*A COMPARISON OF THE KEY-PECK AND TREADLE-PRESS
OPERANTS IN THE PIGEON: DIFFERENTIAL-
REINFORCEMENT-OF-LOW-RATE
SCHEDULE OF REINFORCEMENT¹*

W. KIRK RICHARDSON AND DAVID B. CLARK

GEORGIA STATE UNIVERSITY

Key pecking and treadle pressing in pigeons were compared under concurrent (key-treadle) and single-operant differential-reinforcement-of-low-rate schedules of food reinforcement ranging from 5 to 60 sec (concurrent procedure) or 5 to 120 sec (single-operant procedure). Under both procedures, the two operants followed the same general law: decreasing response rate and reinforcement rate and increasing number of responses per reinforcement as a function of increasing schedule interval. High correlations were found between key pecking and treadle pressing for the measures of response rate, reinforcement rate, and responses per reinforcement. Regression equations allowed the prediction of treadle pressing from key pecking. More bursting occurred in responding to the key, and key pecking showed a more precise temporal discrimination than treadle pressing. A test for sequential dependencies between key and treadle responses showed significant dependencies not only under the concurrent procedure but also in data created artificially by merging key and treadle sequences from different pigeons under the concurrent procedure and from the same pigeon under the single-operant procedure. It seems likely that the sequential dependencies found were due to the independent action of the schedule on each operant and that behavioral dependencies did not occur with the concurrent training procedure. The key-peck operant does not appear to have any special qualities that preclude its use in discovering general laws of behavior, at least under the differential-reinforcement-of-low-rate schedule. The usefulness of the key peck in other situations requires direct experimental study.

Key words: differential reinforcement of low rate, concurrent schedules, spaced responding, IRT distributions, treadle pressing, key pecking, pigeons

A goal of the experimental analysis of behavior is to discover general laws of behavior. A few simple, arbitrary responses are studied under controlled conditions to minimize the influence of extraneous factors and to maximize the generality of experimental results. The responses studied are arbitrary ones in the subject's repertoire and are selected only for ease of recording and other procedural reasons.

¹A version of Experiment I was presented at the Fifteenth Annual Meeting of the Psychonomic Society, Boston, 1974. Experiment I is based on a thesis submitted by the second author to the Department of Psychology, Georgia State University, in partial fulfillment of the requirements for the MA degree. Part of Experiment II was conducted by Anne Lazenby and submitted to the Department of Psychology in partial fulfillment of the requirements for graduation with Honors in Psychology. We wish to thank the Computer Center of Georgia State University for providing the computer time and programs necessary to obtain and analyze the data. Also, special thanks go to Roger Bakeman for assistance with the statistical analysis. Reprints may be obtained from W. Kirk Richardson, Psychology Department, Georgia State University, Atlanta, Georgia 30303.

It is expected, by virtue of the very arbitrariness of the behavior under study and the test environment, that confounding influences due to previous experience or species-specific characteristics of subjects will be eliminated. The results that emerge from experiments undertaken following such a scientific strategy are expected therefore to reveal general properties of operant behavior.

The assumption implicit in this strategy has been called the assumption of "equivalence of associability".

... any emitted response and any reinforcer can be associated with approximately equal facility, and a set of general laws exist which describe acquisition, extinction, discriminative control, generalization, *etc.* for all responses and reinforcers (Seligman, 1970, p. 407).

If such an assumption is adopted then it follows that the study of operant behavior in general may be undertaken by actually investigating experimentally only a few operants.

Skinner (1938, p. 46) even suggested that "the dynamic properties of operant behavior may be studied with a single reflex (or at least with only as many as are needed to assure the general applicability of the results)". Although research has not been exclusively concerned with a single operant, the strategy adopted in the experimental analysis of behavior has been to focus study on relatively few responses (and species) and to assume that the results reveal general properties of operant behavior.

It is important that the few responses selected be minimally subject to influences due to peculiarities of the species chosen for study. In reference to early devices employed in the experimental analysis of behavior, Skinner stated:

The experimenter could choose a response . . . which minimized the peculiarities of a species and thus furthered a comparison between species with respect to properties not primarily related to the topography of behavior. In particular, it was possible to choose a response which was relatively free of extraneous variables and not likely to be confused with responses elicited or evoked by them (Skinner, 1969, p. 108).

Recently, the status of the pigeon's key peck as a response that is "free of extraneous variables" has been questioned. Studies investigating autoshaping, automaintenance, key-peck duration, behavioral contrast, free-operant avoidance, and behavior under response-dependent and response-independent schedules of food presentation illustrate conditions under which pecking appears to be subject to influences other than the programmed contingencies of reinforcement (Brown and Jenkins, 1968; Foree and LoLordo, 1970; Hemmes, 1973; Schwartz and Williams, 1972; Scull and Westbrook, 1973; Smith and Keller, 1970; Staddon and Simmelhag, 1971; Westbrook, 1973; Williams and Williams, 1969).

Further evidence that raises questions about the generality of the key peck is responding under the differential-reinforcement-of-low-rate (DRL) schedule of reinforcement. In their review of behavior under the DRL schedule, Kramer and Rilling (1970) noted a difference among species in the number of responses per reinforcement when DRL values exceeded 20

to 30 sec. They noted that in rats, monkeys, and humans the number of responses per reinforcement remained low at high DRL values, but that in pigeons, the number of responses per reinforcement increased greatly as the DRL value was increased. Kramer and Rilling suggested that perhaps pigeons were unable to delay responding for 20 to 30 sec or more.

Hemmes (1975) took a different approach, suggesting that it was the nature of the operant, rather than the animal that was responsible for the large number of responses per reinforcement. Hemmes trained pigeons to peck a key or to press a treadle under DRL schedules ranging from DRL 5-sec to DRL 14-sec on the key and from DRL 5-sec to DRL 35-sec on the treadle. Birds trained to peck a key showed a rapid increase in number of responses per reinforcement as the DRL value was increased. The response rate of these birds failed to decline as the DRL value was increased. The birds trained to press a treadle showed only a gradual increase in number of responses per reinforcement and a steady decline in response rate as the DRL value was increased. Hemmes, like Schwartz and Williams (1972), concluded that pecking is susceptible to strengthening by contingent reinforcement and also to strengthening resulting directly from presentation of food. Hemmes argued that the high frequency of unreinforced pecking shown by pigeons under DRL schedules of reinforcement resulted from the latter source of strengthening.

