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PERFORMANCE OF CHILDREN UNDER A MULTIPLE RANDOM-RATIO RANDOM-INTERVAL SCHEDULE OF REINFORCEMENT

GREGG A. BAXTER AND HENRY SCHLINGER

WESTERN MICHIGAN UNIVERSITY AND WESTERN NEW ENGLAND COLLEGE

Three children, aged 1.5, 2.5, and 4.5 years, pressed telegraph keys under a two-component multiple random-ratio random-interval schedule of reinforcement. In the first condition, responses on the left key were reinforced under a random-interval schedule and responses on the right key were reinforced under a random-ratio schedule. In the second condition, the schedule components were reversed. In the third condition, the original arrangement was reinstated. For all subjects, rates of responding were higher in the random-ratio component despite higher rates of reinforcement in the random-interval component. The average interreinforcement interval of the random-interval component was increased in the fourth condition, resulting in more similar rates of reinforcement for both schedule components, and then returned to its original value in the fifth condition. In both conditions, all subjects continued to exhibit higher rates of responding in the ratio component than in the interval component. Although these observations are consistent with results from studies with pigeons, it is argued that the response-rate differences between the interval and ratio schedule components are sufficient to demonstrate schedule sensitivity.

Key words: sensitivity to contingencies, schedule control, multiple schedule, random ratio, random interval, button press, children

The question of human behavioral sensitivity to reinforcement schedules has received much attention from behavior analysts in the last three decades (e.g., Baron, Kaufman, & Stauber, 1969; Bentall, Lowe, & Beasty, 1985; Long, 1962; Lowe, Beasty, & Bentall, 1983; Lowe, Harzem, & Bagshaw, 1978; Matthews, Shimoff, Catania, & Sagvolden, 1977; Shimoff, Catania, & Matthews, 1981; Shimoff, Matthews, & Catania, 1986; Weiner, 1969; Weisberg & Fink, 1966). By and large, researchers have ascertained the sensitivity of human behavior by comparing it with that of nonhumans under similar conditions. In general, such comparisons have shown that the behavior of human subjects above the age of 4 years does not resemble that of nonhuman subjects (e.g., Baron et al., 1969; Bentall et al., 1985; Long, 1962; but see Long, Hammack, May, & Campbell, 1958). In contrast, the behavior of very young children (i.e., 2 years and younger) has been similar to that of nonhumans (e.g., Bentall et al., 1985; Lowe et al., 1983; Weisberg & Fink, 1966). For example, Lowe et al. (1983) investigated the performance of two infants on fixed-interval (FI) schedules. The results showed that both the response patterning (the so-called FI "scallop") and the sensitivity to the FI parameter were indistinguishable from those typically found in nonhumans. Bentall et al. (1985) then showed developmental differences in the FI schedule performance of children. They measured the performances of children in three age groups, 2.5 to 4 years, 5 to 6.5 years, and 7.5 to 9 years. In addition, the data from the infants in the Lowe et al. (1983) study were included for comparison. Children in the two older groups exhibited response patterns typical of adults. The performances of the children in the 2.5- to 4-year group showed patterns resembling those of both the infants and the older children. Only the behavior of the preverbal infants in the Lowe et al. study resembled that of nonhumans. The general conclusion of these studies seems to be that, when schedule sensitivity is assessed by comparisons with nonhuman performances, only the per-

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formances of preverbal children will resemble those of nonhumans. As children become more verbal, their schedule performances become more like those found with adults.

With a few exceptions (e.g., Long, 1962, 1963; Rovee-Collier & Capatides, 1979), researchers have investigated the performance of children under simple reinforcement schedules. With adults, however, investigators have examined the effects of more complex schedules, such as multiple schedules (e.g., Hayes, Brownstein, Haas, & Greenway, 1986; Matthews et al., 1977; Matthews, Catania, & Shimoff, 1985; Shimoff et al., 1986). One advantage of using multiple schedules is that behavioral sensitivity can be ascertained without necessarily relying on comparisons with nonhumans. Rather, variations in responding as a direct function of differences in the schedule parameters can be measured (Baron & Galizio, 1983). If it can be shown that behavior varies systematically with the schedule parameters, then it should be possible to claim schedule sensitivity irrespective of any comparisons with nonhuman data.

