FIXED-INTERVAL PERFORMANCE AND SELF-CONTROL IN INFANTS

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Twenty-six infants, 3 to 23 months old, were trained on fixed-interval schedules ranging from 10 s to 80 s. The operant response was touching an illuminated location on a touch-sensitive screen, and 20 s of cartoon presentation was the reinforcer. The subjects were also trained in a six-phase self-control procedure in which the critical phases involved choice between 20 s of cartoon available after a 0.5-s delay (impulsive choice) and 40 s of cartoon delayed for 40 s (self-controlled choice). All the youngest children (3 to 5 months) showed long postreinforcement pauses on the fixed-interval schedule, with most intervals involving the emission of a single, reinforced, response, and all made self-controlled choices. Older subjects (9 to 23 months) either produced the same pattern as the younger ones on the fixed-interval schedule (classified as pause-sensitive subjects) or produced short pauses and higher steady response rates (classified as pause-insensitive subjects). All pause-sensitive subjects made self-controlled choices in the self-control condition, and all pause-insensitive subjects made impulsive ones.

Key words: fixed-interval schedule, self-control, cartoon reinforcer, touch-sensitive screen, infants

Developmental studies have played an important role in clarifying some central issues in the operant psychology of normal humans. Not only are developmental issues interesting in themselves, but the fact that children may lack some of the behavioral capacities of adults, most strikingly language, may shed light on the role of such capacities in the control of operant behavior. The study by Lowe, Beasty, and Bentall (1983), which examined the performance of preverbal infants on fixed-interval (FI) schedules of reinforcement, indicated, for example, that the FI performance of humans could in these circumstances resemble that of nonhumans (showing such features as "scalloped" response patterns and changes in response rate and postreinforcement pause as a function of FI value), whereas that of normal adult humans usually does not (see review by Lowe, 1979). This result supported the view that some of the apparently unique properties of human operant behavior are due to the possession of language by the subjects (see also Devany, Hayes, & Nelson, 1986, for a study of the role of language in equivalence-class formation).

Even when children with highly developed verbal behavior are used as subjects, data from operant studies sometimes show features not usually exhibited by adult behavior, such as striking dissociations between verbal and nonverbal behavior (Pouthas, Droit, Jacquet, & Wearden, 1990). This suggests that the strong association between verbal and nonverbal behavior usually found in adults (Wearden, 1988) may develop long after syntactic aspects of language have been mastered.

Some recent work (Darcheville, Rivière, & Wearden, 1992) used 5- and 6-year-old children in a study of individual differences in behavior on FI schedules and in a self-control procedure. The self-control procedure (see Logue, 1988, for a recent review) involved presenting subjects with a choice between a small reinforcer available immediately (or after a very short delay) and a larger reinforcer available after a longer delay. Choice of the smaller reinforcer (which is usually maladaptive in terms of the amount of reinforcement obtained per unit time) is termed *impulsive*; choice of the larger delayed reinforcer is termed *self-controlled*. Darcheville et al. (1992) offered children the choice between different durations of a cartoon presented with different delays and found both impulsive and self-controlled choices in different 5- and 6-year-old subjects. They also trained the same children on FI, again with a cartoon reinforcer, and found the two behavior patterns characteristically found in adults (Weiner, 1962, 1969), one a *low-rate* pattern with long postreinforcement pauses and low response rates and the other a *high-rate* pattern with short pauses and high steady response rates within the interval. Most strikingly, all subjects who consistently chose the longer delayed reinforcer in the choice pro-

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cedure exhibited the low-rate pattern on the FI schedule, whereas subjects who consistently chose the shorter, but less delayed, reinforcer all showed the high-rate response pattern.

The present article reports a similar study of FI performance and self-controlled or impulsive choice in infants ranging in age from 3 to 23 months at the start of training. Subjects initially received FI training with schedules ranging, for most subjects, over values of 10, 20, 30, 40, 60, and 80 s. A period of presentation of a cartoon served as the reinforcer. Subjects then received training on a choice procedure in which, in the phases used to define behavior as self-controlled or impulsive, different durations of cartoons were available after different delays.

The use of children as young as 3 months means, however, that the present experiment does more than merely duplicate work done with older children, because it also contributes information about the operant performance of very young humans. Lowe et al. (1983) and Bentall, Lowe, and Beasty (1985) presented data on the performance of infants on FI schedules ranging from FI 10 s to FI 60 s, but data from only 4 preverbal children were provided in their two articles. Our study presents data from 8 children much younger than those used by Lowe and his associates, as well as 8 others in the age range they previously studied, and also includes data from a wider range of FI values than previously used.

Our study also presents evidence concerning the performance of very young children on the self-control procedure. Some previous studies (e.g., Miller, Weinstein, & Karniol, 1978) have reported impulsiveness in young children, whereas older children, like adults, are generally found to show self-control (e.g., Sarafino, Russo, Barker, Consentino, & Titus, 1982). Extrapolation of these findings to our very young subjects might therefore suggest that we would find impulsiveness, particularly in our 3- to 5-month-olds. As will be seen below, this prediction was strikingly disconfirmed by the data.

METHOD

Subjects

Twenty-six children between 3 and 23 months of age at the start of the experiment were recruited from the University of Lille nursery. Subjects were chosen at random from the nursery population. No subjects were discarded from the experiment, so all who started the procedures also finished them. Although some children were trained only on FI values up to FI 30 s and others received values up to FI 80 s, these differences were planned and were necessitated by the organization of the nursery and not by the subject's behavior. Table 1 gives the age and gender of each child studied.

Apparatus

The experiment was carried out in a darkened room. Children were seated either on a chair or in a "baby-relax," depending on age, facing a touch-sensitive screen (manufactured by Factory Systems and having a 14-in. diagonal dimension) that served as the response manipulandum. The subject was located at a distance from the screen just greater than arm's length. A color monitor was situated above this screen and was used to deliver the reinforcer, which was various durations of a cartoon with sound. The cartoon was "Le Petit Ours Brun" ("The Little Brown Bear"), a popular French cartoon. Disks or squares of color were projected onto the touch-sensitive screen, according to the condition in force, and touches on these disks or squares were the operant responses registered by a computer (80286, IBM-compatible), which also controlled all experimental events. A touch to any part of the illuminated disk or square with any part of the body caused a response to be registered, but touches to the screen outside the illuminated area did not register. If the subject left his or her hand or finger in contact with the disk or square, no further response was registered until the contact had been broken and reestablished. When no disks or squares were present (e.g., during the prereinforcement delay, see below), the screen was dark (to prevent visual fatigue).

Procedure

All subjects started the experiment with the FI condition, then finished with the self-control procedure. For the first session, each child was introduced to the experimental room by the experimenter and was accompanied by a familiar adult (most often a parent) who did not assist in any way in the experiment. After the first session the familiar adult was absent, and the child was observed through one-way glass by the experimenter. The child was seated

Table 1

Subject number, sex, and age (years-months), and number of sessions at each FI value in the FI condition.

