TESTS OF TRANSITIVITY IN CHOICES BETWEEN FIXED AND VARIABLE REINFORCER DELAYS

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This experiment tested for transitivity in pigeons' choices between variable-time (VT) and fixed-time (FT) schedules. In a discrete-trials procedure, a subject chose between two alternatives by making a single key peck. Each choice was between a "standard alternative," which was the same schedule throughout a condition, and an "adjusting alternative," in which the delay to reinforcement was systematically increased or decreased many times a session. These adjustments enabled an approximate indifference point to be identified—the value of the adjusting delay at which the subject chose each alternative about equally often. Each test of transitivity involved four conditions. In one, the standard alternative was a variable-time schedule with a 2-s reinforcer, and the adjusting alternative also delivered a 2-s reinforcer. A second condition was similar except that the adjusting alternative delivered a 5-s reinforcer. The indifference point from each of these conditions was then converted to a fixed-time schedule for subsequent comparisons in the third and fourth conditions, respectively. Each of these last two conditions compared one of the fixed-time schedules (based upon the previous conditions and including their different reinforcer durations) with an adjusting schedule that delivered the alternative reinforcer duration, to determine whether the obtained indifference points would be those predicted from the prior alternative-duration comparisons with the VT schedule. There was little evidence for intransitivity of choice: Averaged across subjects and replications, the obtained indifference points deviated from perfect transitivity by less than 8%, and these deviations were not statistically significant. These results contrast with those of Navarick and Fantino (1972), who found frequent violations of transitivity between periodic and aperiodic schedules using a concurrent-chains procedure with variable-interval schedules in the initial links.

Key words: transitivity, fixed-time schedule, variable-time schedule, adjusting procedure, reinforcer amount, key peck, pigeons

Over the last 20 years, there have been a number of attempts to develop a general model that can accurately predict animals' choices between periodic and aperiodic schedules. The need for such a model first became evident with Herrnstein's (1964) discovery that pigeons consistently prefer an aperiodic schedule to a periodic schedule with the same arithmetic mean when both schedules are presented as terminal links in a concurrent-chains procedure. Herrnstein suggested that an alternative expression for a schedule's effectiveness might resolve the problem but reported that using geometric means still did not produce an accurate account of his results. Killeen (1968) and Davison (1969) both used a modification of Herrnstein's (1961) matching law in attempts to make more accurate predictions for

choices between fixed and variable schedules. The equation used by these two researchers was:

$$\frac{B_1}{B_1 + B_2} = \frac{F^r}{F^r + \frac{1}{n} \sum_{i=1}^n V_i^r} \quad (1)$$

where B_1 and B_2 are response rates on keys 1 and 2, respectively, in the initial links of a concurrent-chains schedule. F is the size of the fixed-interval (FI) schedule serving as the terminal-link schedule for key 1, and V_i is the size of the i th component of a variable-interval (VI) schedule serving as the terminal-link schedule for key 2. The exponent r was treated as a free parameter. These two studies yielded different values for r : -0.97 for Killeen's study of choice between FI and VI schedules, and -3.0 for Davison's study of choice between FI and mixed-interval (MI) schedules. Duncan and Fantino (1970) argued, on the basis of their own data on preferences between FI and fixed-ratio (FR) terminal links and results from earlier studies, that the exponent r may be

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determined by the shortest interreinforcement interval for either of the two schedules in a choice situation. Navarick and Fantino (1972) used this interpretation to account for intransitivity of pigeons' choices between periodic and aperiodic schedules. If choice between any two terminal links is a function of the shortest interreinforcement interval in either terminal link, they reasoned, then transitivity will not hold if the shortest interreinforcement interval changes substantially from one comparison to another. Navarick and Fantino concluded that if such preferences are intransitive, then a general equivalence rule for periodic and aperiodic schedules must be impossible (see also Navarick & Fantino, 1974, 1975, 1976).

To test for transitivity of preference, Navarick and Fantino (1972) used two procedures, only one of which will be described here. In the first condition of a concurrent-chains procedure, the two terminal links were a VI schedule and a FI schedule. The size of the FI schedule was titrated until the response proportions in the initial links were about 0.5, which was taken as indifference between the two schedules. In the second and third conditions, each of these schedules served in turn as one terminal link, and the other terminal link was a second FI schedule. If the subject's choices were transitive, the response proportions in the initial links should be the same regardless of whether the second FI was pitted against the other FI schedule or the VI schedule. However, Navarick and Fantino found many violations of this prediction, most of which were consistent with the suggestion of Duncan and Fantino (1970) that the exponent r is inversely related to the size of the shortest interreinforcement interval arranged by either terminal link in a given condition. Based on these results, Navarick and Fantino concluded that preferences among periodic and aperiodic schedules are not transitive, and therefore no equivalence rule can successfully predict choices between these two types of schedules.

