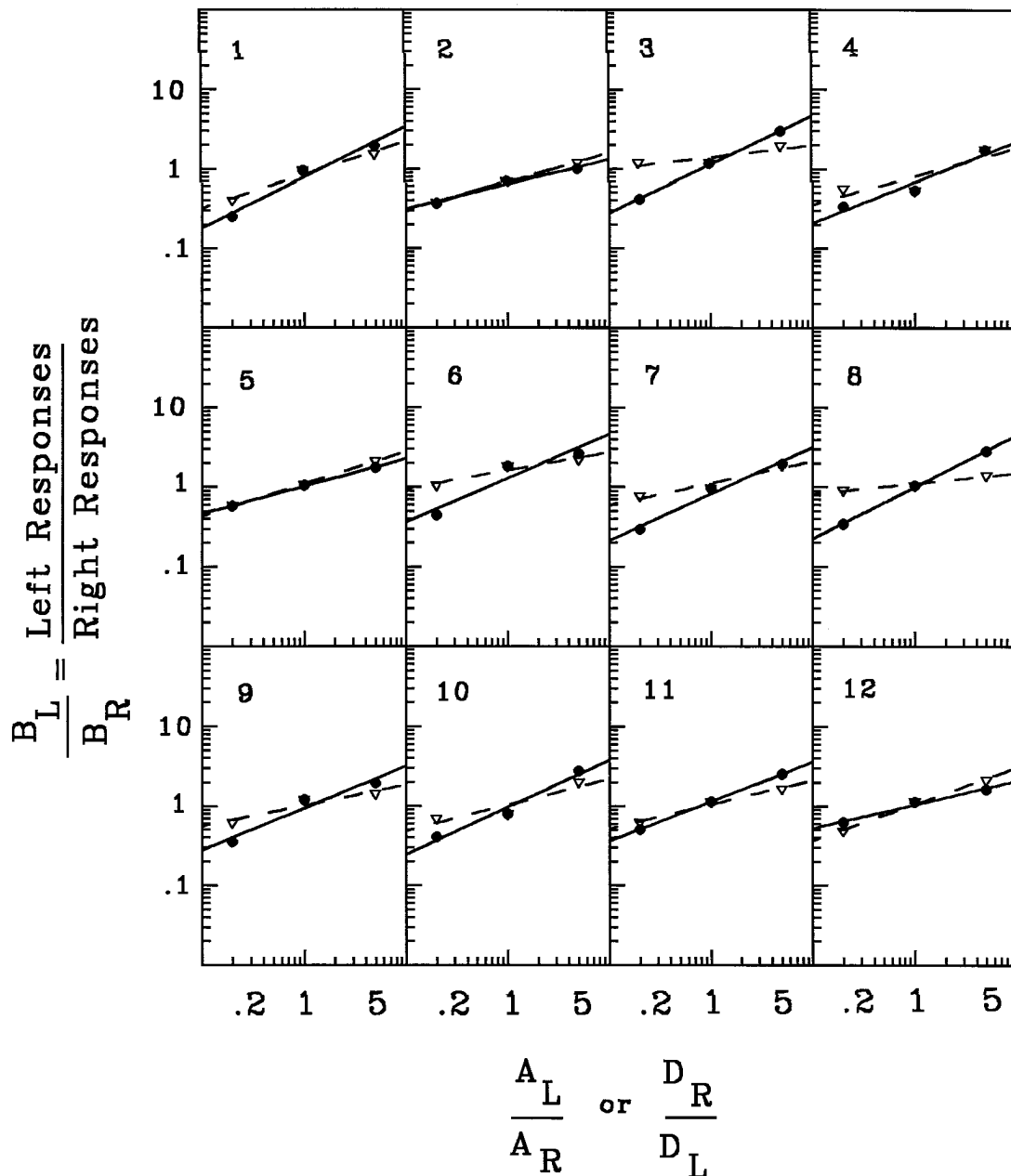
Fig. 1. The ratios (left:right) of effective responses as a function of the ratios (left:right) of the reinforcer amounts or the ratios (right:left) of the reinforcer delays for the key group (Panels 1 to 6) and the treadle group (Panels 7 to 12). The filled circles represent the data from conditions in which the relative amounts were varied, and the solid lines represent the best fitting lines for these data using the method of least squares. The open triangles represent data from conditions in which relative delays were varied, and the dashed lines represent the best fitting lines for these data using the method of least squares. The data are plotted in logarithmic coordinates.