Sub-ject	Gen-der	Age	FI value (s) 10	20	30	40	60	80
1	M	0-3	7	6	6	5	8	8
2	M	0-4	11	8	6	6	8	8
3	M	0-4	9	9	8	7	8	8
4	M	0-4	13	8	7	7	9	9
5	F	0-4	8	8	7	8	10	8
6	F	0-4	9	8	6	6	9	8
7	M	0-5	10	8	8	6	10	6
8	F	0-5	8	7	7	6	9	7
9	M	0-9	12	10	7			
10	F	0-9	17	9	9			
11	M	0-9	5	6	7			
12	M	0-9	8	7	6	7	10	6
13	F	0-11	9	6	6	6	10	8
14	F	0-11	9	8	7	7	9	8
15	F	1-0	7	8	6	6	9	8
16	M	1-1	8	8	7	8	10	8
17	M	1-2	10	8	7	7	7	9
18	F	1-2	10	9	8	5	11	7
19	M	1-3	8	8	7	6	9	8
20	M	1-3	8	7	8	6	10	8
21	F	1-3	11	8	6	5	9	7
22	M	1-3	12	7	6	6	11	9
23	M	1-4	7	6	6			
24	M	1-6	6	7	5			
25	M	1-9	8	7	8			
26	F	1-11	15	10	8			

in front of the touch-sensitive screen and the experiment commenced, without instructions.

FI condition. The session started with the appearance of a yellow disk (10 cm diameter) on the touch-sensitive screen, placed equidistant from the right and left sides of the screen and 3 cm above the bottom. If the child touched this disk before the reinforcer was available under FI, a brief high-pitched sound resulted. A response after the FI interval elapsed was followed by a short low-pitched sound; then the yellow disk disappeared and was replaced by a blue square (5 cm by 5 cm), situated in the same place as the disk. A press on this square produced an orange disk just above the square and a 20-s presentation of a cartoon on the monitor above the touch-sensitive screen. When the cartoon sequence finished, the blue square and orange disk disappeared and the next interval started with the reappearance of the yellow disk. The procedure, in the terminology of Ferster and Skinner (1957), was a chained FI fixed-ratio (FR) schedule.

For the first training session all responses were reinforced; then the FI condition began.

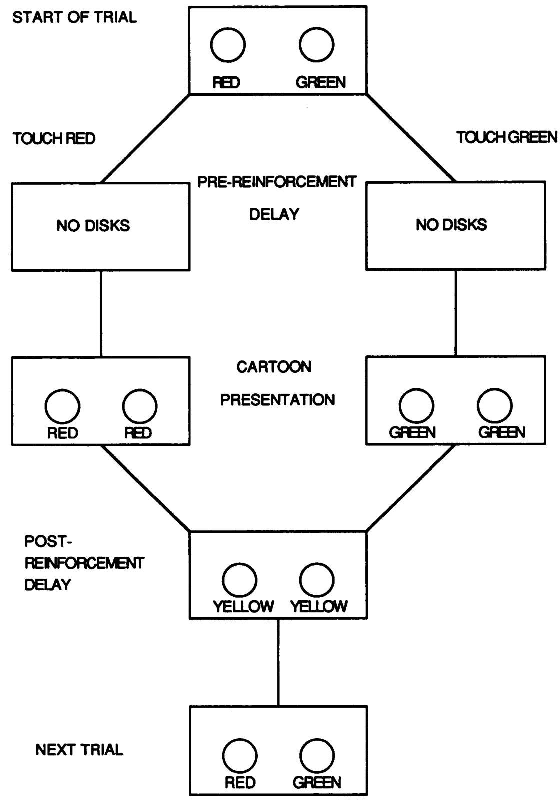


Fig. 1. Schematic outline of the self-control procedure. Size and position of drawn disks do not accurately represent their size and position on the touch-sensitive screen. Trial sequence proceeds from top to bottom, with the left side of the figure showing events following left (red) choice, and the right side showing events following right (green) choice.

All children received at least three different FI values (10, 20, and 30 s), but for most subjects values of 40, 60, and 80 s were also used. The number of sessions at each FI value is shown in Table 1. The passage from one FI value to another was determined by examination of postreinforcement pause values for stability: The mean pause on three consecutive sessions had to vary less than 10% for the FI condition to be terminated. A session lasted on average from 15 to 20 min, but was terminated if the child cried or showed other signs of distress. Four to five sessions were given each week.

Self-control condition. Each self-control session consisted of 14 trials: four forced-choice trials (the first four trials of each session) and 10 free-choice trials (from which the data were collected). The procedure is outlined in Figure 1. During the free-choice trials, the touch-sensitive screen showed two disks in red and green.

Table 2

Procedure for the self-control condition. Values given for the different phases (1 through 6) are seconds of cartoon reinforcer and delays of reinforcer presentation for left and right responses.

	Cartoon duration (s)		Delay (s)	
Phase	Left	Right	Left	Right
1	30	30	0.5	0.5
2	20	40	0.5	40
3	20	40	0.5	0.5
4	30	30	0.5	0.5
5	40	20	40	0.5
6	40	20	0.5	0.5

Table 3

Data from the self-control condition. Shown are phase number (1 through 6), number of sessions in each phase, and the number of left responses in the last session of the phase. The number of right responses is 10 minus the number of left responses. Subjects 1 through 8 were 3 to 5 months old. Older subjects, classified as pause-sensitive under FI, were 10, 13, 16, 17, 21, 22, 23, 25, and 26; subjects classified as pause-insensitive were 9, 11, 12, 14, 15, 18, 19, 20, and 24.

Sub-	Sessions in phase						Left responses in phase					
ject	1	2	3	4	5	6	1	2	3	4	5	6
1	1	3	2	1	4	3	4	2	1	2	9	10
2	1	4	2	1	3	2	6	0	0	0	9	10
3	1	3	3	1	3	3	7	4	0	4	10	10
4	1	2	2	1	2	2	8	2	0	1	10	9
5	1	3	2	1	3	2	3	0	0	0	9	9
6	1	3	2	1	3	2	5	2	2	1	10	10
7	1	4	3	1	3	2	6	1	1	1	10	8
8	1	3	2	1	3	2	8	1	1	2	9	10
9	1	3	3	1	2	2	5	7	1	3	1	10
10	1	3	2	1	3	2	4	2	0	7	9	10
11	1	3	3	1	3	2	6	8	2	3	3	9
12	1	3	2	1	4	3	2	8	1	0	0	9
13	1	4	2	1	5	4	5	2	1	3	9	10
14	1	4	3	1	5	4	3	9	0	2	2	10
15	1	2	2	1	3	3	6	9	0	3	0	8
16	1	3	3	1	3	3	4	3	0	3	9	10
17	1	3	3	1	3	2	7	1	0	4	9	10
18	1	3	2	1	3	3	5	10	1	3	0	10
19	1	4	3	1	4	2	4	8	1	6	1	10
20	1	3	3	1	3	2	4	8	1	0	0	9
21	1	3	3	1	4	3	3	1	0	4	9	9
22	1	4	3	1	3	3	8	1	2	3	9	10
23	1	4	2	1	4	3	7	2	3	6	8	10
24	1	3	2	1	3	2	3	9	0	4	3	8
25	1	2	2	1	3	2	3	1	1	6	8	10
26	1	2	2	1	3	2	3	0	0	5	9	9

If the child touched the left one (red), the two disks extinguished during the prereinforcement delay, the cartoon was presented on the monitor for the arranged duration, and at the same time the touch-sensitive screen showed two red disks. When the cartoon ended, the two disks turned to yellow during the postreinforcement delay, which was calculated so that the total trial length was always 90 s. If the subject touched the right disk (green), the two disks extinguished during the prereinforcement delay, and two green disks were shown on the touch-sensitive screen during cartoon presentation, to be followed by a change to yellow during the postreinforcement delay. At the end of the postreinforcement delay, after both left and right choices, the disks were again both illuminated, one green and one red. The forced-choice trials were identical except that on Trials 1 and 3 the left disk (red) was the only alternative presented, and on Trials 2 and 4 only the right disk (green) was presented. A response produced the consequences shown in Table 2. All subjects received the six phases shown in Table 2, which also shows the duration of the cartoon reinforcer and the delay of reinforcer onset after the response for left and right choices. Subjects received a single session in Phases 1 and 4, which tested for left/right bias (because the delay and the reinforcer duration were the same for left and right response alternatives). For the other conditions, a stability criterion was used, and subjects moved to the subsequent phase when (a) either the choices of the two alternatives remained the same for two sessions or (b) five sessions elapsed in which the choices did not vary by more than 10%. Sessions lasted 23 min on average. The number of sessions of exposure for each subject to each phase is shown in Table 3.