Although two studies by Navarick and Fantino (1972, 1975) are the only ones to test explicitly for transitivity of pigeons' preferences for aperiodic and periodic schedules, the analyses presented in two more recent articles constitute strong implicit tests of this same property. Rather than testing for transitivity among specific schedules, Killeen (1982) and Mazur (1984) instead presented equivalence

rules that were quite accurate in predicting choices among periodic and aperiodic schedules, contrary to the assertion of Navarick and Fantino that no such rule could be found. Killeen used an equation that successfully predicted the data from several studies involving choices between periodic and aperiodic schedules. Mazur introduced a simple hyperbolic equation that fit his own data from mixed-time (MT), fixed-time (FT), variable-time (VT) and random-time (RT) schedules even more successfully than did Killeen's equation. The procedure Mazur used to collect his data differed from earlier studies in that animals chose between two alternatives by making only a single response that led to immediate entry into the terminal link. Mazur concluded that his data indicated systematic choices between fixed and variable schedules, and that they suggested a single undimensional scale of value for reinforcer delay. Failure of earlier studies to find a generalizable orderly relation between delay and preference, he suggested, could have stemmed from the use of standard concurrent-chains schedules with relatively long initial links.

The present study assessed whether the intransitivity effects reported by Navarick and Fantino (1972) could be obtained with a procedure that used a very brief choice period. The general design of the transitivity tests was similar to that of Navarick and Fantino, but Mazur's (1984) adjusting procedure was used instead of a concurrent-chains procedure with extended choice periods. Because the adjusting procedure required only one response in the initial links, the delay between a response and delivery of its reinforcer was determined almost entirely by the terminal-link schedules. FT and VT schedules were used instead of FI and VI schedules, so the obtained durations of the terminal links equalled the programmed durations.

We had other reasons for attempting to replicate the Navarick and Fantino (1972) results as well. These results are difficult to interpret because of variability and inconsistency in the subjects' behavior. A close examination of their data reveals indifferences in choices between variable-ratio (VR) and fixed-ratio (FR) schedules with equal arithmetic means (e.g., Bird 7, p. 394), animals whose baseline performances were not replicated (e.g., Bird 8, p. 394), possible ceiling effects that could have

generated misleading equivalence points (e.g., Bird 9, p. 394), and substantial key bias (e.g., Bird 5, p. 398). Some of these problems were eliminated in a subsequent experiment (Navarick & Fantino, 1975, Experiment 1), but that study involved only one transitivity test for each of the 4 subjects. An advantage of using Mazur's (1984) adjusting procedure was that one delay was adjusted until the animal chose each alternative equally often, so that ceiling and floor effects were avoided.

The logic of the present transitivity tests was similar to that of the Navarick and Fantino procedure, except that the two periodic schedules differed in the magnitudes of reinforcement they delivered rather than the schedule durations. In each of two conditions, the size of an FT schedule was adjusted until a subject exhibited indifference between that FT schedule and a VT schedule. This VT schedule was the same in both conditions; the conditions differed in that their adjusting schedules entailed different reinforcer amounts. In the next two conditions, the subject again chose between fixed and adjusting FT schedules. The reinforcer amount and delay of the two fixed schedules were equal to indifference values of the previous conditions' adjusting schedules, and the new adjusting schedules had the alternative amounts of reinforcement. If the subject's choices were transitive, its indifference values in the second two conditions should equal the indifference points from the comparisons of the same reinforcer durations in the first two conditions. In an attempt to determine whether any deviations from transitivity were due to random variations or to systematic intransitivity in choice, each transitivity test with a particular VT schedule was repeated three times for each subject.

METHOD

Subjects

The subjects were 4 adult White Carneau pigeons maintained at 80% of their free-feeding weights. All had prior exposure in earlier studies to the adjusting procedure used in the present experiment.