The present study examined the performances of 3 children under a two-component multiple random-ratio (RR) random-interval (RI) schedule of reinforcement. A multiple schedule with RR and RI components was selected to extend the investigation of such schedules to children (see Matthews et al., 1985; Shimoff et al., 1986) and to permit a broader assessment of schedule control (sensitivity) than may be possible with simple schedules. To make this assessment more convincing the schedules were arranged such that the RI schedule maintained a higher rate of reinforcement than the RR schedule. It is well known that ratio schedules generate higher rates of responding than interval schedules do, even when rates of reinforcement in the two schedules are equal (e.g., Catania, Matthews, Silverman, & Yohalem, 1977; Ferster & Skinner, 1957, pp. 399–407; Zuriff, 1970). In such cases, differences in response rates can be attributed to characteristics of the schedules and not to differences in reinforcement rates. An even more powerful demonstration of schedule sensitivity could be made if it could be shown that the ratio schedules would generate higher response rates than the interval schedules do, even when they maintained lower reinforcement rates.

METHOD

Subjects

Three female children, who were 1 year 6 months (S1), 2 years 8 months (S2), and 4 years 6 months (S3) of age at the beginning of the experiment, served as subjects. All 3 children were the daughters of the first author.

Setting and Apparatus

During the experiment, subjects were seated in a high chair (with tray removed) located in a cubicle (1.83 m by 1.83 m). The chair was placed directly in front of a counter-top table on which the experimental apparatus was mounted. The cubicle was illuminated by overhead fluorescent lighting, and ambient room temperature was maintained at a comfortable level. A Grason-Stadler white noise generator (Model 901B) provided low-level masking noise through a speaker mounted on the wall above the apparatus. The walls were decorated with pictures of the subjects' favorite cartoon characters.

Figure 1 shows a diagram of the apparatus. The operanda, two telegraph keys spaced 30 cm apart, were located at the base of a 51-cm wide by 28-cm high intelligence panel mounted at the edge of the table. A force of approximately 0.2 N was required for key operation, and the keys were padded with foam rubber to prevent irritation to the subjects' hands. One 7-W light was mounted 10 cm above each key. The light above the left key was yellow, and the light above the right key was white. A universal dispenser, mounted inside a wooden cabinet next to the table, provided small edibles such as M&Ms® and raisins. The feeder dispensed the edibles through a flexible tube into a bowl mounted between the two keys. A "houselight," which was illuminated green when the schedules were in effect, was centered horizontally 22 cm above the base of the response panel.

A PDP-8A® minicomputer equipped with SUPERSKED® software and relay interfacing, scheduled experimental events and collected data.

Procedure

Preliminary training. At the beginning of training all subjects were told to "Push the button" and, when necessary, physically prompted to press the right telegraph key. The light above that key was illuminated, and a RR schedule was in effect. The ratio value was low enough so that almost every key press produced a reinforcer (i.e., a RR 1). Once the subjects were pressing the key regularly, the light above the left key became illuminated and a low RI schedule was in effect for presses on that key. Simultaneously, the light above the right key was turned off and presses on that key no longer produced edibles. This continued until responding occurred reliably in the presence of each light. At this time, the schedule parameters were increased gradually until they reached the terminal values (see below). Subjects occasionally responded on the inactive key during the time before a reinforcer was set up by the active schedule; therefore, a 3-s timeout from experimental conditions was instated for "incorrect" responding. During this timeout, all panel lights were turned off, and whichever schedule had been in effect ceased operation. In addition, responses on both keys reset the 3-s timer. Hence, after a response on the inactive key, a period of 3 s without responding on either key was required before the session was reinstated. This contingency remained in effect throughout the experiment.