Table 3

Summary of generalized matching law regressions.

Subject	Equation 2a			Equation 2b			Combined	
	k	s_A	R^2	k	s_D	R^2	s_A/s_D	mean k
Key group								
1	0.79	0.64	.94	0.86	0.39	.98	1.63	0.82
2	0.63	0.33	.97	0.68	0.37	1.00	0.89	0.65
3	1.15	0.61	1.00	1.41	0.15	.75	4.00	1.28
4	0.69	0.49	.91	0.80	0.37	.72	1.34	0.74
5	1.04	0.33	1.00	1.10	0.40	1.00	0.82	1.07
6	1.29	0.56	.90	1.62	0.23	.91	2.46	1.46
M (*SE*)	0.93 (0.11)	0.49 (0.06)	.95 (.02)	1.08 (0.15)	0.32 (0.04)	.89 (.05)	1.85 (0.49)	1.00 (0.13)
Treadle group								
7	0.83	0.59	.98	1.13	0.28	.93	2.14	0.98
8	1.02	0.66	1.00	1.04	0.07	.98	9.63	1.03
9	0.94	0.53	.94	1.02	0.26	.90	2.04	0.98
10	0.98	0.59	.97	0.93	0.22	.88	2.68	0.96
11	1.19	0.46	1.00	1.06	0.30	.98	1.54	1.12
12	1.07	0.46	.99	0.93	0.33	.87	1.39	1.00
M (*SE*)	1.01 (0.05)	0.55 (0.03)	.98 (.01)	1.02 (0.03)	0.24 (0.04)	.92 (.02)	3.24 (1.29)	1.01 (0.02)

lated to self-control) were not significantly different for the pigeons in the key group and the treadle group. The relatively large amount of variability in the values of s_A/s_D among the pigeons in both groups could have obscured any differences between these groups. However, the fact that the separate values of s_A and s_D (which showed relatively

Table 4

Summary of tests concerning regression results.

Equation 1 parameter	Regression value *M* (*SE*)	Compar-ison value	*t*(5)
Key group			
s_A/s_D	1.8 (0.5)	1	+1.7
s_A/s_D	1.8 (0.5)	0	+3.8*
s_A	0.5 (0.1)	1	−9.2*
s_A	0.5 (0.1)	0	+8.9*
s_D	0.3 (0.04)	1	−16.3*
s_D	0.3 (0.04)	0	+7.6*
Mean k	1.0 (0.1)	1	+0.02
Mean k	1.0 (0.1)	0	+10.0*
Treadle group			
s_A/s_D	3.2 (1.3)	1	+1.7
s_A/s_D	3.2 (1.3)	0	+2.5*
s_A	0.5 (0.03)	1	−14.2*
s_A	0.5 (0.03)	0	+17.2*
s_D	0.2 (0.04)	1	−20.0*
s_D	0.2 (0.04)	0	+6.4*
Mean k	1.0 (0.1)	1	0.5
Mean k	1.0 (0.1)	0	+10.0*

* $p < .05$.

little variability across subjects) were also not significantly different between the two groups supports the hypothesis that pigeons pecking keys and pigeons pressing treadles are indeed similar in their values of s_A/s_D in this procedure. Furthermore, for both groups the mean value of s_A/s_D was not significantly different from 1. Thus, although the mean values of s_A, s_D, and s_A/s_D were not identical for the two groups, the present data do not support the hypothesis that the degree of self-control exhibited by pigeons pecking keys is dependent on special characteristics of the key-peck response. More specifically, the present data do not support the hypothesis that autoshaped key pecks or the similarity between key pecks and eating responses can decrease self-control in pigeons. The present data yielded no evidence for the occurrence of autoshaped key pecks independent of the type of response that resulted in reinforcement. The pigeons that pressed treadles rarely pecked the lit keys during the choice periods.

Nevertheless, one might argue that there is a difference in the values of s_A, s_D, and s_A/s_D involving treadle pressing versus key pecking, but in the present experiment that difference may have been obscured if one of the response types required more effort than the other. However, it is unlikely that the lack of a difference in the values of s_A, s_D, and s_A/s_D

between the two groups was due to any difference in the effort required to peck the keys and press the treadles. If there were an effect of effort, the overall response rates for the two alternatives might have been expected to differ. More specifically, if either key pecking or treadle pressing required more effort, then the overall response rate for that particular response type should have been lower (see Chung, 1965). There were no significant differences between the two groups, however, in the overall response rates, numbers of responses, or changeovers. Note that previous research has found no effect on choice behavior when the amount of effort required to make both choices varied across conditions but was always the same for each choice (Hunter & Davison, 1982).