Apparatus

The experimental chamber was 30 cm long, 30 cm wide, and 33 cm high. Three response

keys, each 2.5 cm in diameter, were mounted in the front wall of the chamber, with their centers 8 cm apart and 23 cm above the floor. A force of approximately 0.10 N was required to operate each key, and each effective response produced a feedback click. A hopper below the center key, 5 cm above the floor, was equipped with two 1.1-W white lights, which were illuminated when the hopper was raised to make grain available. Four 6-W lights (two red and two green) were mounted above the white translucent Plexiglas ceiling of the chamber. Two 2-W white houselights were mounted above the ceiling toward the back wall of the chamber. The chamber was enclosed in a sound-attenuating box that contained a speaker producing continuous white masking noise. A PDP-8[®] computer, programmed in Super-SKED[®], controlled the stimuli and recorded responses.

Procedure

The experiment consisted of 24 conditions, arranged by a procedure that consisted of blocks of four trials—two forced trials followed by two choice trials. A session ended when a subject completed 80 trials or when 90 min had elapsed since the start of the session, whichever came first.

Table 1 indicates for each condition the two schedules that functioned as terminal links. Throughout a given condition, one schedule maintained the same delay (or in the case of a VT schedule, the same mean delay) between choice response and food delivery. This schedule, which will be referred to as the standard schedule, was correlated with green keylights and green houselights. The other schedule in each condition will be referred to as the adjusting schedule because its delay might vary from one four-trial block to another depending on an animal's pattern of choices, as described below. Red keylights and houselights were correlated with this schedule. Table 1 also indicates the reinforcer durations for the standard and adjusting schedules in each condition.

Figure 1 diagrams the two sequences of events that could occur on a choice trial. At the start of each trial, a white center keylight was illuminated, as were the white houselights. An effective peck on the center key extinguished the center keylight and illuminated the two side keylights, one red and one green. For all trials, assignment of red and green

Table 1

Schedules of reinforcement, reinforcer durations, mean delays, and number of sessions for each subject in each condition. (All durations are in seconds.)

Condi- tion	Schedule	Rein- forcer dura- tion	Subject 1		Subject 2		Subject 3		Subject 4		Group
			Mean delay	Ses- sions	Mean delay	Ses- sions	Mean delay	Ses- sions	Mean delay	Ses- sions	Mean delay
1	Standard VT	2	23.0	20	23.0	21	23.0	27	23.0	20	23.0
	Adjusting	5	9.1		14.6		16.1		11.1		12.7
2	Standard VT	2	23.0	20	23.0	20	23.0	26	23.0	26	23.0
	Adjusting	2	7.3		8.0		7.6		7.1		7.5
3	Standard FT	5	9.1	21	14.6	20	16.1	24	11.1	22	12.7
	Adjusting	2	5.3		6.4		9.8		4.7		6.5
4	Standard FT	2	7.3	20	8.0	21	7.6	23	7.1	20	7.5
	Adjusting	5	10.5		14.5		12.9		14.6		13.1
5	Standard VT	2	23.0	23	23.0	20	23.0	20	23.0	22	23.0
	Adjusting	2	8.3		6.4		9.5		8.8		8.2
6	Standard VT	2	23.0	27	23.0	22	23.0	21	23.0	23	23.0
	Adjusting	5	19.5		18.3		14.8		18.1		17.7
7	Standard FT	2	8.3	12	6.4	18	9.5	12	8.8	11	8.2
	Adjusting	5	15.9		11.4		18.5		16.2		15.5
8	Standard FT	5	19.5	12	18.3	17	14.8	13	18.1	13	17.7
	Adjusting	2	12.3		7.8		9.6		7.2		9.2
9	Standard VT	2	54.0	12	54.0	16	54.0	13	54.0	17	54.0
	Adjusting	2	13.0		10.5		12.5		12.0		12.0
10	Standard VT	2	54.0	18	54.0	11	54.0	12	54.0	11	54.0
	Adjusting	5	27.3		26.8		31.9		24.9		27.7
11	Standard FT	2	13.0	15	10.5	10	12.5	11	12.0	18	12.0
	Adjusting	5	20.7		17.2		27.9		22.4		22.1
12	Standard FT	5	27.3	11	26.8	12	31.9	12	24.9	13	27.7
	Adjusting	2	16.4		13.4		17.4		13.0		15.1
13	Standard VT	2	54.0	13	54.0	15	54.0	14	54.0	14	54.0
	Adjusting	5	26.0		24.7		31.3		20.9		25.7
14	Standard VT	2	54.0	16	54.0	17	54.0	11	54.0	16	54.0
	Adjusting	2	13.9		13.4		13.6		12.6		13.4
15	Standard FT	5	26.0	10	24.7	11	31.3	15	20.9	11	25.7
	Adjusting	2	16.7		12.5		23.2		9.9		15.6
16	Standard FT	2	13.9	18	13.4	15	13.6	11	12.6	10	13.4
	Adjusting	5	23.5		19.9		32.0		18.2		23.4
17	Standard VT	2	23.0	20	23.0	20	23.0	27	23.0	26	23.0
	Adjusting	5	18.3		17.5		21.3		13.0		17.5
18	Standard VT	2	23.0	18	23.0	10	23.0	12	23.0	18	23.0
	Adjusting	2	10.0		7.4		9.3		7.9		8.7
19	Standard FT	5	18.3	11	17.5	10	21.3	13	13.0	13	17.5
	Adjusting	2	13.2		7.7		14.0		6.2		10.3
20	Standard FT	2	10.0	17	7.4	14	9.3	11	7.9	10	8.7
	Adjusting	5	20.5		13.1		23.0		14.1		17.7
21	Standard VT	2	54.0	20	54.0	24	54.0	23	54.0	21	54.0
	Adjusting	2	16.7		11.4		18.8		14.9		15.5
22	Standard VT	2	54.0	13	54.0	13	54.0	15	54.0	14	54.0
	Adjusting	5	29.5		25.6		31.2		21.1		26.9
23	Standard FT	2	16.7	12	11.4	12	18.8	15	14.9	12	15.5
	Adjusting	5	28.5		18.7		37.8		22.5		26.9
24	Standard FT	5	29.5	13	25.6	12	31.2	10	21.1	11	26.9
	Adjusting	2	17.8		9.1		16.4		12.7		14.0