Experimental sessions. Although the first key press was established by a simple command and a physical prompt from the experimenter, the subjects were also told about the experiment as follows:

> This is a game in which you can earn candy to eat. The candy will come out of this tube. You can earn the candy by pressing one of these two keys. When a light comes on over a key, that means that you can press the key. When the candy comes out, eat it all right away. When the game is finished I will come and get you. Remember, press only one key and eat the food right away.

Although it is unlikely that the youngest subject understood the instruction, it was nevertheless stated to maintain consistency among the subjects. If a child attempted to leave her seat, the experimenter intervened and prompted appropriate sitting. However, if the subject refused to comply, or stopped responding for a period of more than 5 minutes, the session was terminated. At the end of the session the panel lights were turned off and the experimenter entered the cubicle and removed the child.

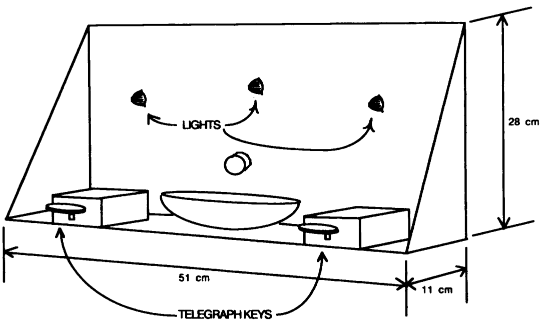

Fig. 1. A diagram of the experimental apparatus.

At the end of every session each subject was asked certain questions, such as, "What do you have to do to make the candy come out?" and "What do you have to do when the lights come on?"

Schedule manipulations. For all 3 subjects, food deliveries were produced by presses on one key according to a RI schedule with a probability of .2 sampled once per second (RI 5 s). For the 2 older subjects (S2 and S3), presses on the other key produced food according to a RR schedule that determined reinforceable responses with a probability of .05 (RR 20); for the youngest subject (S1) the probability of a response producing food was .075 (RR 15). The schedule values were selected based on two considerations: The rates of reinforcement in both schedules maintained steady responding and the rate of reinforcement under the RI schedule was higher than that under the RR schedule. The latter was done to ensure that higher response rates in the RR could not be attributed to higher reinforcement rates in that component.

The particular schedule component that began each session was determined randomly, and each component remained in effect until six reinforcers had been delivered. Hence, obtained component durations depended on the schedule, the rates of response in each component, and the number of timeouts. Sessions consisted of three presentations of each component; thus, sessions were terminated when 36 reinforcers had been delivered. When a reinforcer was delivered, the keylight was turned off and remained off for 3 s to allow the subject time to consume the edible. The edibles were not always consumed immediately. When this was observed, the experimenter would remind the child to eat the candy right away.

