TITRATION OF SCHEDULE PARAMETERS BY PIGEONS¹

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Pigeons were tested in a computer-controlled two-key chamber. A standard (nonchanging) schedule of reinforcement was in force on one key, and an adjusting schedule on the other. The schedules were available concurrently after each reinforcement, but after the first peck on either key (the choice peck), the schedule on the other key was made inoperative. The parameter of the adjusting schedule was decreased when the standard schedule was chosen and increased when the adjusting schedule was chosen. The standard schedule was changed only between sessions. Fixed intervals and fixed ratios were used as standard schedules, and intervals and ratios were used as adjusting schedules. When standard and adjusting schedules were of the same type, median parameters on the adjusting key equalled those of the standard schedules, at four values of each standard schedule. For four of five birds, and for the group median, similar curves could be plotted through the indifference points obtained from a standard ratio with an adjusting interval, and from a standard interval with an adjusting ratio. These points showed consistent individual differences, but they could be predicted by assuming that the median time from the choice peck to reinforcement should be the same on both keys. This is equivalent to treating the schedule as a concurrent chain and assuming that Herrnstein's quantitative law of effect applies.

Key words: titration, indifference curve, adjusting schedule, fixed ratio, fixed interval, matching law, concurrent chains, key peck, pigeons

There are two major ways of describing how a subject's preference between two situations varies with some parameter. One is to plot degree of choice as a function of the parameter. The other is to stipulate a degree of choice, and plot the parameter values that yield it. The resulting function is called an indifference curve or isoutile, and it is a common tool of economic analysis. But it has been used only rarely in the analysis of animal behavior (*e.g.*, Christensen, 1962; Logan, 1965), no doubt because the usual techniques for studying preference in animals (concurrent schedules, see Catania 1966; concurrent chains, see Autor 1969) are designed to give degrees of choice. They are, therefore, highly inefficient as means

of obtaining indifference points, since the stipulated degree of choice will be observed only occasionally.

The same two sorts of descriptive functions are used in psychophysics; a degree of preference curve corresponds to a psychometric function, and an indifference point to a point threshold. A quick and efficient method of finding point thresholds is titration, introduced by Békésy (1947) and Oldfield (1949). Titration procedures have been used widely with animals since the pioneering work of Blough (1955, 1958); see review by Rosenberger (1970). The procedure has been applied to preference in four connections: escape performance (Weiss and Laties, 1958, 1970; however, their results were connected with perception of pain rather than preference), punishment (Rachlin, 1972), intracranial self-stimulation (Stein and Ray, 1959), and determining the maximum cost of switching between two schedules (Verhave, 1963). The present paper describes an attempt to use it in the study of choice by pigeons between schedules of food reinforcement.

The procedure was similar to that used by Hodos and Trumbule (1967) with chimpanzees. A choice was offered between an unchanging schedule (here called a *standard*) and

¹The computer software used in the control of this experiment was written by the author with the support of grant number G970/297/B from the United Kingdom Medical Research Council to Mr. A. J. Watson, in collaboration with Mr. C. K. Crook. I should like to thank Mr. D. J. Nicholas and Miss A. Cauty, who tested the subjects from time to time, and Dr. M. J. Morgan who read preliminary versions of this paper. The results of this experiment were presented to the meeting of the Experimental Psychology Society at Stirling, July 1974. Reprints may be obtained from the author, The Psychological Laboratory, University of Cambridge, Downing Street, Cambridge CB2 3EB, England.

an *adjusting* schedule. Choice of the adjusting schedule caused it to be adjusted upwards in parameter value by one unit, and choice of the standard schedule caused the adjusting parameter to be adjusted downward. As is usual in psychophysical titrations, the downward adjustment was by one unit only, whereas in Hodos and Trumbule's procedure the adjusting value reset to its minimum.