The findings cited suggest that the pigeon's key peck may be subject to influence by factors other than the response-reinforcement contingencies in the experimental situation—factors that may not influence other operants. This evidence raises questions regarding the generality of data obtained using the key peck. Of course, generality of key-peck data has been demonstrated under certain conditions, *e.g.*, patterns of responding under fixed-ratio and fixed-interval schedules of reinforcement. The question, then, is this: to what degree, if any, are key-peck data lacking in generality, and under what conditions? The question may be answered empirically by attempting to predict the performance of other operants from key-peck performance. If the predictions can be made successfully then it may be said that, under the conditions investigated, both operants obey the same law and that any peculiari-

ties of the key peck do not prevent generalizing from the key peck to another operant.

The present studies compared key pecking and treadle pressing in pigeons under DRL schedules of reinforcement and attempted to predict treadle performance from key performance. The treadle press was employed as the second operant because it has been studied frequently and because it is not likely to be subject to the kinds of confounding influences to which the key peck may be subject. The DRL schedule of reinforcement was employed because key-treadle differences have been found under this schedule (Hemmes, 1975) and because any "nonoperant" responding is more likely to be seen against a low-rate baseline if the absolute size of the effect is small.

Reports of studies investigating the pigeon's treadle press often state that the birds come to peck the treadle during the experiment (Hemmes, 1975; LoLordo, McMillan, and Riley, 1974). To solve this problem, these experimenters increased the force requirement of the treadle until pecks would not operate the microswitch. Hemmes (1975) used a treadle requiring 1.3 N for operation, while that used by LoLordo *et al.* (1974) required 1.2 N. Key force requirements are typically 0.1 to 0.2 N. Experiment I made the key and treadle concurrently available to the birds with the force requirements for the two operanda more nearly equal (0.15 to 0.2 N for the key, 0.3 to 0.35 N for the treadle). It was expected that under the concurrent schedule, pecks would be directed at the key rather than the treadle, thereby eliminating the need for widely different force requirements on the two operanda.

EXPERIMENT I

METHOD

Subjects

Four naive adult homing pigeons (P1, P2, P3, P4) were maintained at 70% of free-feeding weights during preliminary training, and at 75% during the experiment proper.

Apparatus

Subjects were tested in two identical operant chambers with inside dimensions 52 cm long, 36 cm wide, and 33 cm high. The response panel in each chamber had a key hole 2.5 cm in diameter centered 22 cm above the floor.

The response key was a translucent Plexiglas paddle. The rear surface of the paddle was painted flat black except for a circle 1 cm in diameter, which was centered behind the key hole. The key was transilluminated from the rear with green light. A force of 0.15 to 0.20 N with an excursion of 1 mm was required to operate the response key. A wooden treadle 5 cm wide and 6.5 cm long extended from a box 15.5 cm long, 6 cm wide, and 8 cm high was placed in a corner of the chamber with the back of the treadle box against the response panel. The treadle was adjacent to the chamber wall, to the right of the key and the food tray, and approximately 32 cm from the food tray. The treadle was 3 cm above the floor. Two stimulus lamps (not used in the present study) were mounted on the upper surface of the box and the entire apparatus was painted gray. A force of 0.3 to 0.35 N with an excursion of 10 mm was required to operate the treadle.

The reinforcer was one 45-mg Noyes pigeon pellet delivered to a Scientific Prototype food tray located 7.7 cm below and 5 cm to the left of the response key. A 28-V shielded bulb located 0.5 cm above the food tray illuminated the tray for 1 sec following delivery of the reinforcer. Houselights consisted of two 28-V bulbs behind a Plexiglas screen placed across the top of the response panel. An 85-dB white masking noise was continuously present and a blower system provided ventilation. An IBM 1800 Data Acquisition System located in an adjacent room controlled the experiment and recorded responses. Responses to either operandum terminating interresponse times (IRTs) shorter than 50 msec were not counted.

Procedure

All birds were initially adapted to test chambers in two 1-hr sessions. With the treadles removed from the chambers, P2 and P3 were magazine trained and key pecking was shaped in one session. They were then given two sessions of continuous reinforcement for responses to the key. The key holes were then covered, the treadles were put in the chambers, and these birds were trained to press the treadle. After shaping of the treadle press, P2 and P3 were given three sessions of continuous reinforcement for responses to the treadle. The order of training key pecking and treadle pressing was reversed for the other two birds. While all birds frequently pecked the treadle box,

none was ever observed to peck the treadle itself. The treadle-press response typically consisted of standing by the treadle and pressing it with one foot while facing toward the response panel.

Following preliminary training, the birds were tested daily with both operanda concurrently available under DRL values of 5, 10, 20, 40, and 60 sec. The DRL value was always the same for both operanda and the DRL schedule of one operandum was completely independent of the DRL schedule of the other operandum. Table 1 presents the order and duration of the experimental conditions. Conditions were changed when the response rates showed, as determined by visual inspection, no systematic changes in any of the birds over at least five consecutive sessions. The DRL schedule reinforced every response with an IRT equal to or greater than the DRL value. The IRTs were measured as the time from the beginning of the session to the first response and thereafter as the time between successive responses. At the start of the session, the house-lights and keylights were illuminated and remained illuminated until the end of the session, when all lights were extinguished.

Table 1
Order and duration of experimental conditions for Experiment I.

Subjects	DRL Value (seconds)	Number of Sessions	Session Length (minutes)
P1 and P2	5	20	20
	10	14	20
	20	18	40
	40	24	40
	60	24	40
P3 and P4	5	20	20
	10	14	20
	20	20	40
	40	32	40
	60	16	40

RESULTS

All birds were observed frequently throughout preliminary training and the experiment proper. No birds was ever observed to peck the treadle. Examination of cumulative records made during the experimental sessions, however, showed that P2 occasionally emitted a burst of 15 to 20 responses to the treadle at a high rate; these bursts may have been episodes of pecking. They occurred only under the 40-

sec and 60-sec schedule values. Cumulative records were obtained from each bird during alternate sessions. Seven bursts were seen in the cumulative records of P2. Bursts were never directly followed by reinforcement under the DRL schedule.