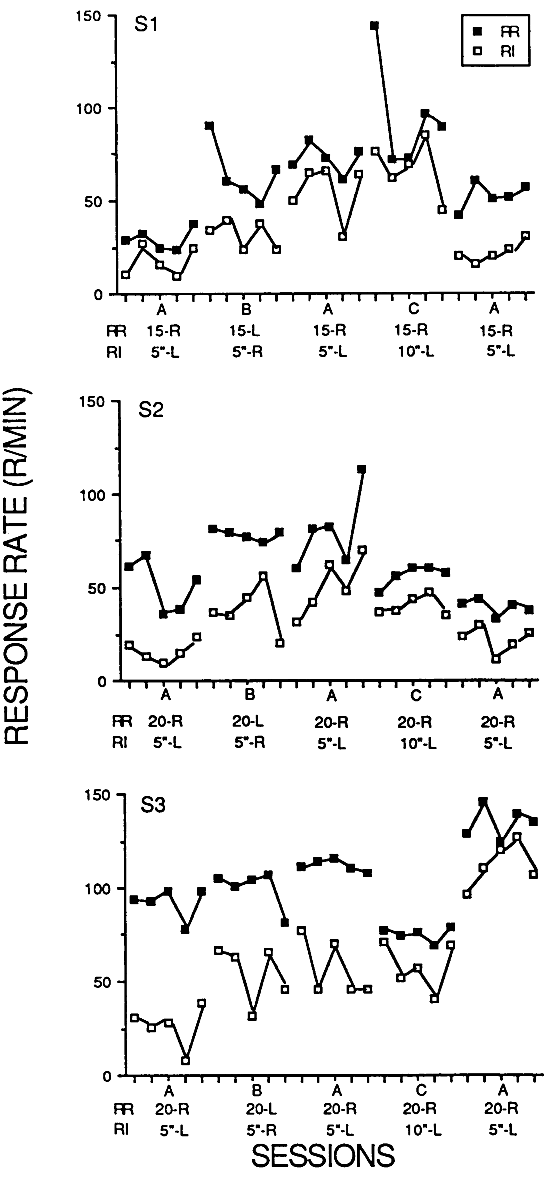

Fig. 2. Rate of response under the multiple RR RI schedule across all experimental conditions. The data are from the last five sessions of each condition. Shown on the abscissa are the schedule values and corresponding key locations for each condition.

Table 1

Mean rates of reinforcement (reinforcers per minute) for the last five sessions of each condition. Numbers in parentheses represent the number of sessions in each condition.

Condition	Subject S1	 S2	 S3
A			
RR	2.44 (40)	2.64 (31)	4.59 (31)
RI	5.05	5.62	9.99
B			
RR	4.32 (12)	3.59 (14)	4.77 (31)
RI	6.8	6.08	9.09
A			
RR	4.31 (31)	4.37 (20)	4.96 (9)
RI	7.01	9.25	8.79
C			
RR	6.14 (14)	2.94 (11)	4.1 (12)
RI	5.34	3.5	5.01
A			
RR	3.60 (10)	2.23 (13)	7.04 (15)
RI	5.56	4.89	11.1

The experiment consisted of five conditions. In the first condition (A), the RI schedule was programmed on the left key and the RR schedule on the right key. In the second condition (B), the schedules were programmed on the opposite keys. The third condition (A) consisted of a reversal to the first condition. During schedule reversals, the lights above the keys remained constant; thus, the keylight colors did not vary with the schedule reversals. In the fourth condition (C), the RI component was increased from an RI 5 s to an RI 10 s. In the last condition (A), the value of the RI schedule was returned to 5 s. Conditions were changed after a minimum of 10 sessions with no visible trend over the last five sessions. The only exception to this was the third condition (A) for S3, in which the condition was changed after nine sessions. Sessions were conducted once per day at approximately the same time, and usually 5 days per week.

RESULTS

Figure 2 shows for each of the 3 subjects the response rates in the interval and ratio components during each of the last 5 days of all conditions. Response rates were calculated by dividing the total number of responses in a component by the total component time minus the cumulative timeout and reinforcement times. Table 1 shows the average of the reinforcement rates for the last five sessions of each condition. The reinforcement rate was calculated by dividing the total number of re-

Table 2

Total component duration in minutes (component time minus reinforcement time and timeouts) for each of the last five sessions of each condition. Numbers in parentheses represent the total duration (in seconds) of timeouts per session.

