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THE DEVELOPMENT OF ADAPTIVE CHOICE IN A SELF-CONTROL PARADIGM

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Sixteen girls (ages 4, 6, 9, and 12) performed on concurrent-chain schedules of reinforcement. The initial links were variable-interval 10-s schedules, and the terminal links offered a long delay (20, 30, 40, or 50 s) followed by two tokens or a short delay (10 s) followed by one token. Tokens were used to buy toys and sweets. The effect of increasing the delay to the large reward differed significantly across age groups. Whereas 6- and 9-year-olds maintained a strong preference for the larger, more delayed reward under all delay conditions, half of the 4-year-olds and all the 12-year-olds showed increasing preference for the small reward as the delay to the large reward increased. The results suggest a two-stage account of the development of self-control. In the first stage, behavior is increasingly controlled by reward size, as children learn how to wait for delayed rewards, and in the second phase behavior is increasingly controlled by reward rate, as children learn when it is in fact profitable to wait.

Key words: development, adaptation, self-control, concurrent-chain schedules of reinforcement, block press, children

Personality theorists have often used choices between large delayed and smaller more immediate rewards as a test of a child's self-control (Mischel, 1981; Pressley, 1979). Subjects who either choose the small immediate reward or are unable to wait for the larger delayed reward are considered to be impulsive (Mischel, 1981). In contrast, a subject who chooses the large delayed reward is said to have attained self-control (Mischel & Patterson, 1976) and so developed "... a more mature personality orientation ..." (Furnham & Lewis, 1986, p. 83). Consequently, increases in preference for the alternative correlated with the large reward are regarded as an important predictor of a child's normal development.

Behavior analysts have taken a different approach. Quantitative models of choice, based on the assumption that organisms sharply discount delayed reward, predict impulsivity, that is, an increase in the relative rate of responding to the alternative offering the small reward, as the delay to the large reward is increased. This choice pattern is assumed to be insensitive to its effects on relative reward rate. Although data from many animal experiments support this prediction (see Ainslie & Herrnstein, 1981; Commons, Mazur, Nevin, & Rachlin, 1987; Navarick & Fantino, 1976; Rachlin & Green, 1972), the evidence that similar processes occur in humans is less convincing.

For example, Logue, Peña-Correal, Rodriguez, and Kabela (1986) found that human subjects were insensitive to manipulations in the length of delay to the larger reward when these increases were unrelated to changes in rate of reward access (i.e., when they were compensated for by increases in postreward delay). Millar and Navarick (1984) did find some sensitivity to postreward delay, in that significantly more subjects chose the small reward when the postreward delay period was removed, so that the rate of reward access was greater for the schedule involving the smaller reward. Subjects who consistently obtained the small immediate rewards on the uncompensated schedules obtained more rewards per experimental session than if they had chosen the large reward. In this situation, waiting for the large reward on the uncompensated schedules is not "rational" in the economic sense (Navarick, 1986; Sonuga-Barke, Lea, & Webley, in press).

The difference between the approaches taken by personality theorists and by behavior analysts makes it necessary to look again at theories of the development of self-control. Is there, in fact, a direct relationship between age and

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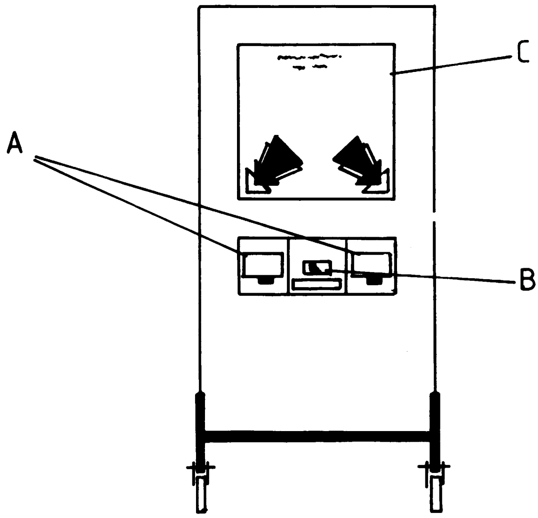

Fig. 1. The experimental apparatus. A; response blocks; B; token dispenser; C; computer monitor.

an increasing preference for the large delayed reward on self-control tasks (e.g., Mischel & Metzner, 1962)? Millar and Navarick's (1984) data suggest that under at least some circumstances, even adult subjects may choose a smaller, more immediate reward and that they are right to do so—or at least, that doing so is economically rational. In other words, subjects eventually develop a sensitivity to the joint effects of delay and frequency of reward and so behave adaptively, even where adaptive behavior requires a reversal of the supposed steady developmental trend toward preference for a larger delayed reward.