RESULTS

FI Condition

Inspection of the results obtained from the FI conditions revealed that two distinct response patterns were produced by different subjects. Some subjects acquired a low-rate response pattern, with a postreinforcement pause (the time from the start of the interval to the first response occurring in it) that usually exceeded the FI parameter value. This meant that most intervals involved the emission of a single, reinforced, response. In these cases, measures of response rate during the interval are meaningless. For other subjects, whose pauses were much shorter than the interval value and who responded many times in the interval, the conventional measure of running response rate (the response rate occurring during the interval after termination of the postreinforcement pause) accurately reflected subjects' behavior and is presented below.

3- to 5-month-olds. The upper panel of Figure 2 shows mean postreinforcement pauses and the lower panel shows the mean percentage of intervals that involved only a single response from the 3- to 5-month-old subjects. The data are from the last three sessions of exposure to each FI value. Postreinforcement pauses of all subjects systematically increased as the FI value was increased from 10 to 80 s; in fact, mean pause value increased monotonically with FI value for all subjects. Values from individual subjects were sufficiently similar to be often nearly superimposed in Figure 2, indicating low between-subject variability. Absolute mean pause values just exceeded the FI value, at all FI values and for all subjects. For example, for a representative subject, S1, the mean pause values in seconds (FI value in parentheses) were 12.1 (10), 21.7 (20), 31.9 (30), 43.2 (40), 63.5 (60), 83.8 (80).

The lower part of Figure 2 shows the percentage of intervals that were of the pause/single-response type, meaning in effect that the postreinforcement pause exceeded the FI value. All subjects produced a high proportion of intervals of this type in the last three sessions of exposure to all FI values, with the minimum percentage being 66.9% and the maximum 88.4%, but no subject showed any monotonic change in percentage of intervals of this type as the FI value changed. For the representative subject S1, the percentages (FI value in parentheses) were 73.5% (10), 81.5% (20), 75.2% (30), 80.7% (40), 72.4% (60), and 83.7% (80).

9- to 23-month-olds. Inspection of the data from the remaining 18 subjects suggested that there were systematic individual differences in performance under FI schedules. For 9 subjects, mean postreinforcement pauses increased monotonically with FI value, and most intervals involved the emission of a single response. This type of change in mean postreinforcement pause can thus be used to classify these subjects as pause-sensitive under the FI contingency, with the requirement for this classification simply being that mean postreinforcement pause increases monotonically with FI value. The subjects falling into this category were Subjects 10, 13, 16, 17, 21, 22, 23, 25, and 26. For the other 9 subjects (classified as pause-insensitive), there was no monotonic change in postreinforcement pause with increases in the FI value, and running rates could be calculated. The pause-insensitive subjects were Subjects 9, 11, 12, 14, 15, 18, 19, 20, and 24. It should be noted that all the 3- to 5-month-old subjects were pause-sensitive according to this classification scheme.

Figure 3 shows postreinforcement pauses and proportion of intervals involving a single, reinforced, response for subjects classified as pause-sensitive, with data coming from the last three sessions of exposure to each FI value. For all subjects, mean postreinforcement pauses increased monotonically with FI value and always exceeded the FI value. Pause values (in seconds) from a representative subject, S13 (FI value in parentheses), were 11.84 (10), 24.81 (20), 34.91 (30), 46.24 (40), 63.46 (60), and 84.51 (80). The percentage of intervals with a single reinforced response was high for all subjects (minimum 69.7%, maximum 90.1%), and in no subject was there any tendency for systematic change in this percentage as the FI value varied. Percentages of single-response intervals for S13 (FI in parentheses) were 78.3% (10), 84.7% (20), 83.5% (30), 84.9% (40), 76.6% (60), and 85.3% (80).

Figure 4 shows data from subjects classified as pause-insensitive. For these subjects, mean pause values were always lower than the FI parameter value and numerous responses preceded reinforcement, thus permitting the use of the conventional running-rate measure of responding. Mean postreinforcement pauses and running rates are shown in Figure 4. Individual mean postreinforcement pauses from pause-insensitive subjects were low (from 3 s to just over 8 s on average), and the group median pause showed no systematic change with FI value. In fact, no subject showed any monotonic increase in postreinforcement pause with changes in FI value. Pause values (in seconds) from a representative subject, S12 (FI value in parentheses), were 5.85 (10), 6.77 (20), 4.39 (30), 5.55 (40), 6.91 (60), and 6.42 (80). Running rates from the pause-insensitive subjects (lower panel of Figure 4) ranged from 12.45 to 91.2 responses per minute over all subjects, but group medians ranged from only