Figure 1 presents response and reinforcement rates for each bird as a function of DRL value. Both axes are plotted as logarithmic scales. The data presented in this and all other figures and analyses are means of the last four sessions under each DRL schedule value. Response rate was always higher on the key than on the treadle. Response rate on both key and treadle tended to decrease as a function of increasing schedule value. Under the 5-sec value, reinforcement rate was higher for key

Fig. 1. Mean response rate and mean reinforcement rate for the key response and the treadle response as a function of schedule value. Both axes are plotted as log scales. Each point is the mean of the last four sessions.

pecking for P1, P2, and P4 and higher for treadle pressing for P3. With the exception of P2 under DRL 10-sec, reinforcement rate was always higher for treadle pressing under the other schedule values. On both key and treadle, reinforcement rate decreased as a function of increasing schedule value, with the key-peck reinforcement rate decreasing faster.

Figure 2 presents number of responses per reinforcement and the proportion of IRTs shorter than 1 sec (a measure of bursting) as a function of schedule value. Bursting on the treadle showed no systematic relationship to schedule value. Bursting on the key showed a clearly increasing trend as a function of increasing schedule value in P2 and P4, a less

clear trend in the same direction in P3, and no trend in P1. Responses per reinforcement showed an increasing trend on both key and treadle as a function of increasing schedule value from DRL 5-sec through DRL 40-sec. Values under DRL 60-sec were lower than values under DRL 40-sec for P1, P2, and P3, and higher for P4. The effect of increasing schedule value was much greater on key pecking. The number of responses per reinforcement was always higher on the key than on the treadle.

Figure 3 presents response probability (IRTs per opportunity) distributions (Anger, 1956) for each bird under all DRL values. The IRTs per opportunity measure is a conditional probability statistic showing the probability that a response occurred with an IRT in the class interval t to $t + x$, given that t sec have passed since the last response. In each case, the bin size (class interval width) on the horizontal axis is one tenth of the schedule value. Under all schedule values, response probabilities at or near the DRL value were higher on the key than on the treadle, and there was a greater range between highest and lowest response probabilities for the key. Probability of IRTs in the first bin was higher for the key. Response probability distributions changed as a function of increasing schedule value. Under DRL 5-sec, there were pronounced differences between the probability of key and treadle IRTs near the DRL value. As schedule values increased, these differences became smaller due to the probability distributions becoming less peaked in the region of the DRL value. Under DRL 5-sec, the peaks of the distributions were quite close to the DRL value, but the peaks tended to occur further short of the DRL value as the schedule value increased.

Figure 4 presents relative frequency distributions for each bird under each schedule value. Under all schedule values, there were fewer responses terminating IRTs longer than the DRL value on the key. Under DRL 5-sec, the peaks of the distributions occur near the DRL value. As schedule value increases, the peaks tend to fall further short of the DRL value. Well-defined peaks are not evident in the distributions under DRL 40-sec and 60-sec.

Figure 5 presents key response rate as a function of treadle response rate, key reinforcement rate as a function of treadle reinforcement rate, and key responses per

Fig. 2. Mean responses per reinforcer and mean proportion of IRTs shorter than 1 sec for the key response and the treadle response as a function of schedule value. The ordinate for the responses-per-reinforcer function and the abscissa for both functions are plotted as log scales. Each point is the mean of the last four sessions.

Fig. 8. IRTs per opportunity distributions for the key response and the treadle response. Each class interval width is one tenth of the schedule value. All IRTs to the right of the vertical, dashed line were reinforced. The right-most point in each function is the fifteenth class interval or the largest class interval with more than 20 opportunities. Each point is the mean of the last four sessions.

reinforcement as a function of treadle responses per reinforcement for both the individual birds and the group data. These functions show to what degree each of the dependent measures for one operant can be predicted from the same measure for the other operant. The straight lines represent the best fitting linear functions as determined by the method of least squares. The regression equation and the Pearson product-moment correlation coefficient (r) are presented for each set of data.

The degree to which the regression line accounts for the variance in the data is indicated by the significance of r . Three of four values of r for the individual birds' response-rate functions were significant ($p < 0.05$), as was the

group function. All of the values of r for reinforcement rate and responses per reinforcement were significant ($p < 0.05$).

Both axes for reinforcement rate and responses per reinforcement are plotted as logarithmic scales and the regression analyses for these data were performed on the logarithmic transformation of the data. The reinforcement rate data were equally well fitted by a straight line when the analysis was performed on the untransformed data; r changed very little, and the significance of the values of r did not change. Thus, the reinforcement rate data are presented as logarithmic scales merely as a matter of convenience. When the responses-per-reinforcement untransformed data were analyzed, r was lower, and only two of the in-

Fig. 4. Relative frequency distributions for the key response and the treadle response. Each class interval is one tenth of the schedule value. All IRTs to the right of the vertical, dashed line were reinforced. The right-most filled symbol in each function is the fifteenth class interval or the largest class interval with at least 1% of the total responses. The open symbols show the per cent of the total responses not included in the functions. N = number of key IRTs, number of treadle IRTs. Each point is the mean of the last four sessions.

dividual birds and the group data had significant values of r . Thus, the responses-per-reinforcement data are better described by the transformed data (power functions) than by the untransformed data (linear functions).