In the present experiment this prediction was tested by studying children of four different ages in an operant self-control paradigm. All subjects were exposed to increasing delays to the larger of two rewards, with no compensating postreward delay accompanying the smaller reward; it was predicted that, whereas the youngest subjects would behave impulsively and so always prefer the shorter delay, the oldest subjects might choose in such a way as to maximize overall reward rate. With the schedule parameters used in the present experiment, this involved choosing the longer delay when it was (relatively) short, but the shorter delay when the longer delay was at its highest values. Because gender differences in the development of self-control have been reported (Trommsdorff & Schmidt-Rinke, 1980), subjects of only one gender were used.

METHOD

Subjects

A total of 16 girls participated, four at each of four ages, 4, 6, 9, and 12 years. They were recruited through personal contact and letters sent out to play groups.

Apparatus

The experimental contingencies were implemented on a microcomputer (BBC Model B, Acorn® Computers PLC). The computer monitor was housed in the portable module shown in Figure 1. On the face of this module were two three-dimensional wooden response blocks, one red and one blue, and a token dispenser. The blocks had dimensions of 9 by 4 by 4 cm and operated switches when depressed with a force exceeding approximately 3.2 N. The token dispenser was operated by a pair of solenoids and dispensed small brass tokens, 2 cm in diameter.

Procedure

Each experimental session lasted 15 min, during which concurrent-chain schedules were operative. In the initial links of the chains, responses were reinforced according to a pair of independent variable-interval (VI) schedules with geometrically distributed interreinforcement intervals. Each schedule was arranged with respect to one of the two response blocks. At the beginning of a session and after each token delivery, entry into the initial links was signaled by the appearance on the monitor of two colored arrows, one red and one blue, each superimposed on a white arrow, with each pair positioned above the response block corresponding to its colored arrow (Figure 2). Feedback for a response on either block was given by the corresponding white arrow, which moved in front of its colored partner and back, so that for a short time the white arrow was superimposed on top of the colored arrow instead of vice versa. At the start of each session the initial-link schedule intervals were set to zero, so that the first response on either block was reinforced. The initial-link intervals were then increased by 1 s after each of the first five token deliveries, and from the sixth token delivery onward the initial-link schedules were VI 10 s. In pilot studies this fading procedure (a more detailed account of which can be found in Sonuga-Barke et al., in press) was found to

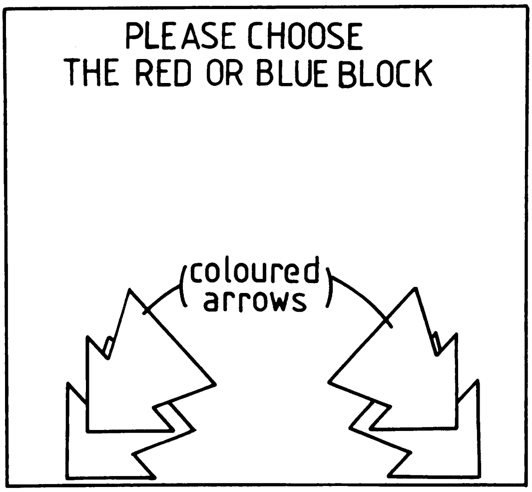

Fig. 2. Screen display during the initial links of the concurrent-chain schedule.

be effective in limiting the superstitious behavior that can be established by chance reinforcement of random sequences of responding on schedules of long duration (Catania & Cutts, 1963; Lowe & Horne, 1985).

Reinforcement of initial-link responding consisted of access to the corresponding terminal link. On entry into the terminal links the timer for the initial link not chosen was stopped, the monitor screen turned white, and a small square corresponding in color to the block last pressed during the initial link appeared in the center of the screen. The terminal link consisted either of a short delay (10 s) followed by the delivery of a small reward (one token) or by a long delay (20, 30, 40, or 50 s, depending on the condition in effect) and a large reward (two tokens). Responses during the terminal link had no scheduled consequences. At the end of the terminal-link period the appropriate number of tokens was dispensed, and a points counter appeared in the center of the screen and was incremented by the appropriate number. Reward delivery in both links took 10 s. Reentry into the initial link followed immediately after this period and was signaled by the reappearance of the two pairs of arrows.

Each subject took part in five experimental sessions, which took place on 3 separate days. After each experimental session the children could spend the tokens they had earned on sweets and toys in the context of a game. On the first 2 days, there were two sessions separated by 20 min. On the third day there was a single session. The delay before the larger reward took values of 20, 30, 40, 50, and 20 s in successive sessions; the final session was thus an attempt to replicate the data of the first condition. All other schedule parameters remained constant across sessions.