Condition	S1		S2		S3	
	RR	RI	RR	RI	RR	RI
A	6.73 (6)	4.08 (28)	7.55 (9)	2.4 (0)	4.25 (0)	2.08 (0)
	8.55 (20)	3.42 (32)	5.68 (3)	3.22 (0)	3.03 (6)	2.25 (3)
	9.0 (23)	5.07 (20)	7.47 (3)	4.1 (0)	4.21 (17)	2.71 (0)
	8.72 (19)	3.9 (15)	8.2 (6)	4.18 (0)	5.01 (0)	2.71 (0)
	5.57 (23)	2.43 (24)	5.9 (0)	2.85 (0)	4.25 (0)	2.6 (0)
B	7.78 (22)	3.68 (0)	5.37 (0)	3.15 (0)	4.48 (3)	1.75 (0)
	3.73 (24)	3.33 (0)	5.95 (0)	2.61 (0)	3.45 (5)	1.83 (0)
	4.23 (6)	2.18 (9)	5.0 (13)	3.22 (3)	4.07 (0)	2.0 (0)
	2.91 (15)	2.03 (6)	4.89 (0)	3.45 (0)	3.45 (3)	2.02 (3)
	4.4 (6)	2.75 (0)	4.19 (0)	2.57 (0)	3.62 (0)	2.43 (0)
A	4.35 (19)	2.78 (14)	5.9 (4)	2.6 (0)	4.7 (3)	1.37 (0)
	3.9 (0)	2.37 (18)	4.56 (3)	2 (6)	3.81 (16)	1.96 (0)
	3.2 (6)	2.07 (3)	6.93 (21)	1.56 (3)	3.3 (9)	2.0 (3)
	4.67 (21)	2.72 (12)	3.06 (3)	1.48 (0)	3.9 (3)	1.96 (0)
	5.45 (15)	3.17 (10)	2.82 (21)	2.7 (50)	4.14 (0)	1.9 (3)
C	2.07 (0)	4.73 (3)	9.28 (0)	7.63 (8)	4.77 (3)	3.78 (0)
	3.18 (10)	3.45 (6)	5.86 (0)	4.67 (0)	4.48 (0)	3.15 (0)
	2.65 (6)	2.65 (3)	5.7 (30)	5.42 (9)	4.98 (3)	3.65 (0)
	4.43 (6)	3.35 (0)	6.03 (30)	4.23 (3)	3.98 (0)	3.42 (3)
	3.27 (18)	3.27 (6)	4.58 (3)	4.82 (0)	3.92 (0)	4.12 (0)
A	5.68 (20)	3.65 (0)	7.6 (4)	3.18 (9)	3.33 (0)	1.62 (0)
	4.32 (16)	3.05 (4)	5.98 (16)	2.73 (23)	2.82 (0)	1.62 (6)
	6.5 (54)	2.68 (17)	11.7 (14)	5.08 (6)	2.37 (4)	1.75 (0)
	5.03 (3)	2.9 (3)	9.28 (6)	4.58 (14)	2.36 (0)	1.4 (7)
	4.17 (34)	4.43 (51)	7.8 (6)	3.8 (9)	2.0 (0)	1.77 (0)

inforcers obtained in a component (which was always 18) by the total component time minus the cumulative timeout and reinforcement times. For all subjects under all conditions, response rates were higher under the RR component than under the RI component despite the fact that, with only one exception (S3, Condition C), reinforcement rates were higher under the RI component than under the RR component. When the schedule components were programmed on opposite keys in the second condition (B), responding remained differentiated, although response rates increased under both components for all subjects. Rates remained near these levels during the reversal in the third condition (A).

In the fourth condition (C), the RI value was increased from 5 s to 10 s. All of the children continued to show higher response rates under the RR schedule than under the RI schedule, although the subjects differed in other aspects of their performances. Interestingly, response rates in the RI component were relatively unchanged; however, for the 2 older subjects (S2 and S3) response rates in the RR component decreased, thus becoming more similar to those under the RI component. Response rates under both schedule components for S1 converged, and there was a slight increase in overall response rates. As would be expected with increases in the interreinforcement interval, reinforcement rates also changed (see Table 1). Mean reinforcement rates under the RI component declined for all subjects. Mean reinforcement rates under the RR schedule also declined for S2 and S3 but increased for S1.

When the RI value was returned to 5 s in the last condition (A), response rates remained higher under the RR component than under the RI component. Table 1 shows that mean reinforcement rates in the RR component decreased for S1 and S2 and increased for S3. Mean reinforcement rates under the RI component increased for all subjects.

Table 2 shows RR and RI total component times per session for all conditions and subjects. Data presented are for the last 5 days of each condition. In most sessions, component times were greater under the RR schedules than under the RI schedules. The exceptions occurred primarily in the fourth condition (C) when the average interreinforcement interval in the RI schedule was increased. Although timeouts occurred for all subjects, the timeout durations were generally greatest for S1, the youngest subject. It might be argued that considerable timeout responding reflects a lack of discrimination between the active and inactive keys, which might then call into question claims of discriminative control by the schedules. The factors responsible for timeout responding cannot be determined at present. However, the consistent differences in response rate between the RR and RI schedules do demonstrate reliable discrimination between the keys associated with the ratio and interval contingencies.