The optimal strategy, *i.e.*, the strategy that maximizes reinforcements per hour or per response, is to choose the standard schedule repeatedly until the adjusting schedule is at its minimum, and then to alternate. The titration would then yield schedule values between which the subjects would not be indifferent in a nontitration situation. The titration may be judged to be valid if (i) the subjects choose the two schedules equally: this demonstrates indifference in the titration situation, and (ii) the schedule value resulting from the titration is one that the subject would treat as indifferent from the standard schedule in a nontitration situation. The first condition may be tested directly; the second may be tested by using standard and adjusting schedules of the same type, when the adjusting schedule should be set equal to the standard. Hodos and Trumbule found that their chimpanzees violated condition (ii). Note that conditions (i) and (ii) are independent: roughly equal choice of the two keys would occur even if exactly the optimum strategy were followed, provided that the session was long enough for the initial run of choices of the standard schedule to affect overall choice probability negligibly; and exactly equal choice of the two schedules could occur with a roughly optimal strategy, and indeed with a wide variety of patterns of behavior.

A further test of validity is possible if standard and adjusting schedules of different types are used. In the present experiment, tests were conducted using an adjusting interval with a standard fixed-ratio schedule, and then using an adjusting ratio with a standard fixed interval. Both procedures ought to give the same information about what ratio the birds regard as indifferent to a given interval. If they do not, the titration procedure is suspect.

METHOD

Subjects

Five London pigeons were maintained at 80% of their caged free-feeding weights.

Apparatus

A commercial pigeon operant chamber (Campden Instruments Ltd., London, Model 417/A) was housed in an air-conditioned room with other similar apparatus. It contained a solenoid-operated grain feeder and two pecking keys that operated sealed-reed switches when pressed with 3.5 g weight (0.035 N) at their centres. The keys could be transilluminated with white light from inline projectors. The chamber was controlled by a digital computer via a distribution panel in a neighboring room, where performance was monitored on a cumulative recorder and electromagnetic counters. White masking noise was present in the chamber and room at all times.

Procedure

The pigeons were trained to peck both keys by successive approximation, exposed to short fixed-ratio and fixed-interval schedules of reinforcement, and then trained in the choice procedure that was used in the rest of the experiment. A standard schedule, which changed only between sessions, was in force on one key, and an adjusting schedule, the parameter of which changed after each reinforcement, was in force on the other. At the beginning of the session, and after each reinforcement, both keys were lit and both schedules were available. The first peck on either key (the choice peck) darkened the other, and reinforcement could then be obtained only by completing the schedule arranged on the key first pecked. The schedules were either fixed interval (FI) or fixed ratio (FR): intervals were timed from the end of the previous reinforcement, and the choice peck counted towards the ratio schedule.

Reinforcement was 4-sec access to wheat grain and was accompanied by illumination of the feeder aperture. Both keys were dark during reinforcement and at the end of the session, which came after 61 reinforcements. The adjusting schedule was in force on the right-hand key and was set to either FI 30-sec or FR 36 at the start of each session. The standard schedule was in effect on the left-hand key and was either FI 30-sec or FR 36. The adjusting schedule parameter was multiplied by 1.5 after every reinforcement earned on the adjusting key, and divided by 1.5 after every reinforcement earned on the standard key (geometric

Table 1

Sequence of experimental conditions. The standard schedule was the same throughout each session except P1. The adjusting schedule was of the same type (interval or ratio) throughout each session, but its parameter was increased whenever it was chosen and decreased whenever the standard schedule was chosen; the changes were by a constant (arithmetic adjustment) or by a constant factor (geometric adjustment). Where a condition is not mentioned in the "Comments" column for a particular block of sessions, it did not change from the previous block.