Unlike pigeons that peck keys, the pigeons that pressed treadles tended to press the treadles at the same rate during the delay periods and during the choice periods. Thus, despite the fact that the keys were lit only during choice periods for the pigeons in the treadle group, these pigeons might not have effectively discriminated between the choice and delay periods. However, the results in Table 4 indicate that these pigeons did indeed discriminate between the left and right reinforcer delay and reinforcer amount periods. More specifically, the results illustrate that the responding of the pigeons in the treadle group was sensitive to the contingencies for both alternatives, because the mean values of s_A and s_D were both significantly greater than 0 for the subjects in this group. Further, as previously discussed, there were no significant differences in s_A, s_D, and s_A/s_D between the two groups. For all of these reasons, any difficulty that the pigeons in the treadle group had in discriminating between the choice and delay periods does not appear to have interfered with their showing significant sensitivity to reinforcer amount and reinforcer delay.

The present results suggest that the degree of self-control exhibited by pigeons when key pecking is not limited to that particular type of response. Furthermore, pigeons' values of s_A, s_D, and s_A/s_D may be similar across different types of responses, thus increasing the generality of self-control experiments with pigeons. However, conclusions based on the present findings may be constrained by the fact that the present procedure failed to produce consistently, in either group of pigeons, values of s_A/s_D less than 1 (values that would be associated with a tendency to be impulsive). Thus one cannot be sure that the present results would apply to situations in which pigeons' values of s_A/s_D are less than 1, as has been reported frequently in the literature. Conclusions based on the present findings may also be constrained by the fact that only two types of responses and only a limited range of reinforcer values were used here.

REFERENCES

Ainslie, G. W. (1974). Impulse control in pigeons. *Journal of the Experimental Analysis of Behavior, 21,* 485–489.

Alsop, B., & Davison, M. (1986). Preference for multiple versus mixed schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 45,* 33–45.

Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior, 22,* 231–242.

Chavarro, A., & Logue, A. W. (1988). Sensitivity to amount and delay of reinforcement: Effects of different types of concurrent variable-interval schedules. *The Psychological Record, 38,* 421–435.

Chelonis, J. J., King, G. R., Logue, A. W., & Tobin, H. (1994). The effect of variable delays on self-control. *Journal of the Experimental Analysis of Behavior, 62,* 33–43.

Chung, S.-H. (1965). Effects of effort on response rate. *Journal of the Experimental Analysis of Behavior, 8,* 1–7.

Davison, M. (1988). Delay of reinforcers in a concurrent-chain schedule: An extension of the hyperbolic-decay model. *Journal of the Experimental Analysis of Behavior, 50,* 219–236.

Davison, M., & Smith, C. (1986). Some aspects of preference between immediate and delayed periods of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes, 12,* 291–300.

de Villiers, P. A. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233–287). Englewood Cliffs, NJ: Prentice Hall.

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior, 5,* 529–530.

Green, L., Fisher, E. B., Perlow, S., & Sherman, L. (1981). Preference reversal and self-control: Choice as a function of reward amount and delay. *Behaviour Analysis Letters, 1,* 43–51.

Grosch, J., & Neuringer, A. (1981). Self-control in pigeons under the Mischel paradigm. *Journal of the Experimental Analysis of Behavior, 35,* 3–21.

Hanson, J., & Green, L. (1986). Time and response matching with topographically different responses. *Animal Learning & Behavior, 4,* 435–442.

Hemmes, N. S. (1975). Pigeons' performance under differential reinforcement of low rate schedules depends

upon the operant. *Learning and Motivation, 6,* 344–357.

Hunter, I., & Davison, M. (1982). Independence of response force and reinforcement rate on concurrent variable-interval schedule performance. *Journal of the Experimental Analysis of Behavior, 37,* 183–197.

Jenkins, H. M., & Moore, B. R. (1973). The form of the autoshaped response with food or water reinforcers. *Journal of the Experimental Analysis of Behavior, 20,* 163–181.