As might be expected, all 3 subjects verbalized during experimental sessions. This included singing, talking to the cartoon-poster characters, and talking to the apparatus. Some of the behavior took the form of magical mands (Skinner, 1957, p. 48). For example, S3 was overheard to say, "Go off light, go off . . . go off!" At the end of most sessions, the subjects were asked questions about the contingencies. When asked what they had to do to make the candy come out, they answered with remarks such as, "When the light goes off, I eat the candy when it comes out here." There was no indication from their answers that they had formulated any descriptions of the schedule requirements.

DISCUSSION

The results showed consistently higher rates of responding under the RR component than under the RI component despite the fact that rates of reinforcement were higher under the RI component than under the RR component. Thus, the higher response rates in the RR component cannot be attributed to higher reinforcement rates in that component but rather to properties of the schedules themselves (Catania et al., 1977; Ferster & Skinner, 1957; Zuriff, 1970). In previous reports, sensitivity of human behavior to schedules of reinforcement has been assessed primarily by comparing human performances to those of nonhumans under similar schedules. However, some researchers have suggested that measuring changes in responding as a function of variations in schedule parameters might be preferable (Weiner, 1983). Both criteria may be used to demonstrate schedule sensitivity in the present study.

When simple schedules, such as FI schedules, have been used, the usual practice has been to compare the patterns of human and nonhuman responding (see Lowe, 1979). Looking at other properties of schedule responding, however, may allow greater flexibility in assessing schedule control. For example, with multiple schedules certain quantitative characteristics can be compared. It is well documented with pigeons responding under multiple variable-ratio (VR) variable-interval (VI) schedules that the ratio components generate higher rates of responding than the interval components do when rates of reinforcement are either equivalent (Catania et al., 1977; Ferster & Skinner, 1957; Zuriff, 1970) or are higher under the interval schedules than under the ratio schedules (Zuriff, 1970). Zuriff examined pigeons' key pecking under two-component multiple VI VR schedules. When he plotted the relative rate of response in the VR component as a function of the relative rate of reinforcement in that component, he found that response rates in the VR component were generally equal to or greater than those in the VI component, even though reinforcement rates in the VR component were equal to or lower than those in the VI component. Although Zuriff investigated a wider range of schedule parameters than the present study, the results of both studies are nevertheless comparable. Consistent with Zuriff's results, the current findings showed that when reinforcement rates in the interval components were as much as twice those in the ratio components, response rates under the ratio components were higher.

Perhaps the main problem with simple schedules is the difficulty in assessing the extent to which schedule parameters actually control performance. Thus, the determination of sensitivity of human behavior is limited to comparisons with nonhuman performance (Baron & Galizio, 1983). Again, use of multiple schedules, and in particular, within-session comparisons, may provide a more sensitive assay (e.g., Catania, Matthews, & Shimoff, 1982). In the present study, within-session comparisons were made under a two-component multiple RR RI schedule of reinforcement. Despite some within- and between-subject variability, the results clearly indicate that responding came under the control of the schedule parameters: For all 3 subjects, when conditions were changed, schedule-sensitive responding soon followed. For example, in Condition B the schedule values were reversed. But by the seventh and ninth session for S1 and S2, respectively, schedule-appropriate responding was occurring on the correct keys. It took longer for S3, but the same results were seen.

For 2 subjects (S2 and S3), when the RI value was changed from 5 s to 10 s, responding in the RI component was relatively unchanged. However, response rates in the RR component decreased. This indicates a type of schedule interaction that resembles negative induction. For S1, response rates increased slightly under both components. However, the RR value for S1 (15 responses) was different than for S2 and S3 (20 responses), and this may have contributed to the different form of schedule interaction. When the RI value was returned to 5 s, interaction-like effects continued. For S1 and S2, response rates in both schedule components decreased, and for S3, response rates increased in both components. These phenomena are pointed out to demonstrate that the performances were sensitive to changes in the schedule parameters, although it is difficult to interpret these effects given the limited range of schedule values investigated.