In the concurrent schedule the two operants may not be independent, *i.e.*, the performance on one operant may be affected by the presence of the other operant. If the two responses were tied together in some fashion such as, "peck twice, press once", the effect of the manipulation of schedule value could have been on the behavioral sequence, artificially inducing correlations between key and treadle behavior. A state transition analysis was performed on the sequence of key-peck and treadle-press responses to determine if there were sequential dependencies between the two responses. This analysis compares the simple probability of one type of response (say key peck) with the conditional probability of that type of response given that the immediately preceding response was a key peck (lag = 1), that the second pre-

ceding response was a key peck (lag = 2), *etc.* The comparison of the simple probability with the conditional probability at each lag is expressed in terms of a z -score, which gives the likelihood that the difference between the simple and conditional probabilities occurred by chance. The data can be plotted as a probability profile where z -score is expressed as a function of lag. If the two probabilities are the same, the z -score is zero. A z -score above zero indicates that the probability of the response at that lag is greater than the simple probability. A score below zero indicates that the probability of response at that lag is less than the simple probability.

The data from the last four sessions under each DRL value were analyzed for lags 1 to 10. Two sequences were analyzed: key peck followed by key peck and treadle press followed by treadle press. The other two possible sequences, key peck followed by treadle press and treadle press followed by key peck are simply the complements of the two sequences

Fig. 5. The relation between key and treadle behavior for response rate (left column), responses per reinforcer (middle column), and reinforcement rate (right column) for individual birds and group data. Responses per reinforcer and reinforcement rate are plotted as log scales. Each point is the mean of the last four sessions under a condition. The regression equations and the lines they represent are presented with each graph. The equations were computed using the method of least squares. R_t = treadle behavior, R_k = key behavior, r = product-moment correlation coefficient, $*$ = $p < 0.05$, $**$ = $p < 0.01$.

analyzed. Figure 6 presents the probability profile for each bird at the 20-sec schedule value where the data showed a moderate amount of sequential dependency relative to the other schedule values. The solid horizontal line in each panel indicates a z-score of zero (corresponding to the simple probability of the second element in the sequence) and the dashed lines indicate z-scores corresponding to p values (two-tailed test) of 0.20 (inside lines) and 0.05 (outside lines). The top panel, second from the left, presents the probability profile of P1 for the treadle-treadle

sequence. The point at lag 1 is positive and is above the outside dashed line, showing that the conditional probability of a treadle press, given that the last response was a treadle press, was significantly greater than the simple probability of a treadle press. The point at lag 2 is negative and is below the outside dashed line, showing that the probability of a treadle press, given that the second immediately preceding response was a treadle press, was significantly less than the simple probability of a treadle press. The remaining points all show that the conditional probability of a

Fig. 6. Results of the state transition analysis for the key and treadle behavior of each bird during the last four sessions under the 20-sec schedule value. Inner dashed lines, $p = 0.20$, outer dashed lines, $p = 0.05$; T $\rightarrow$ T = treadle to treadle transition; K $\rightarrow$ K = key key transition. See text for detailed explanation.

treadle press was greater than the simple probability of a treadle press except at lag 6, where the conditional probability did not significantly differ from the simple probability.

The probability profiles at the other schedule values (data not presented) all showed significant sequential dependencies, ranging from one point significant ($p < 0.05$) to 19 points significant of a possible 20.

Figure 7 presents the results of the same analysis for sequential dependencies on artificially created sequences constructed by merging the key pecking of one bird with the treadle pressing of another. This resulted in a test for sequential dependencies being performed on data where dependency could not possibly exist in the behavior. The analysis was performed for all schedule values. The

Fig. 7. Results of the state transition analysis where the key behavior of one bird was merged with the treadle behavior of another bird. The first bird number is for the key data, the second bird number is for the treadle data. Other details are the same as for Figure 6.

probability profiles for the 20-sec value presented in Figure 7 show several points with significant ($p < 0.05$) sequential dependencies. At the other schedule values, the number of significant points per case ranged from zero (two cases) to 12.

DISCUSSION

Under concurrent DRL schedules of reinforcement, differences on several measures of responding were seen between two operants in the pigeon, the key peck and the treadle press. Rate of key pecking was higher under each schedule value, whereas reinforcement rate tended to be higher for treadle pressing. The number of responses per reinforcement was always higher on the key. Increasing schedule value had a greater effect on key responses per reinforcement. Temporal discrimination was more pronounced for key pecking under all schedule values.

Despite these differences, the data in Figures 1 and 2 show that the two operants obeyed the same general law: response rate and reinforcement rate decreased as a function of increasing schedule value throughout the range of values studied, while the number of responses per reinforcement increased from DRL 5-sec through DRL 40-sec. Values for key pecking and treadle pressing were widely different in some cases, but the general character of the functions relating the three response measures to schedule value was the same for both operants. Gross similarities of key and treadle responding are apparent from visual inspection of Figures 1 and 2. The data in Figure 5 provide a more precise description of these similarities.

Prediction is the essence of generality. If, given one case, the other can be predicted successfully, then generality has been demonstrated for that situation. The regression equations in Figure 5 successfully predicted treadle pressing from key pecking. This appears to indicate that under the conditions studied here, key pecking is characterized by generality. There seem to be no peculiarities of key pecking that diminish its generality under DRL schedules of reinforcement.

Interpreting the results of Experiment I, however, hinges on the question of whether the two activities, key pecking and treadle pressing, were independent of each other. If the two were independent choice alternatives,

and if responding on one operandum did not affect responding on the other, the results may be taken to support the conclusion of generality for the key peck. If, however, the two were linked together into some larger pattern, then they could not be said to be independent. If the responses were joined according to a rule such as "one treadle press, then two key pecks, then another treadle press", the high correlations found would be expected simply as an artifact of this sequential pattern of responding. Changes in one operant would produce closely related changes in the other.

What is needed to answer the question of independence is a test for sequential dependencies between key pecking and treadle pressing that would detect the presence of any consistent sequential patterns. The data in Figure 6 appear to show the presence of clear sequential patterns of responding, which diverge widely from chance. Thus, it appears that key pecking and treadle pressing may have been linked together in some larger pattern and that the two operants were not independent. If this is the case, then the results of Experiment I are quite ambiguous and do not strongly support the generality of the key peck.