Table 1

The total number of tokens that would be obtained in a 15-min session if one terminal link were obtained exclusively.

Delay (seconds)	Tokens per reinforcement	Trials per session	Tokens per session
10	1	30	30
20	2	22.5	45
30	2	18	36
40	2	15	30
50	2	12.9	25.8

Table 1 lists the total number of tokens that would be obtained in each 15-min experimental session if one terminal link were obtained exclusively. As the table shows, the values of prereward delay were selected so that under some conditions, the greater overall rate of reward was produced by the long-delay/large-reward option, whereas with higher delay values the short-delay/small-reward option was the more profitable.

The color (blue or red) and the position (left or right) of the response block correlated with the larger reward were counterbalanced across subjects; each of the four possible combinations was assigned to a different subject in each group. Details of these assignments are given in Table 2.

At the start of each experimental session subjects were given the following instructions: "You are going to play a game in which you can win toys. You can do this by earning pennies on the machine over there." The experimenter then pointed to the apparatus shown in Figure 1. "In all you will have five goes on that machine, each go will last the same amount of time. In between those goes you will be able to spend the tokens you earn on these sweets or toys." The child was then seated in front of the module and informed that, ". . . you earn the pennies by pressing these two blocks." The experimenter then pointed to the red and blue blocks. "You can either press the red or the blue block." The subject was then asked if she understood. If she replied in the affirmative,

Table 2

Details of procedure and results for individual subjects, showing the position and color of the initial-link response block leading to the longer terminal-link delay, the value of that delay, the numbers of responses made in each initial link, the numbers of terminal-link entries produced, and the initial-link relative response rate to the schedule leading to the longer terminal-link delay. Numbers of responses and relative response rates were calculated from the fifth to the 20th token delivery in each session. Terminal-link entries were calculated over the entire session.

		Long delay schedule			Initial-link responses (terminal-link entries)		
Age	Subject	Position	Color	Value (s)	Long	Short	Relative
4	1	left	red	20	26 (9)	35 (20)	.43
				30	14 (10)	15 (14)	.48
				40	7 (6)	16 (13)	.30
				50	4 (8)	31 (17)	.11
				20	3 (6)	20 (19)	.13
4	2	right	blue	20	29 (13)	31 (14)	.48
				30	5 (9)	88 (16)	.05
				40	11 (4)	43 (24)	.20
				50	1 (8)	97 (22)	.01
				20	6 (9)	96 (18)	.06
4	3	left	blue	20	17 (10)	10 (18)	.63
				30	9 (11)	18 (11)	.33
				40	37 (10)	6 (7)	.86
				50	13 (10)	19 (8)	.41
				20	6 (10)	43 (13)	.12
4	4	right	red	20	21 (11)	17 (10)	.55
				30	33 (9)	65 (14)	.34
				40	30 (11)	33 (7)	.47
				50	12 (7)	8 (7)	.60
				20	18 (11)	15 (11)	.54
6	1	left	red	20	12 (14)	11 (13)	.52
				30	15 (11)	22 (13)	.40
				40	20 (15)	0 (0)	1.00
				50	11 (10)	14 (8)	.44
				20	17 (13)	20 (15)	.46
6	2	right	blue	20	32 (17)	2 (6)	.94
				30	83 (18)	0 (0)	1.00
				40	76 (14)	0 (0)	1.00
				50	81 (13)	0 (0)	1.00
				20	125 (13)	0 (0)	1.00
6	3	left	blue	20	22 (14)	12 (13)	.65
				30	37 (17)	0 (0)	1.00
				40	71 (15)	0 (0)	1.00
				50	26 (14)	0 (0)	1.00
				20	59 (22)	0 (0)	1.00
6	4	right	red	20	24 (13)	18 (16)	.57
				30	48 (13)	10 (11)	.83
				40	82 (13)	11 (6)	.88
				50	60 (12)	23 (6)	.72
				20	54 (18)	8 (11)	.87
9	1	left	red	20	102 (13)	24 (13)	.81
				30	27 (15)	7 (7)	.88
				40	45 (15)	14 (1)	.79
				50	57 (11)	17 (3)	.77
				20	43 (13)	53 (14)	.45
9	2	right	blue	20	36 (22)	2 (2)	.95
				30	54 (17)	0 (2)	1.00
				40	27 (15)	0 (0)	1.00
				50	34 (13)	0 (0)	1.00
				20	90 (22)	0 (0)	1.00
9	3	left	blue	20	91 (17)	5 (7)	.95
				30	62 (17)	0 (0)	1.00
				40	97 (14)	0 (0)	1.00