lights to side keys was determined randomly. A single effective peck on either key extinguished both keylights and the white houselights and illuminated the houselights of the same color as the pecked key. Following a delay determined by the schedule in effect, the hopper was raised to make grain available, the lights above the hopper were illuminated, and the houselights were extinguished. When the hopper retracted, a 15-s intertrial interval (ITI) ensued, during which the white houselights were lit.

The procedure on forced trials was the same as on choice trials, except that only one side key was lit, red or green, and a peck on this key led to the appropriate delay. Of every two forced trials, one involved the red key and the other the green key. The temporal order of these two types of trials varied randomly.

After each block of four trials, the adjusting schedule delay might be changed, depending on the animal's behavior during the two choice trials. If the subject chose the adjusting schedule on both trials, the adjusting schedule delay increased by 1 s for the next trial block. If the subject chose the standard schedule on both trials, the adjusting schedule decreased by 1 s for the next trial block provided the delay was not already 0 s. The adjusting schedule delay remained the same for the next block of trials if the animal chose each schedule once. For the first trial block of a session, the adjusting delay was determined by these rules, based on the subject's last two choices in the previous session.

The first six conditions lasted for a minimum of 20 sessions and the other conditions for a minimum of 10 sessions, with two exceptions. Conditions 17 and 21, in which the size of the VT schedule changed from that of the previous conditions, lasted for a minimum of 20 sessions. After the minimum number of sessions, a condition was terminated for each subject individually when three stability criteria had been met. Beginning with the third session of a condition, sessions were divided into two 40-trial blocks, and for each block the mean delay on the adjusting key was calculated. The three criteria were: (a) neither the highest nor the lowest single-block mean of a condition could occur in the last six blocks of the condition, (b) the mean adjusting delay across the last six blocks could not be the highest nor the lowest six-block mean of the con-

Fig. 1. A schematic diagram of the two series of events that could occur on a choice trial, depending on whether the standard or adjusting key was chosen.

dition, and (c) the mean delay of the last six blocks could not differ from the mean of the preceding six blocks by more than 10% of the former mean or by more than 1 s (whichever was larger). The mean adjusting delay over the six blocks that met these criteria was used as an estimate of the indifference point.