The probability profile would show sequential dependencies if they existed. It might, though, show dependence where it *did not exist* in the behavior. For example, if key pecking or treadle pressing under DRL schedules of reinforcement were characterized by consistent temporal patterns of responding that were unrelated to other responding, then the "dependencies" shown by this test might simply be the result of superimposing two independent patterns and not the result of an overall pattern in which the two responses were intertwined. This kind of "dependence" would not be damaging to the conclusion of generality. A test for such a possibility is to merge the key pecking of one bird with the treadle pressing of another and subject the resulting data to the same analysis. In such a case, the kind of sequential dependencies in question could not possibly exist, and any "dependencies" shown by the test would have to be the result of something else. Figure 7 presents the results of this test, which does indeed show "dependencies" in these data. Thus, the results of the sequential dependency analysis supported the conclusion of behavioral independence of treadle pressing and key

pecking, although statistical dependencies were present. There did not appear to be any stronger sequential dependency effect in the artificial sequences than in the actual concurrent data.

EXPERIMENT II

The existence of sequential dependencies in the artificially constructed sequences found in Experiment I may depend on the concurrent schedule training. That is to say, if data were obtained from each operant alone, and these data were artificially merged, sequential dependencies might not be present. Experiment II tested this possibility by testing each operant alone under each of the schedule values used in Experiment I. Also, a 120-sec schedule value was used and the birds were exposed to the 10-sec value twice for each operant.

METHOD

Subjects

Four naive, adult, racing homing pigeons (P5, P6, P7, P8) were maintained at 70% of their free-feeding weights.

Apparatus

Same as for Experiment I, except four test chamber were used.

Procedure

After adaptation and magazine training, the birds were trained by successive approximations to press the treadle with their feet and were then tested under schedule values ranging from 5 to 60 sec. Next, the birds were trained by the method of successive approximations to peck the key and were tested under schedule values ranging from 5 to 120 sec. Finally, the birds were tested under a 120-sec schedule value using the treadle response. Usually, conditions were not changed until visual inspection of the response-rate data showed no systematic change for any of the birds over at least five successive sessions. The one exception was when three birds were changed to Condition 7 while one bird remained under Condition 6 for eight additional sessions. See Table 2 for the sequence and details of experimental conditions. The key was covered with a metal plate when the treadle-press response was being tested. When the key-peck response was being

Table 2

Order and duration of experimental conditions for Experiment II.

Ordinal Number	Response	DRL Value (seconds)	Number of Sessions ^a	Session Length (minutes)
1	treadle press	10	10	40
2	treadle press	20	10	40
3	treadle press	40	15	40
4	treadle press	60	14	40
5	treadle press	5	23	30
6	treadle press	10	22 (30)	40
7	key peck	10	27 (19)	40
8	key peck	20	20	40
9	key peck	40	20	80
10	key peck	60	35	120
11	key peck	5	20	20
12	key peck	10	34	40
13	key peck	120	29	240
14	treadle press	120	24	240

^aNumbers in parentheses are for P6.

tested, the treadles were removed from the chambers. All other details of the procedure were identical to Experiment I.

RESULTS

The birds were occasionally observed throughout the experiment. Although P5 and P8 were observed to peck the treadle, treadle pecking was never sustained for a long period of time within a session and never constituted a significant proportion of the recorded responses. All birds were observed to peck the top of the treadle box and the wall next to the treadle.

Figure 8 presents response rate (top panels) and reinforcement rate (bottom panels) as a function of schedule value for individual birds. In general, both response and reinforcement rates decreased as schedule value increased. The two exceptions were a higher reinforcement rate under the 60-sec value than under the 40-sec value for the key-peck response of three of the four birds, and a higher reinforcement rate under the 120-sec value than under the 60-sec value for the treadle-press response of three of the four birds. The key-peck response rate was equal to or higher than the treadle-press response rate at all schedule values. The largest difference between the response rate of the two operants tended to occur under intermediate schedule values. The reinforcement rate was higher for the key-peck response than for the treadle-press response

Fig. 8. Mean response rate and mean reinforcement rate for the key response and the treadle response as a function of schedule value. Both axes are plotted as log scales. Each point is the mean of the last four sessions.

under low schedule values; as schedule value increased, the key-peck reinforcement rate fell below the treadle-press reinforcement rate. Since the axes of Figure 8 are logarithmic, the key-peck reinforcement rates are, in absolute terms, considerably higher than the treadle-press reinforcement rates under the 5-sec schedule value.

Figure 9 presents bursting (proportion of IRTs shorter than 1 sec, top panels) and responses per reinforcement (bottom panels) for both operants. In general, more bursting occurred for the key-peck response than for the treadle-press response, but appreciable bursting did occur for the treadle-press response in several cases. All birds except P6 showed more bursting for the treadle-press response than the key-peck response under the 5-sec schedule value. As schedule value increased, bursting did not systematically change for the treadle-

press response, key-peck bursting seemed to increase and then, in some cases, decrease.

All birds, except P8, emitted more treadle-press responses per reinforcement under the 5-sec schedule value. As schedule value increased, responses per reinforcement increased for both operants, with the key-peck response increasing at a faster rate. All birds emitted fewer key-peck responses per reinforcement under the 60-sec schedule value than under the 40-sec schedule value, while three of four birds emitted fewer treadle-press responses per reinforcement under the 120-sec schedule value than under the 60-sec schedule value.

Figures 10 and 11 present the relative frequency distributions of IRTs for both operants. The key-peck distributions were lower at small IRTs and higher in the reinforced region than the treadle-press distributions under the 5-sec schedule value. However, the treadle-press distributions had more very long IRTs (open symbols) than did the key-peck distributions. As the schedule value increased, the functions for both responses tended to become monotonically decreasing. The major difference between the two operants was the large percentage of treadle-press responses terminating very long IRTs, and the greater concentration of IRTs around the schedule value for the key-peck response under low schedule values.

The IRTs/Op distributions (Anger, 1956) are presented in Figure 12. The IRTs/Op functions for the key-peck response showed an increase as time since the last response increased for most cases. This effect was consistent and large for the 5-, 10-, and 20-sec schedule values and weakest at the 40-sec schedule value. The IRTs/Op was low at the small class intervals for small schedule values. With increases in schedule value, the IRTs/Op value at the small class intervals increased for both operants.