<i>Session Numbers</i>	<i>Standard Schedule</i>	<i>Initial Value of Adjusting Schedule</i>	<i>Comments: Changes from Previous Session Block</i>
P1	FI 3 to 30-sec	FI 3-sec	Arithmetic adjustment by 0.5 sec. All schedule parameters were manipulated as the subject's adaptation to the schedule allowed. Adjusting schedule on left key.
P2	FI 30-sec	FI 30-sec	Further pretraining. Arithmetic adjustment by 5 sec.
1-20	FI 30-sec	FI 30-sec	As P2. Data collected from here on.
21-40	FI 30-sec	FI 30-sec	Geometric adjustment by 1.5 from here on.
41-96	FI 30-sec	FI 30-sec	Adjusting schedule on right key from here on.
97-104	FI 30-sec	FI 8/102-sec	Initial value of adjusting schedule 8 sec or 102 sec on alternate sessions.
105-114	FI 30-sec	FI 30-sec	
115-126	FI 9/20/45/102-sec	FI 30-sec	Three consecutive daily sessions at each of the four standard intervals (Test series 1).
127-146	FI 30-sec	FI 30-sec	Baseline recovery.
147-176	FR 36	FI 30-sec	
177-188	FR 11/24/54/130	FI 30-sec	Test series 2; cf. test series 1.
189-198	FR 36	FI 30-sec	
199-218	FI 30-sec	FR 36	
219-230	FI 9/20/45/102-sec	FR 36	Test series 3; cf. test series 1.
231-245	FI 30-sec	FR 36	
246-265	FR 36	FR 36	
266-277	FR 11/24/54/130	FR 36	Test series 4; cf. test series 1.
278-287	FR 36	FR 36	

adjustment). There were some exceptions to these rules, as listed in Table 1. Note that at the beginning of the experiment, the adjusting schedule was in force on the left key and the adjustment was arithmetic (increase or decrease by 5 sec).

Sessions were occasionally terminated early if the adjusting parameter had been driven to a high value and the bird was persistently choosing the adjusting key, the criterion of "high" varying according to the bird and the stage of the experiment. If the adjusting parameter reached a ratio of one or an interval of 1 sec, it was not further reduced by further choices of the standard key.

In all sessions except the first two on the titration procedure (P1 and P2), a record was made after each reinforcement of: the latency of the first peck, and the first key pecked, after

the previous reinforcement (postreinforcement pause and schedule chosen); the time since that first peck (postchoice interval); and the number of responses made on each key since the previous reinforcement.

Table 1 lists the conditions that were used. They may be summarized as follows. The experiment began with exploratory sessions (1 to 104) to assess the effects of varying the rule used for changing the adjusting parameter, the location of the adjusting key, and the initial value of the adjusting parameter. Four test series followed. Before each, a baseline was established, using the same standard schedule for at least 10 sessions. In the test series proper, three consecutive sessions were given at each of four values of the standard schedule parameter. An attempt was then made to recover the baseline over at least 10 sessions. There was one

test series with each of: fixed interval (standard)—fixed interval (adjusting); fixed ratio (standard)—fixed interval (adjusting); fixed interval (standard)—fixed ratio (adjusting); fixed ratio (standard)—fixed ratio (adjusting). In each test series, the order of presentation of the four standard schedules was different for different birds.

Sessions were normally conducted five days a week; the 289 sessions described in Table 1 were spread over 17 months. The order of the test series was chosen so that the series here labelled 2 and 3 should be consecutive, since a comparison of their results was needed.

RESULTS

The results are presented in terms of the median schedule parameter on the adjusting key. The medians include only the values of the adjusting parameter from trials when the

adjusting schedule was chosen, for only these values were experienced by the pigeon.

A. *Exploratory phase.* Figure 1 shows the median adjusting interval chosen in Sessions 1 to 136; that is, up to the first 10 baseline recovery sessions following test series 1. In all these sessions, the standard schedule was FI 30-sec, and the adjusting schedule was an FI. It is plain that all birds tended to set the adjusting value above the standard value (indicated by the horizontal line), whether the rule of adjustment was arithmetic or geometric (compare Sessions 1 to 20 with 21 to 40); whether the adjusting schedule was on the left or right key (compare Sessions 21 to 40 with 41 to 96); and whatever the initial value of the adjusting interval (Sessions 97 to 104). There is some sign of a drift toward 30 sec in the long series with geometric adjustment on the right key, and after test series 1 the median adjusting interval chosen tends to be at or below 30 sec. The data

Fig. 1. The median value of the adjusting interval chosen in Sessions 1 to 136. The standard schedule was FI 30-sec and the adjusting schedule was an interval. Note the logarithmic scale on the ordinate. Each point is the median over a block of five sessions, except in Sessions 91 to 96 (six sessions); and 97 to 104 (four sessions).

do not permit a conclusion as to whether that is a result of the interpolation of the test series or a continuation of the drift just mentioned. Note that the difference between the standard interval and the median adjusting interval chosen does not imply that the two schedules were chosen to different extents. In fact, as discussed below, they were chosen equally often. Inequality of the schedules arises if a sequence of choices of the adjusting schedule precedes an equally long sequence of choices of the standard schedule.