Each test of transitivity involved a set of four consecutive conditions. In two conditions, adjusting FT schedules with different reinforcer amounts were separately compared to the same VT schedule, and in the next two conditions these two FT schedules were compared to each other. The design can be illustrated by considering the first four conditions. In Condition 1, the standard schedule was VT 23 s with a 2-s reinforcer, and the adjusting schedule delivered a 5-s reinforcer. In Condition 2, the standard schedule remained the same, but the adjusting schedule now delivered a 2-s reinforcer. In Condition 3, the standard schedule was now an FT schedule, with its delay equal

	$I_3 < I_2$	$I_3 > I_2$
$I_4 > I_1$	A INTRANSITIVITY OPPOSITE TO NAVARICK & FANTINO PREDICTION	B BIAS FOR THE ADJUSTING KEY
$I_4 < I_1$	C BIAS AGAINST THE ADJUSTING KEY	D INTRANSITIVITY CONSISTENT WITH NAVARICK & FANTINO PREDICTION

I_n = INDIFFERENCE POINT FROM CONDITION n

Fig. 2. The four possible ways the results from Conditions 1 through 4 might deviate from perfect transitivity, and suggested interpretations of these four possibilities. The notation I_n refers to the indifference point obtained in condition n .

to that of the adjusting schedule at the indifference point obtained in Condition 1, and the reinforcer duration was 5 s, which had also been the reinforcer duration for the adjusting schedule in that condition. The adjusting schedule delivered a 2-s reinforcer, which had been the reinforcer for the standard schedule in Condition 1. If the subject's choices were transitive, the indifference points in Conditions 2 and 3 should be the same. Condition 4 was similar to Condition 3, but now the standard FT schedule had a delay equal to that of the adjusting schedule at the indifference point obtained in Condition 2, and it delivered a 2-s reinforcer. The adjusting schedule delivered a 5-s reinforcer, and if choices were transitive the indifference points in Conditions 1 and 4 should be the same. The 24 conditions provided six tests of transitivity for each subject, three involving VT 23 s and three involving VT 54 s. These schedule durations were selected because they had been used by Navarick and Fantino (1972), although their schedules were VI, not VT, schedules. Each VT schedule was composed of 12 different components selected to approximate an exponential distribution, based on the technique of Fleshler and Hoffman (1962). The 12 components of the VT 23-s schedule were 1, 3, 5, 8, 11, 14, 18, 23, 28, 36, 48, and 81 s. The 12 components of the VT 54-s schedule were 2, 7, 13, 19, 25, 33, 42, 53, 67, 85, 113, and 189 s.

RESULTS

Table 1 shows the number of sessions needed for subjects to meet the stability criteria in each condition. This table also shows the standard schedule and the indifference point obtained for each subject in each condition.

To illustrate how these results provide tests of both transitivity and response bias, consider the results from the first four conditions. As explained in the Procedure section, if a subject's choices were transitive, the indifference points from Conditions 1 and 4 should be the same, as should those from Conditions 2 and 3. There are four main ways the results from Conditions 3 and 4 might deviate from this prediction, as shown in the two-by-two matrix in Figure 2. (For the moment, we set aside the possibility that such deviations are simply due to random variations in the measured indifference points.) Panel B represents the case where the indifference points in both Conditions 3 and 4 are larger than those obtained in Conditions 2 and 1, respectively. Because an indifference point is simply the average delay for the adjusting alternative, consistently longer delays suggest a bias for this alternative. This bias could be due to a preference for the somewhat variable delays delivered by the adjusting alternative, or to a preference for the red keylights or red houselights. Panel C represents the opposite result, where the indifference points in Conditions 3 and 4 are both smaller than in Conditions 2 and 1, respectively, suggesting a bias against the adjusting alternative.

Panel D represents the case where the indifference point in Condition 3 is larger than in Condition 2, but the indifference point in Condition 4 is smaller than in Condition 1. The performance of Subject 3 displayed this pattern, as Table 1 shows. Thus the indifference points from the two FT-FT conditions were closer together than those from the two VT-FT conditions. This pattern suggests a type of intransitivity that is consistent with the results reported by Navarick and Fantino (1972). According to Equation 1, this pattern is predicted if r is more negative in the FT-FT conditions than in the VT-FT conditions. Navarick and Fantino would predict this difference in r , because the smallest interreinforcement interval is larger in FT-FT conditions than in VT-FT conditions. Finally, Panel

Fig. 3. Results of each transitivity test, with those involving the VT 23-s schedule in the left graph and those involving the VT 54-s schedule in the right graph. Each open circle represents a transitivity test for 1 subject, based on the indifference points from four conditions. The x-axis plots the difference in indifference points from the two conditions with a 2-s reinforcer on the adjusting schedule (the indifference point obtained with a FT schedule as the standard minus that obtained with a VT schedule as the standard). The y-axis plots the analogous difference from the two conditions with a 5-s reinforcer on the adjusting schedule. The four quadrants of each graph parallel those of Figure 2, and suggested interpretations of points lying in each quadrant are shown. The filled circles are group means from the three sets of transitivity tests, and the number next to each circle indicates the order in which the tests were conducted.