The IRTs/Op functions for the treadle-press response increased as time since the last response increased at the 5-sec schedule value. At other schedule values, the curves were usually low and flat. Only for P8 at the 120-sec schedule value was the change in IRTs/Op, as a function of time since the last response for the treadle-press response, as large as for the key-peck response.

Figure 13 presents the group data for Experiments I and II for the dependent measures

Fig. 9. Mean responses per reinforcer and mean proportion of IRTs shorter than 1 sec for the key response and the treadle response as a function of schedule value. The ordinate for the responses-per-reinforcer function and the abscissa for both functions are plotted as log scales. Each point is the mean of the last four sessions.

Fig. 10. Relative frequency distributions for the key response and the treadle response. Each class interval is one tenth of the schedule value. All IRTs to the right of the vertical, dashed lines were reinforced. The right-most filled symbol in each function is the fifteenth class interval or the largest class interval with at least 1% of the total responses. The open symbols show the per cent of the total responses not included in the functions. Each point is the mean of the last four sessions. N = number of key-peck IRTs, number of treadle-press IRTs.

of response rate, reinforcement rate, responses per reinforcement, and proportion of IRTs shorter than 1 sec. The form of these functions was approximately the same for both the concurrent and the single-operant procedures. There were, however, some differences in absolute value. Bursting did not systematically vary as a function of schedule value for the treadle-press response. More bursting occurred with the key-peck response at all schedule values under both procedures except for the 5-sec schedule value under the one-operant pro-

cedure. Key-pecking bursting increased as a function of schedule value under the concurrent procedure but, except for the 5-sec schedule value, remained constant over schedule values for the one-operant procedure. Key-peck response rate was higher under the concurrent procedure than under the one-operant procedure at all schedule values except the 40-sec value, where the concurrent and one-operant procedures had the same response rate. Treadle-press response rate was lower under the concurrent procedure at the 5-, 40-, and

Fig. 11. Relative frequency distributions for the 60- and 120-sec schedule values. Details are the same as for Figure 10.

60-sec schedule values and was the same for both procedures at the 10- and 20-sec schedule values. Reinforcement rate was lower under the concurrent procedure for both responses at the 5-, 10-, and 20-sec schedule values. The key-peck response had a higher reinforcement rate under the concurrent procedure at the 40- and 60-sec values, while the treadle-press response had approximately equal reinforcement rates under both procedures at the 40- and the 60-sec values.

The left panels of Figure 14 present the mean key-peck response rate on the ordinate and mean treadle-press response rate on the abscissa for individual birds and the group data of Experiment II. The straight lines represent the least-squares fit of linear functions to the data. Analysis of variance showed the

linear functions to account for a significant ($p < 0.05$) portion of the variance for all functions, except that of P7. The Pearson product-moment correlation coefficient (r) ranged from 0.62 to 0.95 for the individual birds and was 0.83 for the group data. The regression equation is presented for each set of data.

The right panels of Figure 14 present mean key-peck reinforcement rate on the ordinate and mean treadle-press reinforcement rate on the abscissa for individual birds and the group data. Both axes are plotted as logarithmic scales. The straight lines represent the least-squares fit of linear functions to the logarithmic transformation of the data. Analysis of variance showed the linear functions accounted for a significant ($p < 0.025$) portion of the variance in each case. The value of r ranged from 0.87 to 0.98 for the individual data and was 0.92 for the group data. The regression equation is presented for each set of data.

The reinforcement rate data were also analyzed without the logarithmic transformation. The slopes were all significant and r was only slightly affected by the logarithmic transformation. The functions were plotted as logarithmic scales simply as a matter of convenience. The data do not indicate that the logarithmic transformation (power functions) provide a better fit than the untransformed data (linear functions).

Similar analyses for the responses-per-reinforcer dependent measure (data not shown) found only P5 had a significant r ($p < 0.01$) for the untransformed data, while all birds except P8 had a significant r ($p < 0.01$) with the logarithmic transformation, r ranging from 0.59 to 0.92. Also, the group data analysis showed r to be significant ($p < 0.01$) with an r of 0.78. Thus, a power function provides a better fit for the responses-per-reinforcement dependent measure.

The sequential dependency analysis described in Experiment I was performed on the data from Experiment II. To perform this analysis, the data for key-pecking from the last four sessions at a given schedule value were merged with the data for treadle pressing from the last four sessions at that schedule value for each bird. In those cases where the session lengths were different for the key-peck and the treadle-press training, the data from the longer sessions were truncated so that the data analyzed were of equal duration for both

Fig. 12. IRTs per opportunity distributions for the key response and the treadle response. Each class interval width is one tenth of the schedule value. All IRTs to the right of the vertical, dashed line were reinforced. The right-most point in each function is the fifteenth class interval or the largest class interval with more than 20 opportunities. Each point is the mean of the last four sessions.

operants. That is to say, the data were artificially merged based on IRTs to produce a sequence of key pecks and treadle presses as though they had occurred concurrently in time. The analysis showed significant dependencies ($p < 0.05$) in this contrived sequential data for all birds at all schedule values (the data from replications were not analyzed) using lags 1 through 10. Some cases showed as few as two significant z-scores, while P5 at the DRL 120-sec schedule value had 15 significant z-scores. Although we know of no way to perform a quantitative analysis there seem to be as many apparent "sequential dependencies" in these contrived concurrent data as in the actual concurrent data of Experiment I.

DISCUSSION

The results of Experiment II were similar to those of Experiment I. Although there were

some differences between key pecking and treadle pressing, several dependent measures were similar functions of schedule value for both operants, and regression equations permitted prediction of treadle pressing from key pecking. The presence of apparent sequential dependencies in the data of Experiment II indicates that the sequential dependencies observed with the concurrent schedule do not indicate a behavioral dependence.