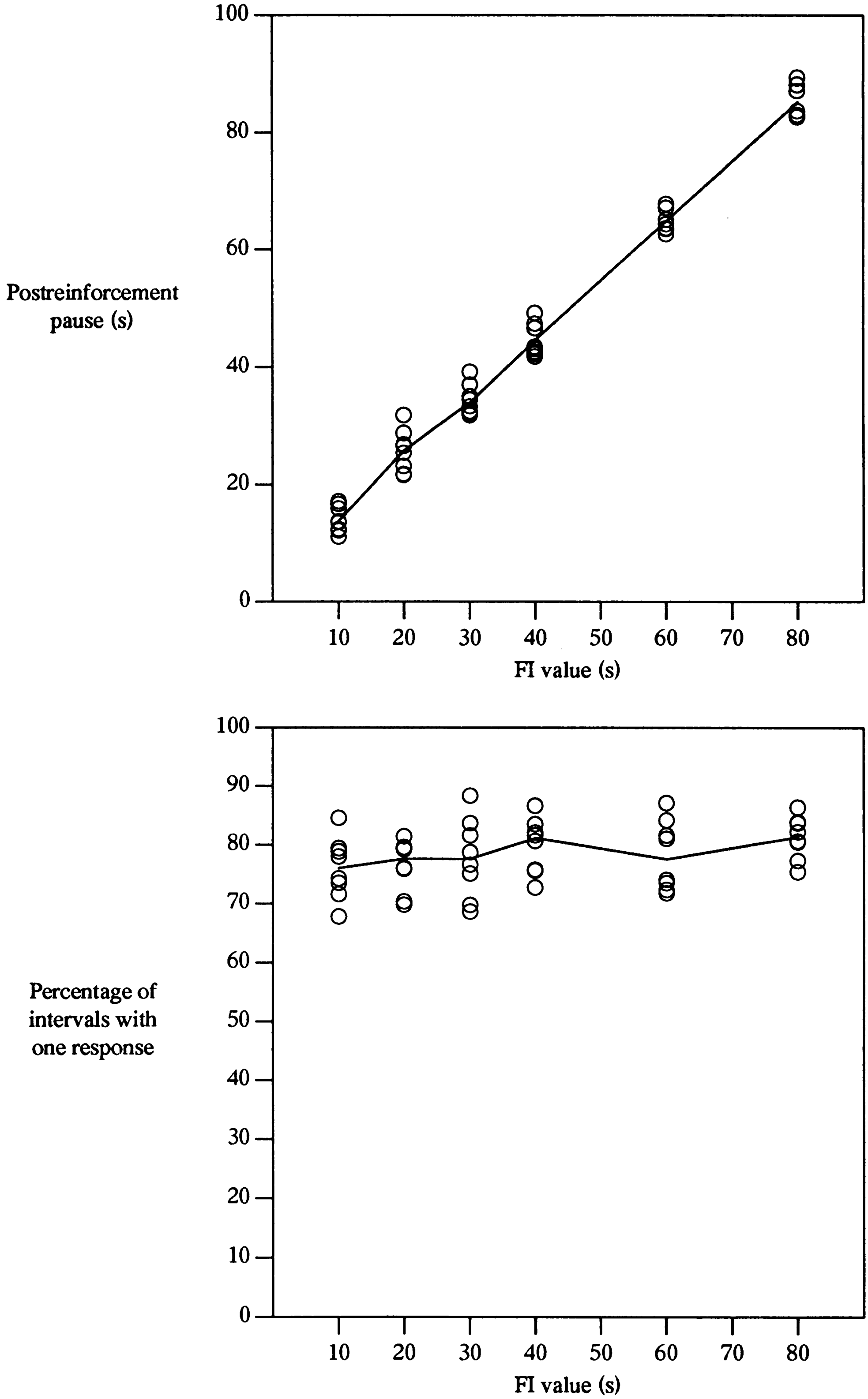


Fig. 2. Fixed-interval performance of the 3- to 5-month-old subjects. Upper panel: mean postreinforcement pause (s) plotted against FI value (s). Lower panel: percentage of intervals containing a single response at each FI value used. In both panels, unfilled circles show data from individual subjects and solid lines connect group medians.

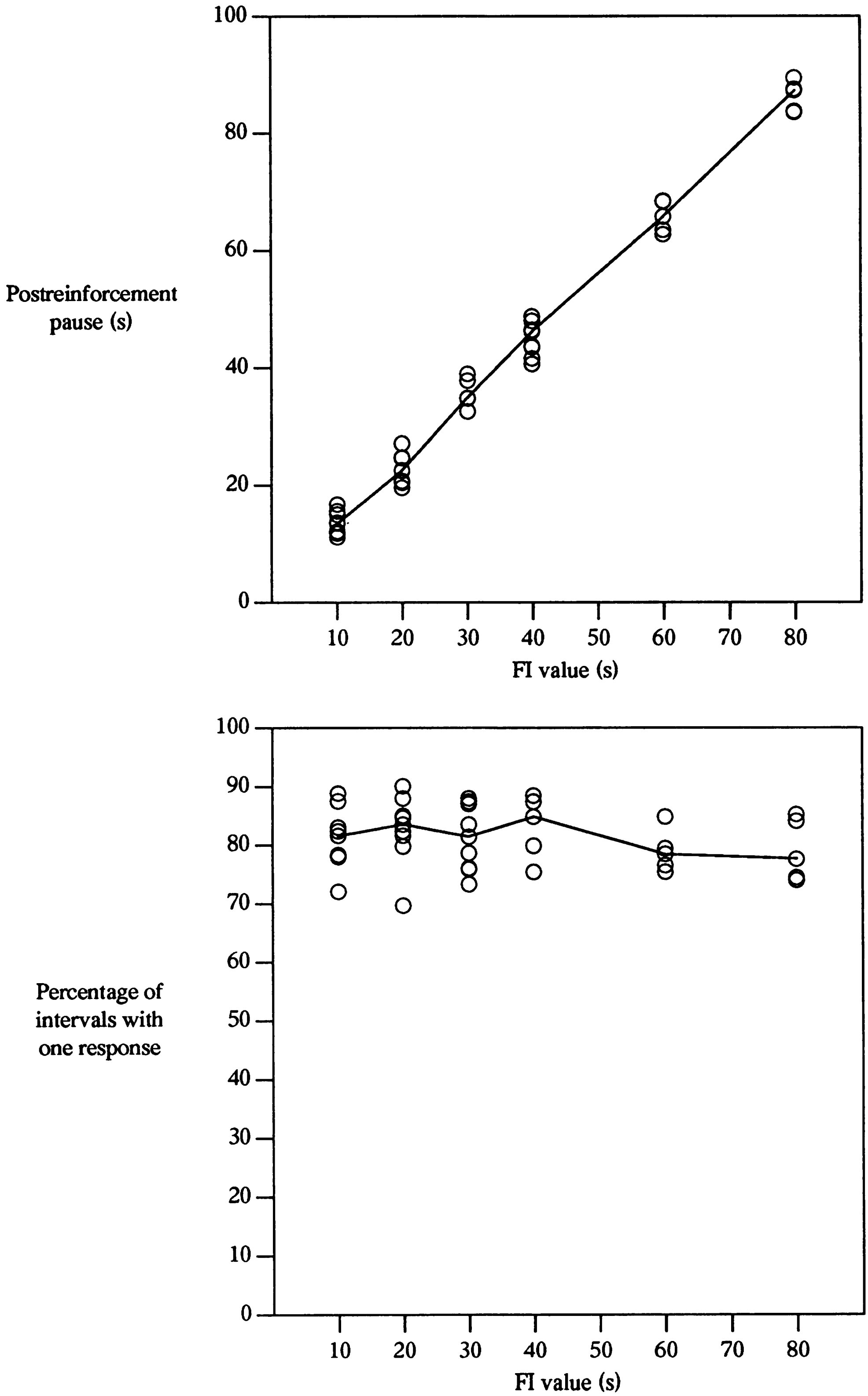
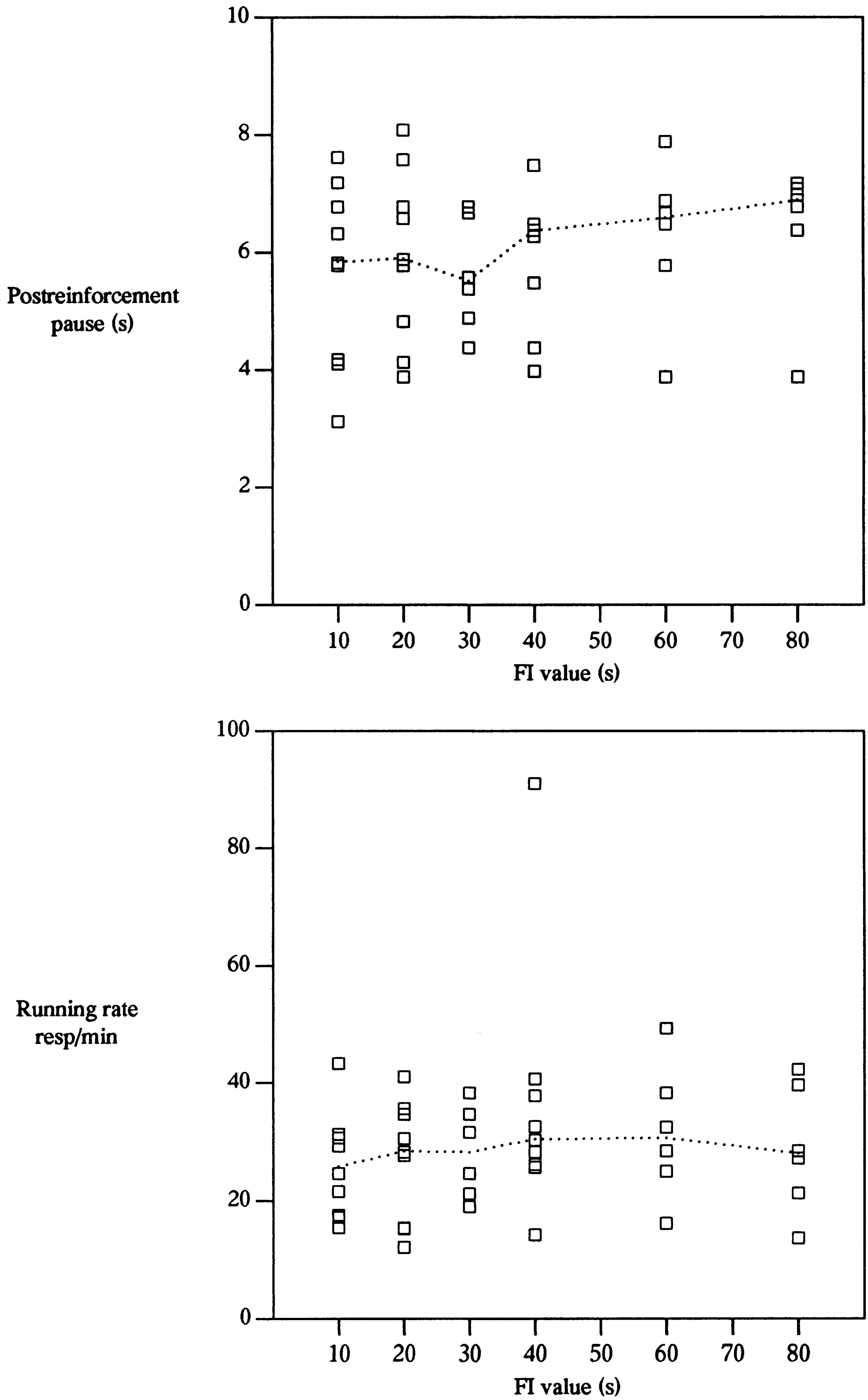