A represents the case where the indifference point in Condition 3 is smaller than in Condition 2, but the indifference point in Condition 4 is larger than in Condition 1. Subjects 1 and 4 displayed this pattern. This pattern is the opposite of Panel D, and it suggests a type of intransitivity that is the opposite of what Navarick and Fantino would predict.

Figure 3 presents the results in a form that parallels the four panels of Figure 2. The x-axis plots the difference in indifference points from the two conditions with a 2-s reinforcer for the adjusting alternative, and the y-axis plots the difference in indifference points from the two conditions with a 5-s reinforcer for the adjusting alternative. In both cases, the indifference point from the FT-VT choice is sub-

tracted from that of the FT-FT choice. The four quadrants represent the four possibilities shown in Figure 2. The open circles in the left graph show the results of the 12 transitivity tests involving VT 23 s (3 from each bird), and the open circles in the right graph show those involving VT 54 s. The three filled circles in each graph are the group means for the three replications with each VT schedule, and the numbers next to the points indicate the order in which the points were obtained.

The data points from the VT 23-s tests were fairly evenly distributed about the origin, and the three group means were all close to the origin. This distribution suggests that the observed deviations in the VT 23-s tests were due to random variability, not to systematic

Fig. 4. Mean indifference points (and standard errors of the mean) for the four types of conditions that comprised a single transitivity test for the VT 23-s tests and the VT 54-s tests. The right panel shows the results from only the second and third VT 54-s tests, for reasons discussed in the Discussion section. The four types of conditions in each panel differed in whether the standard schedule was VT or FT, and whether the adjusting reinforcer duration was 2 s or 5 s. The number in parentheses beneath each bar is the reinforcer duration on the standard schedule.

intransitivities in choice or to bias. The data points from the VT 54-s tests exhibited somewhat more variability, and 6 of the 12 points (and two of the three group means) were found in the quadrant representing intransitivity consistent with the Navarick and Fantino (1972) predictions.

Figure 4 presents the mean indifference points from the four conditions that constituted a transitivity test, averaged across all subjects and all replications. For reasons explained in the Discussion section, the right panel of Figure 4 shows the results from only the second and third series of tests with the VT 54-s schedule. According to the Navarick and Fantino (1972) predictions, the second white bar in each panel should be larger than the first, and the second striped bar should be smaller than the first. This was the case for both the VT 23-s and VT 54-s tests, but in neither case were these trends statistically significant. Two three-way repeated-measures analyses of variance were performed, one for the indifference points from the VT 23-s tests and one for those from the VT 54-s tests. The three independent variables were the reinforcer duration on the adjusting schedule, the type of standard sched-

ule (VT or FT), and replication. The predictions of Navarick and Fantino would be supported by a significant interaction between adjusting reinforcer duration and standard schedule. In the VT 23-s tests, this interaction was not significant, $F(1, 3) = 0.57$, $p = .50$, nor were any of the other two-way or three-way interactions. The only significant main effect was that of adjusting reinforcer duration, $F(1, 3) = 448.82$, $p < .001$. For the VT 54-s tests, the interaction between adjusting reinforcer duration and standard schedule again failed to reach statistical significance, $F(1, 3) = 6.28$, $p = .09$. The only significant effects were those of adjusting reinforcer duration, $F(1, 3) = 73.48$, $p = .003$, and the three-way interaction between adjusting reinforcer duration, standard schedule, and replication, $F(2, 6) = 5.95$, $p = .038$.

DISCUSSION

The results of this experiment suggest that when subjects choose between FT and VT schedules by making a single, brief response, the type of intransitivity effects predicted by Navarick and Fantino (1972) are small at best. With both VT 23 s and VT 54 s, the evidence for intransitivity failed to reach statistical significance. Of course, the results may not have reached statistical significance because not enough tests were conducted, given the amount of variability in the measured indifference points. The overall trends shown in Figure 4 were all in the direction predicted by Navarick and Fantino. Furthermore, the greater trends toward intransitivity in the VT 54-s tests are also consistent with the Navarick and Fantino theory. They suggest that intransitivity occurs when the exponent r in Equation 1 changes across conditions, and that r depends on the smallest delay to reinforcement that is presented in a given condition. The sizes of the smallest delays varied more across conditions in the VT 54-s tests than in the VT 23-s tests, so larger intransitivity effects would be predicted by Navarick and Fantino. Thus, one possible interpretation of the present study is that there actually were systematic intransitivities of choice but that these effects were obscured by the variability in the data. If this interpretation is accepted, however, it must be acknowledged that these intransitivity effects were not large. The pairs of mean indifference

points in the two left panels of Figure 4, which should have been equal if there were perfect transitivity, differed by an average of only 7.3%.