GENERAL DISCUSSION

The concurrent schedule seems to be adequate for simultaneously determining functional relations for two operants. In general, the findings seem to be the same as in the single-operant procedure. The sequential dependencies found, where, behaviorally, none could exist, indicate the inadequacy of the analysis for deciding the independence of the

Fig. 13. Group graphs of key behavior and treadle behavior for response rate, reinforcement rate, responses per reinforcer, and proportion of IRTs shorter than 1 sec as a function of schedule value. Each point is the mean of all birds over the last four sessions of each condition. All axes are plotted as log scales except for the ordinate of the proportion of IRTs shorter than 1 sec figures.

two operants where the null hypothesis is that the simple probability and the conditional probabilities are the same. The appropriate null hypothesis is that the amount of sequential dependency is the same for the concurrent situation as for a contrived sequence with no possibility of behavioral dependence. Experiment II showed that such statistical dependencies were found even when the components of the artificial sequence did not come from a concurrent training situation. The reason for the existence of sequential dependencies in artificially merged data is not known, but it seems that the schedule may result in some pattern of responding in each operant such that when the two are merged some statistical sequential dependencies are created. This must be due to the independent influence of the schedule on the behavior, not to the influence

Fig. 14. The relation between key and treadle behavior for response rate (left column) and reinforcement rate (right column) for individual birds and group data. Details are the same as for Figure 5.

of one operant on the other. Thus, the sequential dependencies should be derivable from basic aspects of the influence of the DRL schedule on behavior.

The present studies sought to determine the adequacy of the key-peck response for determining general laws of behavior by comparing the key peck with the treadle press in a standard laboratory situation under the DRL schedule of food reinforcement. The general strategy was to determine if the two responses would react the same to manipulation of schedule value. To assess this, the functional

relationships for different dependent measures were determined. In general, the relationships were the same for both operants: response rate and responses per reinforcer increased with schedule value while reinforcement rate decreased. Regression equations permitted prediction of response rate, responses per reinforcer, and reinforcement rate of one response given the other response. These results and those of McSweeney (1975) support each other. McSweeney had pigeons press a treadle under several concurrent VI VI schedules of food presentation and found both positive and negative behavioral contrast, as well as compliance of the behavior with the matching law. Similar results have been obtained with key pecking, so it seems that key pecking and treadle pressing obey the same general laws in this situation.

Bursting was generally greater for the key response and a greater amount of key-peck bursting occurred under the concurrent procedure. The direct strengthening of pecking by food presentation could account for the greater amount of key-peck bursting found under the concurrent procedure. The combined reinforcement density of the key peck and the treadle press in the concurrent situation was greater than the reinforcement density for the key alone in the single-operant procedure. If elicited pecks are likely to occur as bursts and are a positive function of reinforcement density, the difference in amount of bursting would be explained.

Another comparison of interest is the degree of temporal control shown by each operant. The IRT and the IRTs/Op distributions showed that temporal control, in terms of peaking of the distributions in the reinforced region, was more pronounced for the key-peck response. In this sense, the key peck was more sensitive to the delay contingency than the treadle press. The key-peck response also had a higher reinforcement rate under the 5-sec schedule value for both procedures. At higher schedule values, the treadle-press response had a higher reinforcement rate, but this resulted from extremely long IRTs not found with the key-peck response; it was not the result of a more precise temporal discrimination. The treadle IRTs are, in many cases, distributed in a manner indicating little temporal control, but resulting in a high reinforcement rate relative to the key.

It is reasonable from an evolutionary point of view to expect a response system as biologically important to the organism as the peck is to the pigeon, to have developed sensitivity to many environmental variables, including temporal events. Pigeons, however, feed in a group situation where a high rate of pecking gets the most grain, another selective pressure. When tested under the DRL contingency, a contingency that probably never occurs in the natural environment, the two tendencies are in opposition. The temporal discrimination is present, but the birds often peck too soon. The foot press, less biologically important, shows little or no temporal discrimination, and the IRTs are often much longer than required.

It is of interest to compare the temporal discrimination data with the responses-per-reinforcement measure. Hemmes (1975) concluded that the key-peck response was not susceptible to control by response-delay contingencies. This conclusion was based on the observations that, in her data, key response rate did not decrease as a function of schedule value and that the responses-per-reinforcer ratio was higher for key pecking than for treadle pressing. The present data did show more responses per reinforcer for the key, but the key response rate clearly decreased as schedule value increased—a general finding (Kramer and Rilling, 1970). The failure of the study by Hemmes to find differences in key response rates as a function of schedule value was probably due to the small number of training sessions (four) at each schedule value. In general, responses per reinforcement or other measures of “efficiency” are not adequate indicators of the degree of temporal discrimination, as the present data showed. The conclusion by Hemmes that the key peck is subject to “non-operant” sources of strengthening not found with the treadle press may be true but, if so, this did not diminish the predictability of treadle pressing from key pecking.

Several other investigators have reported differences among operants, including the key peck, which they suggest may prevent generalizing from one to another. Schwartz and Williams (1972) argued that pecking is susceptible to sources of strengthening in addition to the scheduled contingencies of reinforcement. Segal (1972) proposed that differences in responding might be expected as a

function of different sources of induction of operants. Segal considers the key peck to be induced by releasing stimuli that "may or may not show some continuing control" (Segal, 1972, p. 22). The treadle press, induced by reinforcement, is thought not to be subject to such influences. Seligman (1970) suggested that differences in responding might occur as a function of the "preparedness" of animals to associate particular stimuli and responses. The pigeon would be expected by virtue of its evolutionary history to be prepared to associate pecking with food, but unprepared to associate food with pressing a treadle.

Certainly, special qualities of the key peck have been demonstrated and plausible explanations of these qualities have been offered. Further contributions to the literature may even document and explain special qualities of other operants. The question of generality, however, is basically an empirical one, and it is concerned with predictability. The present data show that, while differences in responding were found as a function of the operant, these differences did not prevent generalizing from the key peck to the treadle press on several response measures. The data strongly suggest that there are no peculiarities of key pecking that greatly diminish its generality under DRL schedules of reinforcement.

A study by Ayres, Benedict, Glackenmeyer, and Matthews (1974) is relevant to the differences between operants seen in the present study. Ayres *et al.* found some similarities and some differences in rats between head poking (thought to be a species-specific defense reaction and therefore "prepared") and lever pressing to avoid shock in free-operant avoidance paradigm. The differences that were found, moreover, "did not appear related to the responses *per se*, but seemed due to variables inadvertently confounded with response topography" (Ayres *et al.*, 1974, p. 378). Differences between the two operants were eliminated by altering the experimental apparatus.