Figure 2 shows the relative frequency of alternated choices across the same group of sessions, and the 95% confidence limits within which the data for all five birds should lie if there are no sequential dependencies in the choices. It can be seen that initially, all birds chose the key on which they had last received reinforcement, as would be expected on the basis of data obtained by Findley (1958, pp. 131ff) from pigeons and Morgan (1974) from rats. By Session 96, repetition was replaced by

alternation, except for Bird 30. Alternation would necessarily stabilize the value of the adjusting interval, and a spurious match to the standard interval might then result from the two intervals being set equal at the beginning of the session. But in Sessions 97 to 104, the initial value of the adjusting intervals was varied, and the means across session and birds of the median adjusting intervals chosen given initial values of 8 and 102 sec were 50.2 and 56.4 sec. Thus, alternation was not pursued without regard to the current value of the adjusting interval.

It is plain from Figure 2 that there was no tendency to alternate during the phase of arithmetic adjustment, except perhaps for Bird 42. It was common during this phase for birds to choose the adjusting key repeatedly, thus driving the adjusting interval up to high values. There was no tendency for it to come down again, and the result was often extinction within the sessions; the session then had to be aborted. Such persistent choice of the

Fig. 2. The relative frequency of choosing the key through which the last reinforcement was not obtained. Data are shown for Sessions 1 to 136, taking means over the same session blocks as in Figure 1, and over each standard interval in test series 1. The standard and adjusting schedules were both intervals. The broken lines mark the 95% confidence limits within which data for all five birds should lie on the null hypothesis that the true probability of alternation is 0.5.

adjusting key was much less common under geometric adjustment, though it still occurred occasionally throughout the experiment, especially following any disturbance. Recovery at the beginning of the next session was always immediate.

Fig. 3. Median value of the adjusting schedule parameter chosen as a function of the standard schedule, in all four test series. Each point gives data from the last of three consecutive sessions at a given standard schedule. The broken lines represent equality of the standard and median chosen adjusting schedule parameters; the continuous lines join the medians across birds. Note that both coordinates have logarithmic scales, and that the adjusting schedule parameter changed by a factor of 0.5 (a constant on these scales) after each choice.

B. Test series. The indifference points obtained in the four test series are shown in Figure 3. Each data point represents the median value of the adjusting schedule parameter chosen by a single bird in a single session, the last of a block of three with the same standard schedule. The solid lines connect the median values averaged over the five birds. The straight lines on the graphs for test series 1 and 4 are theoretical curves in which the

median adjusting schedule parameter chosen equals the standard schedule parameter.

In Figure 4, the data from test series 2 and 3 are replotted to allow comparison between the indifference points obtained when fixed intervals were titrated against a standard fixed ratio (test series 2) and when fixed ratios were titrated against a standard fixed interval (test series 3). The variable plotted on the X-axis is the FR schedule parameter, which in test series 2 was the independent variable (the standard ratio set), but in test series 3, was the dependent variable (the median adjusting ratio chosen).

Figures 5, 6, and 7 show the relation between the interreinforcement intervals (Figure 5), postchoice intervals (Figure 6), and the number of responses made per reinforcement (Figure 7) on the adjusting and standard sched-

Fig. 4. Indifference points between ratios and intervals obtained by titrating intervals against ratios (filled squares and solid lines) and by titrating ratios against intervals (open squares and broken lines). The median adjusting schedule parameter chosen is plotted against the standard schedule parameter, or *vice versa*. Each point gives data from the last of three sessions with a given standard schedule in test series 2 or 3. Note the logarithmic scale on both axes.

Fig. 5. The median interreinforcement interval on the standard key, when intervals were titrated against ratios (filled squares and solid lines) and when ratios were titrated against intervals (open squares and broken lines). Data are from the same sessions as in Figure 4. Note the logarithmic scale on both axes. The straight lines are those of best fit after the logarithmic transformation.

ules. The data plotted are the medians from trials when the birds chose each schedule, from the same sessions as the data of Figure 4. The figures also show lines of perfect matching, and linear regressions lines of Y upon X (calculated after a logarithmic transformation of both). Statistical comparison of the regression lines is inappropriate, for the variable on the X -axis meets the assumption of zero random variation to different degrees for the two lines on each graph (*cf.* Kendall and Stuart, 1967, p. 414).