King, G. R., & Logue, A. W. (1990). Choice in a self-control paradigm: Effects of reinforcer quality. *Behavioural Processes, 22,* 89–99.

King, G. R., & McSweeney, F. K. (1987). Contrast during multiple schedules with different component response requirements. *Animal Learning & Behavior, 15,* 97–104.

Llewellyn, M. E., Iglauer, C., & Woods, J. H. (1976). Relative reinforcer magnitude under a nonindependent concurrent schedule of cocaine reinforcement in rhesus monkeys. *Journal of the Experimental Analysis of Behavior, 25,* 81–91.

Logue, A. W. (1988). Research on self-control: An integrating framework. *Behavioral and Brain Sciences, 11,* 665–709.

Logue, A. W., & Chavarro, A. (1987). Effect on choice of absolute and relative values of reinforcer delay, amount, and frequency. *Journal of Experimental Psychology: Animal Behavior Processes, 13,* 280–291.

Logue, A. W., Chavarro, A., Rachlin, H., & Reeder, R. W. (1988). Impulsiveness in pigeons living in the experimental chamber. *Animal Learning & Behavior, 16,* 31–39.

Logue, A. W., King, G. R., Chavarro, A., & Volpe, J. S. (1990). Matching and maximizing in a self-control paradigm using human subjects. *Learning and Motivation, 21,* 240–368.

Logue, A. W., Rodriguez, M. L., Peña-Correal, T. E., & Mauro, B. E. (1984). Choice in a self-control paradigm: Quantification of experience-based differences. *Journal of the Experimental Analysis of Behavior, 41,* 53–67.

LoLordo, V. M., McMillan, J. C., & Riley, A. L. (1974). The effects of food-reinforced pecking and treadle-pressing of auditory and visual signals for response-independent food. *Learning and Motivation, 5,* 24–41.

Mazur, J. E., & Logue, A. W. (1978). Choice in a ''self-control'' paradigm: Effects of a fading procedure. *Journal of the Experimental Analysis of Behavior, 30,* 11–17.

Mischel, W., & Ebbesen, E. B. (1970). Attention in delay of gratification. *Journal of Personality and Social Psychology, 16,* 329–337.

Mischel, W., Ebbesen, E. B., & Zeiss, A. (1972). Cognitive and attentional mechanisms in delay of gratification. *Journal of Personality and Social Psychology, 21,* 204–218.

Poling, A., Thomas, J., Hall-Johnson, E., & Picker, M. (1985). Self-control revisited: Some factors that affect autoshaped responding. *Behavioural Processes, 10,* 77–85.

Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior, 17,* 15–22.

Richardson, W. K., & Clark, D. B. (1976). A comparison of the key-peck and treadle-press operants in the pigeon: Differential-reinforcement-of-low-rate schedule of reinforcement. *Journal of the Experimental Analysis of Behavior, 26,* 237–256.

Rodriguez, M. L., & Logue, A. W. (1986). Independence of the amount and delay ratios in the generalized matching law. *Animal Learning & Behavior, 14,* 29–37.

Stubbs, D. A., & Pliskoff, S. S. (1969). Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior, 12,* 887–895.

Sumpter, C. E., Foster, T. M., & Temple, W. (1995). Predicting and scaling hens' preferences for topographically different responses. *Journal of the Experimental Analysis of Behavior, 63,* 151–163.

Tobin, H., & Logue, A. W. (1994). Self-control across species (*Columba livia, Homo sapiens,* and *Rattus norvegicus*). *Journal of Comparative Psychology, 108,* 126–133.

Tobin, H., Logue, A. W., Chelonis, J. J., Ackerman, K. T., & May, J. G. (1996). Self-control in the monkey *Macaca fasicularis. Animal Learning & Behavior, 24,* 168–174.