Fig. 3. Fixed-interval performance of 9- to 23-month-old subjects classified as pause-sensitive during the FI condition. Upper panel: mean postreinforcement pause (s) plotted against FI value (s). Lower panel: percentage of intervals containing a single response at each FI value used. In both panels, unfilled circles show data from individual subjects and solid lines show group medians.



Postreinforcement pause (s)
10
8
6
4
2
0
10 20 30 40 50 60 70 80
FI value (s)
Running rate resp/min
100
80
60
40
20
0
10 20 30 40 50 60 70 80
FI value (s)

25.9 to 30.5 responses per minute, indicating no overall systematic change in response rate with FI value. In fact, no individual subject exhibited a monotonic change in running rate with FI value. Rates from S12 (responses per minute with the FI value in parentheses) were 30.88 (10), 35.81 (20), 34.94 (30), 32.83 (40), 38.47 (60), and 39.76 (80).

Acquisition of low-rate responding. Because the pause/single-response pattern exhibited by the 3- to 5-month-old subjects and the pause-sensitive older subjects, at all FI values, was somewhat unusual and illustrated an unexpected precision of temporal regulation of behavior, it is important to demonstrate that this response pattern was an acquired mode of responding and not, for example, the result of very low-rate random responding. Acquisition data become clearly relevant here, and Figure 5 shows some typical examples of responding in the first session after transition from one FI value to another (in this case from FI 10 s to FI 20 s) and final performance on the second FI schedule after prolonged exposure.

The upper panel of Figure 5 shows the postreinforcement pause and the number of responses per interval (including the reinforced response) during the last 13 intervals (roughly representing the last 5 min) of the first session of FI 20 s after previous FI 10 s training for S5 and S6, both 3- to 5-month-olds. It is clear that the transition to the pause/single-response pattern that would later be characteristic of these subjects was not immediate. Pauses for both subjects averaged about 13 s, and different intervals contained from two to five responses (including the reinforced response). Translated into conventional running rates, values would be 36 responses per minute for both subjects if the reinforced response was included and 25 and 26 responses per minute if it was not. The lower panel of Figure 5 shows postreinforcement pauses produced in the last 15 intervals from the final session (Session 8) of FI 20 s for S5 and S6. Number of responses per interval is not shown, because all intervals but one had a single response (the remaining interval had two responses after a pause of 19.2 s). It is clear from comparison of the data in the two panels that the pause/single-response pattern observed in our 3- to 5-month-olds was an acquired behavioral adjustment that developed with schedule exposure. Although running rates from the final

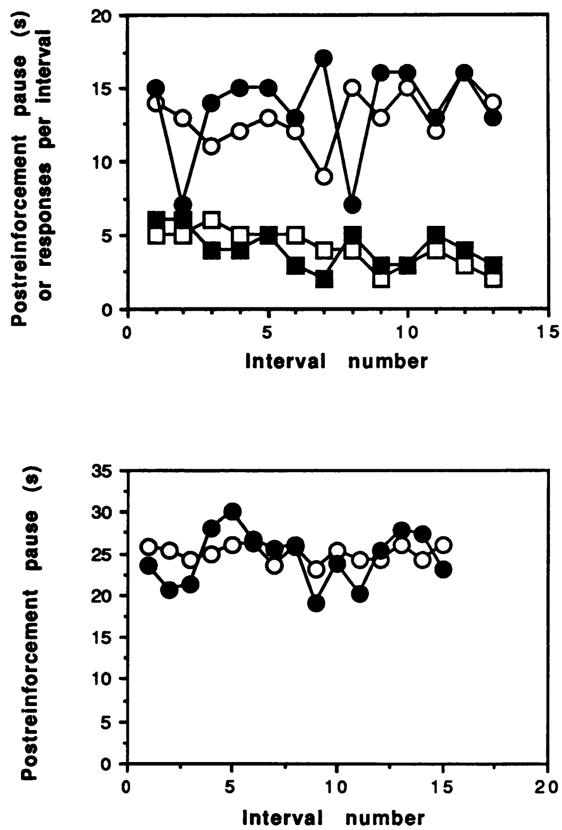


Fig. 5. Acquisition of pause/single-response pattern under FI from 2 representative subjects (S5, open circles and squares; S6, filled circles and squares). Upper panel: data from last 5 min of the first session of FI 20 s after previous FI 10 s training. Circles show postreinforcement pauses per interval, and squares show number of responses per interval, including the reinforced response. Lower panel: data from last 15 intervals of a session showing stable performance under FI 20 s. Postreinforcement pause values are shown, and all intervals except one (see text for details) involved the emission of a single, reinforced, response. Note the different scales for the two panels.