DISCUSSION

A. *The exploratory phase: adaptation to the titration schedule.* The validity of the titration procedure in the study of indifference points depends in part on the pigeons choosing the

Fig. 6. The median postchoice interval on the adjusting key as a function of its value on the standard key. Details as for Figure 5.

two schedules equally. A reasonable criterion of indifference would be choice of the adjusting schedule on between 45% and 55% of trials (in practice this means between 28 and 33 of the 61 trials in a session). In Sessions 1 to 20, choice probabilities lay outside these limits 15, 5, 9, 11, and 8 times for the five birds in order. The proportions of the remaining 267 sessions giving choice probabilities outside these limits were 0.07, 0.03, 0.07, 0.02, and 0.05. Thus, after a short adaptation, the birds did interact with the titration procedure to produce a schedule on the adjusting key that they chose just as often as the standard schedule.

The second requirement for validity is that the adjusting schedule should be set equal to the standard schedule where objective equality can be assessed. Optimal behavior, on the other hand, is to set the adjusting schedule below the standard schedule. Figure 1 shows that throughout the exploratory phase, the pigeons tended to set the adjusting interval near but above the standard interval of 30 sec.

Fig. 7. The median number of responses to earn a reinforcement on the adjusting key as a function of its value on the standard key. Details as for Figures 5 and 6.

This is in contrast to the near-optimal behavior of chimpanzees in Hodos and Trumbule's (1967) experiment, in which both standard and adjusting schedules were ratios.

Possibly, the difference in results is due to differences in procedure. In particular, choice of the adjusting ratio in their experiment reset the adjusting ratio to its minimum. As a result, subjects would be forced to experience the lowest values of the adjusting ratio, while in the present experiment low adjusting intervals might never be reached. In practice, they were quite commonly reached in early sessions, but as the medians show (Figure 1), they were not maintained. Increased exposure to lower values of the adjusting interval during the test series might explain the lower median adjusting intervals after test series 1 (compare "baseline recovery" with "baseline" in Figure 1), and the fact that median adjusting intervals did equal standard intervals in test series 1 (see Figure 3), even though they had not before. But both in the present experiment, and in Hodos and Trumbule's, optimal behavior involves choosing the schedule that gives the

longer delay to the next reinforcement. It is plausible that chimpanzees should be more far-sighted than pigeons. No doubt this species difference, if it exists, is only relative, and chimpanzees and indeed men will fail to sacrifice the short-term to the long in some situations—just as pigeons will succeed in doing so given the right opportunities (Rachlin and Green, 1972).

It has already been stated that, given the results from Sessions 97 to 104, the near match of median adjusting interval to standard interval could not have been an artifact of alternation. In any case, the match was not exact in this phase of the experiment. Possibly, the pigeons set the adjusting interval above the standard interval because it varied somewhat; under some conditions, variable-interval schedules are preferred to fixed intervals of the same mean value (Davison, 1969; Herrnstein, 1964).

There is a plausible explanation for the failure to alternate during the phase of arithmetic adjustment. Stubbs (1968) obtained a Weber fraction of 0.4 for 75% correct temporal discrimination by pigeons. On this basis, the pigeons in the present experiment could scarcely have been expected to detect a 5-sec change in the adjusting schedule parameter, even from its initial value of 30 sec, let alone from higher values. Titration with arithmetic adjustment might still work, because the proportional difference between standard and adjusting intervals would become much greater than 0.4 if the pigeon persistently pecked one key. Since arithmetic adjustment tended to produce long runs of choices of the adjusting key, resulting in within-session extinction, it seems that adaptation to the titration procedure depends on discrimination of the sequential properties of the adjusting schedule. This conclusion must be tentative, for the phase of arithmetic adjustment came at the beginning of the experiment, and the improvement when geometric adjustment was introduced was neither sudden nor dramatic.