APPENDIX

Subject	Condition[a]				Effective response	
					Left	Right
	A_L	A_R	D_L	D_R	M (SE)	M (SE)
Key group						
1	6	6	6	6	282.4 (14.6)	293.6 (15.4)
	10	2	6	6	412.0 (20.3)	208.4 (9.4)
	6	6	10	2	193.2 (18.4)	479.6 (34.9)
	2	10	6	6	132.6 (5.5)	521.0 (25.5)
	6	6	2	10	241.2 (24.4)	155.2 (7.8)
2	6	6	6	6	122.2 (7.7)	174.4 (4.6)
	10	2	6	6	158.4 (15.2)	156.4 (10.6)
	6	6	10	2	85.4 (3.0)	229.2 (8.3)
	2	10	6	6	74.0 (4.7)	199.4 (6.7)
	6	6	2	10	125.0 (8.4)	103.6 (7.2)
3	6	6	6	6	204.4 (6.9)	171.8 (9.5)
	10	2	6	6	387.6 (14.8)	128.8 (4.8)
	6	6	10	2	191.0 (9.8)	160.0 (9.7)
	2	10	6	6	118.2 (10.7)	284.2 (25.7)
	6	6	2	10	308.0 (13.1)	157.2 (8.0)
4	6	6	6	6	132.0 (16.3)	247.8 (20.0)
	10	2	6	6	250.2 (14.4)	141.8 (5.6)
	6	6	10	2	157.0 (10.2)	279.0 (4.8)
	2	10	6	6	116.0 (8.0)	343.8 (35.3)
	6	6	2	10	266.4 (13.4)	150.2 (4.4)
5	6	6	6	6	211.0 (15.4)	197.6 (12.0)
	10	2	6	6	332.0 (26.2)	188.2 (9.7)
	6	6	10	2	155.0 (5.3)	264.4 (6.6)
	2	10	6	6	158.6 (9.5)	273.2 (13.3)
	6	6	2	10	315.8 (15.0)	147.6 (6.9)
6	6	6	6	6	342.2 (22.8)	186.0 (12.6)
	10	2	6	6	405.8 (12.7)	153.4 (6.3)
	6	6	10	2	237.6 (13.7)	225.4 (15.4)
	2	10	6	6	123.6 (10.3)	275.2 (9.1)
	6	6	2	10	320.2 (19.9)	146.4 (8.9)
Treadle group						
7	6	6	6	6	201.2 (9.1)	207.0 (17.4)
	10	2	6	6	248.4 (12.9)	126.6 (9.8)
	6	6	10	2	184.2 (8.9)	238.0 (13.9)
	2	10	6	6	135.4 (11.1)	456.2 (35.5)
	6	6	2	10	319.4 (12.2)	169.6 (5.0)
8	6	6	6	6	188.4 (10.1)	177.6 (5.9)
	10	2	6	6	307.0 (15.9)	106.8 (7.0)
	6	6	10	2	187.0 (12.2)	201.8 (7.3)
	2	10	6	6	101.6 (4.9)	291.8 (19.8)
	6	6	2	10	237.2 (13.2)	167.4 (8.9)
9	6	6	6	6	269.6 (10.3)	224.0 (9.1)
	10	2	6	6	362.8 (16.4)	186.2 (10.3)
	6	6	10	2	212.4 (3.9)	343.0 (16.3)
	2	10	6	6	141.0 (7.4)	395.2 (18.1)
	6	6	2	10	211.8 (7.7)	149.2 (11.8)
10	6	6	6	6	166.0 (4.9)	207.6 (13.4)
	10	2	6	6	331.4 (15.6)	118.8 (5.3)
	6	6	10	2	182.2 (7.2)	260.6 (20.4)
	2	10	6	6	142.8 (8.2)	349.2 (39.3)
	6	6	2	10	320.0 (5.9)	159.6 (11.2)
11	6	6	6	6	293.2 (5.6)	256.2 (14.4)
	10	2	6	6	365.8 (11.8)	143.6 (4.5)
	6	6	10	2	197.6 (5.9)	315.6 (5.0)

APPENDIX

(*Continued*)

Subject	Condition[a]				Effective response	
					Left	Right
	A_L	A_R	D_L	D_R	*M* (*SE*)	*M* (*SE*)
	2	10	6	6	189.8 (3.9)	367.6 (16.1)
	6	6	2	10	303.0 (20.8)	184.0 (6.6)
12	6	6	6	6	263.4 (4.0)	227.0 (15.9)
	10	2	6	6	351.6 (24.9)	163.2 (12.2)
	6	6	10	2	147.6 (5.7)	306.4 (15.2)
	2	10	6	6	132.4 (10.8)	270.8 (22.7)
	6	6	2	10	238.0 (8.6)	169.0 (2.3)

[a] A_L, A_R, D_L, and D_R represent the number of seconds of the left and right reinforcer access and reinforcer delay periods, respectively.