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Fig. 4. Fixed-interval performance of 9- to 23-month-old subjects classified as pause-insensitive during the FI condition. Upper panel: mean postreinforcement pause (s) plotted against FI value (s). Lower panel: running response rate (responses per minute). In both panels, unfilled squares show data from individual subjects and dotted lines connect group medians.

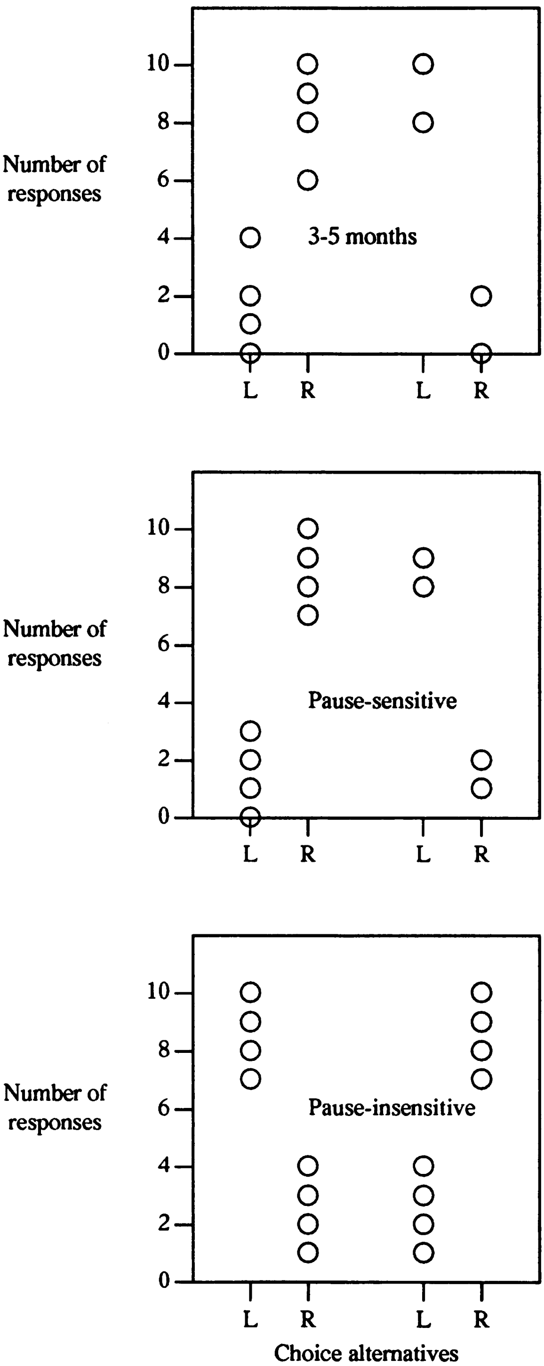

Fig. 6. Performance of subjects during the last session of Phases 2 and 5 of the self-control condition. In each panel, the left half shows data from Phase 2 (L choice is impulsive, R choice shows self-control), and the right half shows data from Phase 5 (L choice shows self-control, R choice is impulsive). In each panel, unfilled circles show individual-subject data, and in many cases data points are superimposed. Upper panel: 3- to 5-month-olds. Center panel: older subjects classified as pause-sensitive under FI. Bottom panel: older subjects classified as pause-insensitive under FI.

sessions of FI in these subjects are not meaningful, a schedule transition like the one illustrated in the upper panel of Figure 5 shows that subjects could respond more than once each interval early in training.

The acquisition pattern shown in Figure 5 was typical of transitions from one FI value to a longer one in all 3- to 5-month-old subjects, and in all pause-sensitive 9- to 23-month-old subjects. In general, behavior immediately after the transition reflected the influence of previous training (i.e., pause length appropriate to the previous FI, and a number of responses per interval), and this was succeeded over sessions by the pause/single-response pattern characteristic of the stable FI performance of these subjects.

Self-Control Condition

The different phases of the self-control condition examined different aspects of responding in this situation. Phases 2 and 5 tested whether behavior was self-controlled or impulsive, in that 40 s of cartoon delayed for 40 s was offered concurrently with 20 s of cartoon delayed for 0.5 s. In Phase 2 the left response was impulsive and the right self-controlled, and in Phase 5 the right response was impulsive and the left self-controlled. Table 3 shows the number of left responses made in the last session of each of the six phases of the self-control condition, but data from Phases 2 and 5, the self-control tests, are abstracted in Figure 6.

Figure 6 shows performance in Phases 2 and 5 of the self-control condition separately for the 3- to 5-month-olds, the pause-sensitive 9- to 23-month-olds under FI, and subjects whose pauses showed no systematic change as the FI varied. There are fewer data points shown than subjects, because many data points overlapped. Consider first the data from the 3- to 5-month-olds (upper panel). It is evident that subjects overall exhibited self-controlled choices (choice of right in Phase 2, left in Phase 5), manifested in more right than left choices in Phase 2 and more left than right choices in Phase 5. All subjects showed this pattern; S1, for example, produced 2 out of 10 responses on the left in Phases 2 and 9 out of 10 on the left in Phase 5.

The center panel of Figure 6 shows performance of 9- to 23-month-old subjects who were pause-sensitive to the previous FI contingencies during Phases 2 and 5 of the self-control condition. Here, all subjects exhibited self-controlled choices, making more right than left choices in Phase 2 and more left than right choices in Phase 5. Data for S13, for example, were 2 out of 10 on the left in Phases 2 and 9 out of 10 on the left in Phase 5.

The bottom panel of Figure 6 shows performance of subjects who were pause-insensitive during the previous FI. Here, impulsive choice was evident, in that all subjects made more left than right choices in Phase 2 and more right than left choices in Phase 5. Data from S12 were 8 out of 10 on the left in Phase 2 and no left responses in Phase 5.

Phases 1 and 4 of the self-control condition tested any left/right bias that subjects might possess; in both cases, 30 s of cartoon delayed for 0.5 s was presented after both left and right choices. In the 3- to 5-month-old group, all subjects (except S6 in Phase 1) made unequal numbers of left/right choices in Phases 1 and 4. In Phase 1, 5 subjects made more left than right choices and 2 more left than right (with S6 equal). In Phase 4, all 8 subjects made more right than left responses. This means that some subjects shifted bias markedly between Phases 1 and 4 (e.g., S8 with eight left responses in Phase 1 and two left responses in Phase 4). The possible cause of the consistent right bias in Phase 4 is the fact that in the previous phase the longer cartoon duration was available after a right response. For older pause-sensitive subjects, biases in the self-control condition were about equally spread between left and right in Phase 1 (4 subjects left bias, 4 right bias, and 1 no bias) and only slightly biased to right in Phase 4 (4 subjects right bias, 3 left bias, 1 unbiased). Previously pause-insensitive subjects likewise tended to exhibit left/right biases. In Phase 1, 5 subjects had a right bias, 2 a left bias, and 2 no bias; in Phase 4, 7 subjects showed right bias and 2 left. In general, therefore, all 3 subject populations exhibited stronger right-response biases in Phase 4 than in Phase 1, but changes of bias between phases were common.