The evidence supporting the predictions of Navarick and Fantino may be even weaker than suggested by Figures 3 and 4, because there are reasons to treat the results from the first series of VT 54-s tests (from Conditions 9–12) as aberrant. After two series of tests involving the VT 23-s schedule, the VT 54-s schedule was first introduced in Condition 9, and this condition was continued for a minimum of only 10 sessions. The indifference points for all 4 subjects were lower in Condition 9 than in the other two conditions involving a VT 54-s schedule and a 5-s adjusting reinforcer, which suggests that these indifference points may have been affected by hysteresis from the previous VT 23-s conditions. If there was this sort of hysteresis, it would affect the indifference points obtained in Conditions 11 and 12 in the same direction as would intransitivity of the type predicted by Navarick and Fantino. Having suspected a problem after the first set of VT 54-s tests was completed, we tried to minimize hysteresis in subsequent conditions by continuing them for a minimum of 20 sessions whenever the VT schedule was changed from its previous size.

In fact, Figure 3 shows that the group mean from the first set of VT 54-s tests provided what appeared to be the strongest support for the Navarick and Fantino predictions. Furthermore, the three individual data points in Figure 3 that provided the strongest support for Navarick and Fantino (those furthest to the bottom right) were all from this first test. If the results of the first set of VT 54-s tests are excluded because of possible hysteresis, the remaining tests provide very little evidence for intransitivity. The pairs of mean indifference points in the right panel of Figure 4 differed by an average of only 3.5%.

It is not clear why the results from this study differed from those of Navarick and Fantino (1972), who observed many substantial deviations from transitivity. The procedures in these two studies differed in several ways. First, in the present study all comparisons of schedules were based on the estimation of indifference points, whereas Navarick and Fantino compared two schedules that were equally preferred over a third. Second, the two FI schedules used in the present study had different

reinforcer amounts, whereas Navarick and Fantino did not vary reinforcer amounts in their studies designed to compare fixed and variable schedules. However, there is no obvious reason why these procedural differences would have produced the differences in results. The variation in reinforcer amounts in the present study was an additional complication which, if anything, should have increased the likelihood of observing intransitivities of choice. This is especially true since Navarick and Fantino (1975, Experiment 3) found some evidence for intransitivity among schedules that differed in the reinforcer amount.

A procedural difference of possibly greater importance was the use of the adjusting-delay procedure. As already discussed, Navarick and Fantino predict violations of transitivity when the shortest delay interval varies across conditions. If the adjusting delays fluctuated greatly within each condition, so that the shortest delays a subject experienced were similar across the four conditions of a transitivity test, the Navarick and Fantino theory would predict no intransitivity. This is because equally small delays should mean equal values of r in Equation 1, and if r does not change across conditions there should be no intransitivity.

To evaluate this possibility, the following analysis was performed: For each subject and each condition, the smallest value of the adjusting delay during the last six half-session blocks was identified. In some cases, this delay was the smallest one the subject received, whereas in other cases the standard schedule delivered a smaller delay. In either case, the smallest delay presented during the last six half-session blocks was compared across the four conditions of each transitivity test. If the smallest delays differed substantially across these four conditions, Navarick and Fantino would predict violations of transitivity. In the 12 VT 23-s tests, the difference in minimum delays across the set of four conditions averaged 7.3 s (ranging from 5.4 s to 9.0 s). In the 12 VT 54-s tests, the difference in minimum delays averaged 11.6 s (ranging from 8.5 s to 16.8 s). These differences are comparable to those used in the Navarick and Fantino (1972) study, so the absence of large intransitivity effects in the present study cannot be attributed to a relative constancy of minimum delays across conditions.