Some of the differences between the two operants in the present study might also be reduced by changing the apparatus. The differences in response rate could probably be reduced by increasing the force or excursion requirement of the key; it may also be possible to construct a treadle that would result in higher rates of responding. Hemmes (1975) reported that no noncriterion responses to the

treadle were observed (responding to the treadle was described as a "circumscribed" event) and concluded that manipulating the force requirement of the treadle would not affect responding. The birds in Experiment I were observed during approximately 30 sessions throughout the experiment and were frequently observed to make noncriterion responses to the treadles, often making several responses in rapid succession, some of them being recorded and others not. In addition to noncriterion responses made with the feet to the treadle itself, many responses were made with feet, wings, and beak to the box from which the treadle extended. Klein and Rilling (1972) also observed rapid sequences of treadle pressing in pigeons. It seems likely, therefore, that altering force and excursion requirements, and possibly the dimensions of the treadle apparatus, would affect the rate of responding to the treadle.

Even if such manipulations produced equal response rates, this would be of no importance. Making the response rates of two operants equal would not make the operants equivalent. It does not even provide a good basis for equating for rate-dependent effects, because rate dependency functions may differ for different response systems. The problem involved in comparing two response systems within a species has much in common with the problem in comparative psychology of making between-species comparisons. How can all controlling variables, except the one of interest, be equated? They probably can not be in any direct fashion. Equating the key and treadle response rates under a given condition does not validate other comparisons any more than equating the response rates of a pigeon pecking, a rat lever pressing, and a human pushing a button.

Hemmes (1975) concluded that key pecking is not susceptible to control by response-delay contingencies and that her data "join a growing body of literature which indicates that treadle pressing in pigeons is more comparable to the operant behavior shown by other species than is keypecking" (pp. 355-356). The present data do not support such a conclusion. In fact, the IRT and IRTs/Op distributions show more precise temporal discrimination for the key peck than the treadle press. Also, Richardson and Loughhead (1974) trained pigeons to peck a key under DRL schedules

ranging from DRL 1-min to DRL 45-min, and obtained correlation coefficients between mean IRT and DRL value ranging from 0.96 to 0.99, as well as IRTs/Op functions that increased as a function of time since the last response in some cases. The evidence indicates that for the DRL schedule there are no special qualities peculiar to the key peck which preclude its use in a science whose objective is to discover general laws of behavior.

Even if the differences that were found between the two responses were regarded as significant, there is no indication of which response would be more suited for behavioral research. The question is basically concerned with which response has greater generality—an empirical question requiring the study of other responses. Undoubtedly, different response systems, different requirements within response systems (*e.g.*, force, excursion), different species, *etc.*, will all show some differences when closely compared. The task at hand is to decide if observed differences are important enough to warrant research effort and, if so, whether observed differences can be explained in a systematic fashion, allowing a correction factor to be included in statements of generality.

REFERENCES

- Anger, D. The dependence of interresponse times upon the relative reinforcement of different interresponse times. *Journal of Experimental Psychology*, 1956, **52**, 145-161.
- Ayres, J. J. B., Benedict, J. P., Glackenmeyer, R., and Matthews, W. Some factors involved in the comparison of response systems: acquisition, extinction, and transfer of head-poke and lever-press Sidman avoidance. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 371-379.
- Brown, P. and Jenkins, H. M. Auto-shaping of the pigeon's key peck. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 1-8.
- Force, D. D. and LoLordo, V. M. Signalled and un-signalled free-operant avoidance in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 283-290.
- Hemmes, N. S. Behavioral contrast in pigeons depends upon the operant. *Journal of Comparative and Physiological Psychology*, 1973, **85**, 171-178.
- Hemmes, N. S. Pigeons' performance under differential reinforcement of low rate schedules depends upon the operant. *Learning and Motivation*, 1975, **6**, 344-357.
- Keller, K. The role of elicited responding in behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 249-257.
- Klein, M. and Rilling, M. Effects of response-shock interval and shock intensity on free-operant avoidance responding in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 295-303.
- Kramer, T. J. and Rilling, M. Differential reinforcement of low rates: A selective critique. *Psychological Bulletin*, 1970, **74**, 225-256.
- LoLordo, V. M., McMillan, J. C., and Riley, A. L. Effects upon food-reinforced pecking and treadle-pressing of auditory and visual signals for response-independent food. *Learning and Motivation*, 1974, **5**, 24-41.
- McSweeney, F. K. Matching and contrast on several concurrent treadle-press schedules. *Journal of the Experimental Analysis of Behavior*, 1975, **23**, 193-198.
- Richardson, W. K. and Loughhead, T. E. Behavior under large values of the differential-reinforcement-of-low-rate schedule. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 121-129.
- Schwartz, B. and Williams, D. R. Two different kinds of key peck in the pigeon: some properties of responses maintained by negative and positive response-reinforcer contingencies. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 201-216.
- Scull, J. and Westbrook, R. F. Interactions in multiple schedules with different responses in each of the components. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 511-519.
- Segal, E. F. Induction and the provenance of operants. In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement: behavioral analyses*. New York: Academic Press, 1972. Pp. 1-34.
- Seligman, M. E. P. On the generality of the laws of learning. *Psychological Review*, 1970, **77**, 406-418.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Skinner, B. F. Operant behavior. In *Contingencies of reinforcement: a theoretical analysis*. New York: Appleton-Century-Crofts, 1969. Pp. 105-132.
- Smith, R. F. and Keller, F. R. Free-operant avoidance in the pigeon using a treadle response. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 211-214.
- Staddon, J. E. R. and Simmelhag, V. I. The superstition experiment: A re-examination of implications for the principles of adaptive behavior. *Psychological Review*, 1971, **78**, 3-43.
- Westbrook, R. F. Failure to obtain positive contrast when pigeons press a bar. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 499-510.
- Williams, D. R. and Williams, H. Automaintenance in the pigeon: sustained pecking despite contingent non-reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 511-520.

Received 10 January 1975.

(Final Acceptance 13 May 1976.)