Phases 3 and 6 of the self-control condition tested preference for the longer cartoon duration when durations of 20 and 40 s were both delayed by 0.5 s, with the larger value being available for the right choice in Phase 3 and the left choice in Phase 6. All 3- to 5-month-old subjects chose the longer cartoon duration more frequently in both Phases 3 and 6, with choice often being exclusive. For example, S1 made 8 out of 10 responses on the right in Phase 3, and 10 of 10 on the left in Phase 6. The same pattern of response was noted in all the older subjects (whether pause-sensitive or pause-insensitive under FI), in that all subjects chose the longer cartoon duration over the shorter one in all conditions, with choice often being exclusive.

DISCUSSION

The results of the present experiment can be summarized simply. Under FI schedules (usually values ranging from FI 10 s to FI 80 s) behavior of 3- to 5-month-old subjects adjusted to the FI schedule by producing mean postreinforcement pauses just exceeding the FI value and few responses, usually only one, in each interval. Older subjects (9 to 23 months) exhibited two different response patterns. Nine subjects, defined as pause-sensitive, behaved like the younger children, whereas 9 others, defined as pause-insensitive, produced shorter postreinforcement pauses that did not change with interval value, and also produced higher response rates. Under the self-control condition, all subjects preferred the longer duration of cartoon to the shorter (thus, all were sensitive to the reinforcer duration to some extent), but only the 3- to 5-month-olds and the pause-sensitive older children exhibited self-controlled choices. The relation between performance under FI and the self-control condition is sufficiently striking to emphasize that all subjects defined as showing pause sensitivity to the FI schedule showed self-control in both the self-control tests (with no failures) and all subjects who were pause-insensitive under FI failed to exhibit self-control (with no exceptions). The FI/self-control relation found here thus replicates, with much younger children, the result obtained by Darcheville et al. (1992) with children of 5 and 6 years of age. There, likewise, subjects showing pause sensitivity to FI schedules (by exhibiting long pauses and low response rates) also showed self-controlled choices, whereas pause-insensitive subjects made impulsive ones. Thus, apparently, performance on either task can be used as a near-perfect predictor of performance on the other. In the Darcheville et al. (1992) study, performance in the self-control phase was used to define two groups whose behavior was found to differ under FI; in the present study, performance under FI, coming first, could be used to classify subjects who were subsequently found to behave differently during the self-control tests.

In addition to the clear FI/self-control relation obtained in our experiment, another striking feature was the performance on FI and the self-control procedure shown by our young subjects. We will discuss their FI performance first. In our study, all 8 3- to 5-month-old children exhibited a type of temporal regulation under FI previously noted in older children and adults—that of low-rate responding—in which subjects pause for a period that averages close to the FI value, then make one or a few responses that are immediately reinforced (see Weiner, 1962, 1969, and Lowe, 1979, for examples). Our youngest subjects did not show the nonhuman-like scalloped performance reported by Lowe et al. (1983) and Bentall et al. (1985) from infants ranging in age from 9 to 13 months. It should be emphasized, however, that the different results we have obtained do not constitute a failure to replicate a well-established finding. Data from only 4 children are presented in the two articles by Lowe and his colleagues, with FI values ranging from FI 10 s to FI 60 s (although no subject experienced more than three FI values), whereas the present study provides a larger body of data (8 children in the 3- to 5-month range and another 8 between 9 and 13 months, the age range used in the experiments by Lowe and his associates) as well as a wider range of FI values (10 to 80 s), with most children being exposed to six different FI values.

Why were our results different from those obtained by Lowe et al. (1983) and Bentall et al. (1985)? Part of the answer may lie in procedural differences. Our study was carried out in a laboratory, without any adult present after the first experimental session, whereas their studies were conducted in the children's homes, with adults presumably present throughout the experiment. The absence of other people in the experimental setting meant that behavior other than that related to the operant task (such as social behavior) was less likely to occur and be reinforced in our study than in those carried out by Lowe and his associates.

Another procedural difference was that the response manipulanda were different in the Lowe studies and our own, in that they employed a metal cylinder (40 cm long) as a manipulandum and a touch-sensitive screen was used in our work, with the response directed towards a precise location on this screen. Some studies with animals have noted that the type of behavior exhibited on schedules involving temporal regulation can depend on the response employed (for a review see Lejeune, 1990), although effects of response manipulanda on the form of responding are usually clearer on temporal differentiation schedules (Jasselette, Lejeune, & Wearden, 1990) than on FI schedules (Lejeune & Jasselette, 1985).

A further difference between our study and those from Lowe's laboratory involved the reinforcer used. We employed the same reinforcer (cartoon presentation) for all subjects, whereas the Lowe studies used different reinforcers (musical stimuli, snacks, etc.) that differed among subjects as well as sometimes being variable for a single subject. The relative reinforcing power of our cartoons and the reinforcers in the earlier studies cannot be directly assessed, but our reinforcers not only supported behavior on longer FI schedules than used previously (their maximum value, attained by 1 subject, was FI 60 s) but also produced parametric sensitivity to reinforcer duration, in that all subjects preferred 40 s to 20 s of cartoon in self-control Phases 3 and 6. This latter result, as well as the performance on the self-control task in Phases 2 and 5, indicates that subjects were sensitive to reinforcer duration and preferred longer durations.

The self-control performance of our youngest subjects, like their FI performance, differs somewhat from what might be expected on the basis of downward age extrapolation based on the results of other research. Most previous work describes younger children as more impulsive than older children (Miller et al., 1978; Sonuga-Barke, Lea, & Webley, 1989a, 1989b) and adults (Logue, Peña-Correal, Rodriguez, & Kabela, 1986), with the exception of situations in which the choice of the smaller immediate reinforcer yields higher overall reinforcement rate, in which case older children may choose the smaller reinforcer (Sonuga-Barke et al., 1989b). Recent comparisons of self-controlled and impulsive choices in children from 4 to 12 years old (Sonuga-Barke et al., 1989a, 1989b) suggest that 4-year-old children made impulsive choices, whereas 6- to 9-year-olds were sensitive to reinforcer amount rather than to delay and so chose the larger reinforcer even when, as in Sonuga-Barke et al. (1989b), this led to an overall lower reinforcer rate per session than did choice of the smaller reinforcer. In our procedure, because total trial duration was fixed at 90 s, the choice of the longer cartoon duration (even if delayed) always produced more total cartoon time per session than did choice of the shorter duration, so the conflict between reinforcer magnitude and overall reinforcement duration did not arise. Our 3- to 5-month-old subjects all exhibited self-controlled behavior by choosing the longer, delayed, cartoon presentation, and thus tended to maximize the total duration of cartoon per session.

Because adults usually behave in a self-controlled way on operant tasks and children often do not, self-control tends to be regarded as a behaviorally more advanced adaptation to the choice situation than is impulsivity (except in the cases described above in which choice of the larger reinforcer decreases overall reinforcement rate); this leads to the apparent paradox in our data that the youngest children appeared to exhibit more mature behavior than did many of the 9- to 23-month-olds (and even many of the 5- and 6-year-old subjects in Darcheville et al., 1992). One way to deal with this apparent problem is to note that in our study, a simple preference for the longer cartoon duration, which takes no account of delay, would lead to self-controlled choice, whereas impulsivity would result from some combination of delay and reinforcer duration, such as some sort of temporal discounting mechanism based on delay of reinforcement (Ainslie & Herrnstein, 1981; Navarick & Fantino, 1976). If there is no discounting, then self-controlled responding will result. By this argument, the behavior of our youngest subjects is, in fact, simpler than that of the older children, because it takes account of only one dimension of the reinforcer, whereas the older children's choice may result from a "balance" of reinforcer magnitude and delay.