We propose that one difference between the

two studies that may have produced the differing results was the duration of the choice period. With VI schedules as the initial links in the Navarick and Fantino study, the average choice period lasted about 28 s. In contrast, the duration of the choice period in the present study was only about 1 s, the time required for a subject to make a single peck on one of the side keys. It seems reasonable to assume that, in the present study, choice was determined almost entirely by the delays in the terminal links (and of course the different reinforcer durations), but that the time spent in the initial links of the Navarick and Fantino study had a much larger influence on choice.

It is not difficult to develop a theory of why longer initial links might produce intransitivities in choice between fixed and variable schedules. To demonstrate this point, we will present a simple model and illustrate its predictions with a hypothetical example. Mazur (1984) found that the following equation accurately predicted indifference points between periodic and aperiodic schedules obtained with the adjusting procedure:

$$V = \sum_{i=1}^n p_i \frac{A}{1 + KD_i} \quad (2)$$

V is the value of a reinforcement schedule that might present any one of n different delays before reinforcement, and p_i is the probability that a delay of D_i seconds will occur on each trial. A is a parameter that depends on the magnitude of reinforcement, and K is a free parameter. For this illustration, A and K will be set equal to 1. For his discrete-trials procedure, Mazur assumed that the values (V s) for the two alternatives were equal at the indifference point.

To extend this model to a concurrent-chains procedure with longer initial links, we will make the following assumptions. D_i will now represent the duration of a terminal-link schedule plus the cumulative time, per terminal-link entry, spent responding on the initial-link key that gives access to this schedule. That is, we will assume that the relevant initial-link duration is not the total time spent in the initial links but rather the time spent responding on one initial-link schedule. We assume that the subject will allocate more and

more initial-link time to the alternative with the higher value (thereby increasing D_i for this alternative and decreasing D_i for the other alternative) until the values of the two alternatives are equal.

Suppose a concurrent-chains procedure has two VI 30-s schedules as the initial links. In the first of three conditions, one terminal link is a MT 2,118-s schedule, which means that the delay to reinforcement after entering the terminal link is either 2 s or 118 s, with equal probability. The other alternative is a FT schedule whose duration is titrated until the subject is allocating 50% of its initial-link time to this schedule. When this happens, the subject will spend an average of 15 s responding on each initial-link schedule for each entry into its terminal link. If the 2-s component of the MT 2,118-s schedule occurs, the total time allocated to this alternative will be 15 s plus 2 s, or 17 s. If the 118-s component occurs, the total time will be 15 s plus 118 s, or 133 s. With these two values for D_i , Equation 2 states that $V = .0315$ for the MT 2,118-s schedule, and that an FT schedule with a duration of 15.74 s will have the same value.

In the second condition, the terminal links are FT 15.74 s and FT 25 s. It follows from Equation 2 that the two alternatives will have equal value when the subject spends 65.4% of its initial-link time on the key that gives access to the shorter FT schedule: With this allocation of initial-link time, the total time allocated to each alternative (again summing across initial-link time and terminal-link delays) will average 35.37 s for each alternative. In the third condition, the terminal links are MT 2,118 s and FT 25 s, and Equation 2 states that the values of the two alternatives will be equal when the subject spends 62.1% of its time on the MT schedule. Thus, this model predicts more extreme initial-link time allocation with the FT-FT comparison than with the MT-FT comparison, a prediction that is consistent with the type of intransitivity found by Navarick and Fantino (1972).

The main point of this illustration is that it is possible to develop a theory that assumes a unidimensional scale of value and nevertheless predicts intransitivity of choices in concurrent-chains procedures. In contrast, because the initial links of the single-response procedure used in the present study were very brief (and roughly constant regardless of the terminal-

link schedules used), Equation 2 predicts no intransitivity for this choice procedure.

In light of previous studies that used the adjusting procedure to study choice between fixed and variable schedules (Mazur, 1984, 1986), the absence of large intransitivities of choice in the present study is not surprising. Mazur used Equation 2 to describe the relation between delay and reinforcer value, and was able to make accurate predictions for indifference points between fixed and variable schedules. Hence, this research supported a single, unidimensional scale of value applicable to both periodic and aperiodic schedules. Any intransitivity effects of substantial size would presumably have led to inaccurate predictions in Mazur's studies, yet no large or systematic deviations from the predictions were observed.

To prove that there are no intransitivity effects whatsoever when initial links are brief would be to prove the null hypothesis, which is impossible. The results of the present study, however, suggest that any systematic deviations from transitivity that might occur in procedures with brief choice periods are small and have relatively little influence on choice between periodic and aperiodic schedules.

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