Other studies that have investigated human performances under multiple schedules have also shown apparent schedule sensitivity (e.g., Matthews et al., 1977; Shimoff et al., 1986). Some researchers, however, have suggested that these performances may not have been schedule sensitive at all, but rather were "rule governed" (Hayes et al., 1986; Shimoff et al., 1981, 1986). Therefore, the influence of verbal stimulus control must be considered in any experiment in which verbal humans are subjects. The present study showed schedule-sensitive performance for children from approximately 1.5 to 5 years of age. At the beginning of the study, S1 was in an age range that Bentall et al. (1985) described as "preverbal." Recall that of the four age groups compared by Bentall et al., the preverbal infants (from the Lowe et al., 1983, study) were the only subjects who behaved in a fashion similar to nonhumans. Children in the 2.5 to 4-year age group showed patterns of responding that resembled both older children and preverbal infants. In the present study, the 2.5- and 4.5-year-old subjects (S2 and S3) behaved essentially no differently than the youngest subject. In fact, if anything, their performances were more stable, that is, more sensitive. Moreover, because the present study lasted for 6 to 8 months, the children were all comparatively much older at the experiment's conclusion. And although some of the within-subject variability may have been a function of age- and experience-related variables, the results across conditions remained remarkably stable.

But how do we account for the fact that the behavior of the oldest subject showed schedule sensitivity? Recall that previous studies with children this age reported relative insensitivity (e.g., Bentall et al., 1985). It is possible that, with the use of multiple schedules in which reinforcer availability is determined randomly, it is more difficult for older children to predict what they have to do and thus to formulate task-relevant rules. Hence, future research might compare the behavior of older children under variable (or random) reinforcement schedules with behavior under fixed schedules. It is also possible that defining schedule sensitivity only in terms of comparisons with nonhumans may be, at best, incomplete. In fact, with FI schedules even nonhumans show insensitivity if it is defined solely in terms of response patterning (e.g., Wanchisen, Tatham, & Mooney, 1989). One reason for this insensitivity is the conditioning history of the organism. For example, Wanchisen et al. (1989) showed that, when rats responded under FI schedules, those that were trained initially under VR schedules did not exhibit the classical scalloping pattern characteristic of the performance of rats trained only under FI schedules. Humans are not naive experimental subjects; they bring with them unknown and surely complex histories of responding under a variety of reinforcement schedules. Thus, one explanation of the differences between performances of humans and nonhumans, or between preverbal infants and older children or adults on FI schedules, may be the difference in conditioning histories.

Other possible problems with defining schedule sensitivity by comparing human and nonhuman performances are the procedural differences between human and nonhuman studies. Some authors have noted that humans are typically exposed to experimental contingencies for shorter periods of time than nonhumans are and that human schedule performance is frequently established by instruction rather than by shaping (e.g., Perone, Galizio, & Baron, 1988; Wanchisen et al., 1989). However, the procedure in the present study resembled the typical nonhuman experiment in several ways. First, performances were established primarily through exposure to the contingencies. Second, the study consisted of daily sessions lasting several months. And third, the reinforcers were food items and required a consummatory response. Perhaps these characteristics contributed to the schedule-sensitive performances observed in our study.

In summary, the present results demonstrate that schedule-controlled performances in young children can be established via fairly traditional shaping methods in concert with edible reinforcers that require a consummatory response, and that the responding of children under complex schedules of reinforcement can come under the control of schedule parameters. Moreover, these findings suggest that we may have to modify our criteria for judging whether human behavior is sensitive to reinforcement schedules. Perhaps a better criterion than the similarity to nonhuman performances under similar conditions is whether the behavior varies systematically in any way with changes in the schedules or their parameters.

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