However, this explanation does not take into account the FI/self-control relation noted above (and in Darcheville et al., 1992) in which subjects who make self-controlled choices emit low response rates and long postreinforcement pauses under FI, whereas subjects who make impulsive choices produce higher response rates and short pauses that do not vary with the FI value. If our younger children were sensitive only to reinforcer duration, and not delay, in the self-control phase, it is unclear why their FI performance should show the low-rate pattern in a situation in which reinforcer duration remained constant but the delay from the start of the interval to the time of availability of the next reinforcer delivery varied systematically across FI values. The fact that subjects' mean postreinforcement pauses tracked the interval so precisely indicates high, rather than zero, sensitivity to reinforcer delay. This sensitivity seems to contradict the notion that our 3- to 5-month-old subjects were unable to take account of delay, and so reopens the question of why their behavior exhibited such clear self-control when that of half the older subjects did not. One possibility is that the development of verbal behavior, as it occurs in the older group, actually interferes with temporal regulation and adaptive choice in some subjects, even though later on in adults, verbal behavior may play an adaptive role. A similar suggestion, that younger children may exhibit better temporal regulation than older children, or even adults, because later developmental processes exert an interfering effect, was advanced by Brackbill and Fitzgerald (1972) following their discovery that Pavlovian temporal conditioning of pupillary reactions was established much more easily in 1- to 3-month-old children than in adults.

Following from this, our results clearly bear on the issues of whether the operant behavior of normal humans is like that of nonhumans, and why not, if it is not. As noted above, our youngest subjects made self-controlled choices in the self-control task and long pauses and low response rates on FI, a pattern shown also by half the 9- to 23-month-olds. In general, most studies of nonhuman choice show it to be impulsive, although exceptions exist (Logue, 1988), and nonhumans do not usually exhibit the low-rate behavior pattern on FI noted in our 3- to 5-month-old subjects. Thus, our subjects behaved differently than nonhumans do on both tasks. One explanation advanced for the often-obtained differences between nonhuman and human operant performance is that human operant behavior, unlike that of nonhumans, is under verbal control (Lowe, 1979). That is, "human language may be the principal factor involved in these [nonhuman/human] differences" (Bentall et al., 1985, p. 165). There is ample evidence that the operant behavior of normal adults and older children can be under verbal control. For example, verbal instructions markedly change behavior in both children and adults (Bentall & Lowe, 1987; Buskist, Bennett, & Miller, 1981), strong correlations are found between schedule performance and verbal behavior in subsequent postexperimental questionnaires (Lippman & Meyer, 1967; Wearden & Shimp, 1985), and verbalizations generally precede nonverbal behavior changes both in adults (Wearden, 1988) and in 11-year-old children (Pouthas et al., 1990). The verbal control exhibited in adult operant behavior must have developed in some way, and the verbal-control hypothesis has clear developmental implications, although exactly how adult-like verbal control of behavior develops is still obscure (Pouthas et al., 1990). Bentall et al. (1985) advanced a strong developmental prediction that "the schedule performance of infants, who have not yet acquired the relevant verbal skills, should show animal rather than human adult characteristics" (p. 165), and found that this prediction was supported by the FI performance of 4 9- to 13-month-old children (see also Lowe et al., 1983). It is clear, however, that the FI performance of our youngest group and of our other subjects who were in the same age range (9 to 13 months) as the infants studied by Lowe et al. (1983) and Bentall et al. (1985) did not support Bentall et al.'s prediction, because these obviously preverbal infants produced either low-rate response patterns (3- to 5-month-olds) or both low-rate and high-rate patterns (9- to 13-month-olds). These results, which are supported by a larger body of data than that provided from infants in Lowe et al. (1983) and Bentall et al. (1985), may not so much contradict the verbal-control hypothesis (because, as noted above, it is supported by evidence obtained in experiments with adults and older children) as suggest that it needs some refinement.

It should be acknowledged that some authors have challenged the exclusive emphasis on verbal behavior as an explanation of apparent nonhuman/human differences in operant behavior. For example, Perone, Galizio, and Baron (1988) argue that nonhuman performance is often less regular than claimed (e.g., "classic" FI schedule effects like scalloping may not always be found in nonhuman experiments; see also Wanchisen, Tatham, & Mooney, 1989), and that measures of verbal behavior taken in some experiments may be neither reliable nor objective. They further note that conditions of exposure to reinforcement schedules are very different in nonhumans and humans (e.g., different reinforcers, different numbers and lengths of sessions, etc.), and that these procedural differences may play a critical role in determining apparent nonhuman/human differences. These arguments are somewhat peripheral to the data presented in the present article, because our subjects (either completely nonverbal or with only the most rudimentary verbal skills) generally emitted behavior very different from that exhibited by nonhumans without any possibility of the intervention of extensive verbal behavior. Furthermore, the data from our youngest subjects and the pause-sensitive older ones exhibit a remarkable degree of orderliness under FI, as well as striking regularities in the self-control condition, and stabilized rapidly even though the amount of schedule exposure was much smaller than usually given to nonhumans.

In a discussion of developmental changes in choices made in a self-control procedure, Sonuga-Barke et al. (1989a, p. 196) argued that self-control develops because of increasing socialization in societies that value delay of gratification and regard larger delayed reinforcers as more attractive. Although this may be true of older children, it is hard to see how the self-controlled performance of our youngest subjects can be explained in these terms. The behavior of our youngest subjects may provide an example of the case in which the behavior of humans does not resemble that of other animals but is nevertheless not under verbal control, nor is it reasonable to suppose that it has developed as the result of social contingencies.

Reports of behavior with these characteristics are by no means unprecedented, even when human adults are used as subjects. One case is apparently provided by studies of eyelid conditioning in humans (Martin & Levey, 1991). With this technique, postexperimental questionnaires showed little evidence of awareness of the stimulus relations presented (the task was usually described to subjects as one involving simple reactions to stimuli), so the behavior exhibited was presumably not under strong verbal control (Frcka, Beyts, Levey, & Martin, 1983), nor is it clear how social contingencies might influence such a response. Nevertheless, human eyelid conditioning exhibits some features different from the analogous behavior in other animals; for example, extinction is extremely rapid, often within a few trials, and the phenomenon of "blocking," routinely obtainable in the nonhuman laboratory, is extremely difficult to demonstrate in humans (Martin & Levey, 1991).

Conversely, it is possible that nonhuman-like behavior in humans may occur in situations in which behavior is clearly under verbal control. One example is provided by Lowe and Horne (1985), who discussed verbal behavior linked to strategies of "matching" on concurrent variable-interval schedules (a behavior commonly found in nonhumans, see Wearden & Burgess, 1982, for a review), and even provided an example of how a matching rule was communicated from 1 subject to another, presumably by verbal behavior. In addition, Wearden (1988) discussed the possible case in which nonhuman-like behavior may be established by direct instruction.

The present data illustrate that much remains to be discovered about the conditions under which the operant behavior of humans and other animals appears similar or different. Although previous work has suggested an important role for verbal behavior in explaining these behavioral differences, the methods used in the present work, which obtained "conventional" operant responses from children much younger than normally studied, show that even when verbal behavior is completely absent or extremely rudimentary, our own species may exhibit unique behavioral characteristics.

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