Although performance under geometric adjustment was generally more stable, median adjusting intervals chosen were no lower than under arithmetic adjustment. But higher adjusting intervals are of course more quickly reached under geometric adjustment.

B. Test series. Three main questions arise from the results of the test series: is titration a valid way of getting indifference points; does it

produce them as quickly as it produces thresholds in psychophysics; and, can the indifference points obtained be predicted from any general principles? The third question concerns, in the first instance, only the results with standard and adjusting schedules of different types (test series 2 and 3).

Figure 3 strongly supports the validity of the titration procedure; statistics relevant to this part of the discussion are collected in Table 2.

(a) The correlation between the median adjusting schedule parameter chosen, and the standard schedule parameter is near unity for every test series. The coefficient used was a version of Kendall's tau that assesses the overall correlation across the group of subjects without the inflation that would be caused by finding the correlation of means: see Jonckheere (1954, especially p. 99).

(b) The theoretical curves account for a high proportion of the variance of the data from test series 1 and 4. The only sign of systematic deviation of the median adjusting schedule parameter chosen from the standard schedule parameter is a slight tendency to undershoot at low standard ratios in test series 4.

(c) There is an intelligible pattern in the concordances (Kendall's W coefficient: see Siegel, 1956) between the four standard sched-

ule values in ordering the birds by the median adjusting schedule parameter chosen. In the two test series in which the standard and adjusting schedules were of the same type, so that there is a theoretical curve to plot in Figure 3, there was no significant concordance; that is, the good fit of the median curve to the theoretical curve did not result from some birds consistently overshooting and others consistently undershooting. Where the standard and adjusting intervals were of different types, however, the concordances were large and significant, indicating that birds differed in the trade-off between ratio and interval schedules: for example, in test series 2, Bird 30 tended to set the adjusting interval relatively high at all ratios, while Bird 43 set it relatively low.

Each data point in Figure 3 is derived from a single session, preceded by only two others with the same standard schedule. It follows that all the evidence that the test series favor the validity of the titration procedure is also evidence that titration can yield indifference points quickly. In fact, the deviations from equality of standard interval and median adjusting interval are no greater in test series 1 than in Sessions 91 to 96, after 50 consecutive sessions with a single standard schedule (compare Figures 1 and 3). On the other hand, extensive training was needed before the pigeons began to alternate or the median adjusting in-

Table 2
Summary Statistics for the Indifference Points Obtained in the Test Series

<i>Test series</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
<i>Adjusting schedule</i>	<i>FI</i>	<i>FI</i>	<i>FR</i>	<i>FR</i>
<i>Standard schedule</i>	<i>FI</i>	<i>FR</i>	<i>FI</i>	<i>FR</i>
Jonckheere's tau between standard schedule parameter and median adjusting schedule parameter chosen	0.97****	1.00****	0.90****	1.00****
Kendall's W concordance between standard schedule parameters in ordering the birds by median adjusting schedule parameter chosen	0.42	0.62*	0.68*	0.05
Proportion of variance accounted for by the theoretical lines joining indifference points (after log transformation).	0.72			0.82

*Significant beyond the 0.05 level.

****Significant beyond the 0.00001 level; two-tailed test.

interval approached 30 sec, so the advantages of titration seem to be greatest where many indifference points are wanted from the same animals.

Figure 4 compares test series 2 and 3, in which the standard and adjusting schedules were of different types. If titration gives indifference points, without interference from properties of procedure as such, we should expect to get indifference points that lie on the same curve, no matter which schedule is used as standard. The two median curves are reasonably close (though not as close as the theoretical and observed medians in test series 1 and 4); on the other hand, there is something odd about Bird 43 and possibly about Bird 34. This test therefore gives only qualified support for the validity of the titration procedure, though it must be remembered that the data being compared are drawn from two test series quite widely separated in time.

Figures 5, 6, and 7 show that the indifference points in test series 2 and 3 can be predicted approximately by assuming that, at indifference, either interreinforcement interval, postchoice interval, or responses per reinforcement are the same on both keys. All three measures yield strong correlations between their values on standard and adjusting keys. The method of Jones and Fiske (1953) was used to amalgamate the significance of deviations from 1.0 for the slopes of the 10 regression lines in each figure. Nonsignificant chi-squares were obtained for all three measures (the values are 22.24, 28.22, and 27.01 for Figures 5, 6, and 7; with 20 degrees of freedom in each case, $p > 0.05$).

Although none of the three measures can be rejected as a basis for indifference, there are reasons for preferring postchoice interval. Table 3 shows for each measure, the proportion of the variance of its values on the adjusting key that is accounted for by the hypothesis that median values chosen were the same on both keys. This proportion is greatest for postchoice interval for all but test series 2. Secondly, over the 16 test conditions (four per test series) and the five birds, a total of 40 cases could be expected in which a measure that was matched on the two keys gave a greater median value on the adjusting key than on the standard key. The observed totals were 17 for the interreinforcement interval, 36 for the postchoice interval, and 21 for responses per reinforcement.

Tentatively, it may be concluded that on all four test series, the birds interacted with the titration procedure to produce schedules on the two keys that had the same median postchoice interval. Since the birds were also indifferent between the two keys, the results are consistent with Herrnstein's (1970) quantitative law of effect, if the schedule is regarded as a concurrent chain (Autor, 1969) in which the initial-link schedule was a fixed-ratio 1. Where interval schedules were arranged, the terminal-link schedule was not completely under the experimenter's control; but since median postreinforcement pauses rarely exceeded 10% of median interreinforcement intervals, the variability of the terminal-link schedule was probably not large.

The small deviations from perfect indifference that occurred in each session cannot be

Table 3

Proportion of variance of adjusting schedule values of three measures accounted for by the hypothesis of equality with standard schedule values. The hypothesis tested is that the median value of the measure on trials when the adjusting schedule was chosen was the same as its median value on trials when the standard schedule was chosen. The data used are those plotted in Figures 5 to 7. The variances were calculated after a log transform.

Measure	Test series	1	2	3	4
	Standard schedule	FI	FR	FI	FR
	Adjusting schedule	FI	FI	FR	FR
(1) Interreinforcement interval		0.72	0.74	0.75	0.90
(2) Postchoice interval		0.76	0.68	0.86	0.92
(3) Responses per reinforcement		0.59	0.49	0.66	0.81

used to explain the deviations from matching in Figure 6. First, because they were too small; second, because the two sets of deviations were not correlated.

Indifference between equal terminal-link schedules in concurrent chains has been demonstrated by Fantino (1967) and Schwartz (1969) for fixed ratios, and Davison and Temple (1973) and Hursh and Fantino (1973) for fixed intervals. No data are available on choice between interval and ratio schedules on concurrent chains; but in simple concurrent schedules, the results of LaBounty and Reynolds (1973) are consistent with equal numbers of responses being made on schedules that yield equal reinforcement rates.

In all these cases, there is reason to think that Herrnstein's (1970) matching law does not hold for relative reinforcement rates other than 0.5 (Duncan and Fantino, 1970; LaBounty and Reynolds, 1973). The present results thus suggest that the law may be useful as a predictor of the direction of choice, even where it fails as a predictor of degree of choice. The titration procedure could be used to see whether matching would still predict indifference correctly if, for example, deprivation or magnitude of reinforcement was varied.

The results are also consistent with Baum's (1974) generalized matching law. Baum suggested that log response ratio should be linearly related to log reinforcement ratio; in the present situation, with response ratio fixed by the procedure at unity, he would predict that the reinforcement rates on the two keys should be related by a straight line of unit slope, and intercept given by the quotient of his "bias" and "undermatching" parameters. Thus, non-unity slopes of the regression lines in Figures 5 and 6 would have refuted Baum's model. In a degree-of-preference experiment, the model can be refuted only by demonstrating non-linearity in the regression of log response ratio on log reinforcement ratio, so the present technique provides a simpler test than has been available hitherto.

There are other models that might be tested, differing in the way in which the various inter-reinforcement intervals (or other measures) in a session are averaged over a session. Unfortunately, so many averaging techniques have been proposed that some of them are bound to yield a match: see the review by Hursh and Fantino (1973).

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Received 3 December 1974.

(Final Acceptance 6 October 1975.)