Table 2 (*Continued*)

		Long delay schedule			Initial-link responses (terminal-link entries)		
Age	Subject	Position	Color	Value (s)	Long	Short	Relative
				50	107 (13)	0 (0)	1.00
				20	42 (17)	23 (12)	.65
9	4	right	red	20	88 (23)	0 (0)	1.00
				30	69 (17)	0 (0)	1.00
				40	53 (15)	0 (0)	1.00
				50	60 (9)	33 (10)	.64
				20	92 (19)	8 (4)	.92
12	1	left	red	20	67 (17)	19 (7)	.78
				30	21 (12)	79 (13)	.21
				40	5 (5)	96 (23)	.05
				50	0 (3)	97 (24)	.00
				20	59 (21)	10 (7)	.85
12	2	right	blue	20	81 (21)	2 (4)	.98
				30	26 (15)	11 (8)	.79
				40	3 (4)	93 (23)	.03
				50	0 (2)	120 (28)	.00
				20	0 (2)	129 (31)	.00
12	3	left	blue	20	43 (17)	7 (6)	.86
				30	42 (11)	40 (12)	.51
				40	1 (6)	90 (26)	.01
				50	0 (1)	78 (30)	.00
				20	26 (14)	50 (14)	.34
12	4	right	red	20	36 (17)	10 (12)	.78
				30	48 (15)	4 (6)	.92
				40	6 (8)	106 (16)	.06
				50	1 (6)	97 (26)	.01
				20	75 (15)	17 (12)	.81

the experimenter told her, "While you're playing the game I will go behind this screen, and I will see you in a while." If not, the instructions were read again. The reference to all the sessions lasting the same amount of time was included to make the subjects aware that they were performing under a time constraint. At the end of the each experimental session subjects were asked, "Which block did you like best?" and, "Why did you like this one best?" Their answers were tape-recorded.

RESULTS

Table 2 shows the number of responses each subject made on each of the two initial links, and the relative rate of responding, from the fifth token delivery onward in each experimental session. Figure 3 summarizes these data by showing the mean relative response rates during the first four experimental sessions as a function of age.

The effects of delay to the larger reward on relative response rate were different for the different age groups. In the 12-year-old group, a strong preference for the large reward was established under the 20-s delay to that reward. This preference decreased as the delay to that reward was increased. By the fourth experimental session, with delay to the large reward at 50 s, all 4 subjects approximated absolute preference for the alternative offering the small reward. The trend is evident in the individual subjects' data and was statistically significant, F (3, 12) 27.85, $p < .01$. Six- and 9-year-old subjects maintained high relative rates of responding on the initial link leading to the long-delay/large-reward terminal link at all values of delay, and analysis of variance showed no statistically significant differences in relative response rate between the delay values, $F(3, 12) = 1.27$ and $F(3, 12) = 0.96$, NS. Finally, the effect of delay on the performance of the 4-year-olds was ambiguous. Two of the 4 subjects exhibited an increasing preference for the smaller reward across sessions, but this trend was not statistically significant, $F(3, 12) = 1.13$.

In the replication session (where the delay to the larger reward was returned to its initial

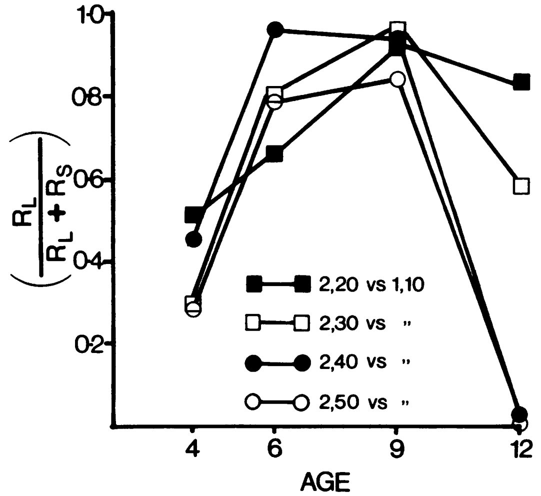

Fig. 3. Mean relative rates of initial-link responding on the schedule correlated with the large-reward/long delay terminal link, as a function of age of subjects, at each of the levels of the longer delay.

value), 2 subjects in the 12-year-old group and 1 subject in the 4-year-old group approximated their original relative response rates. The criterion used to test for such recovery was that relative rates in the final session should lie within .2 of values recorded in the initial session. But these figures do not tell the whole story. For the 12-year-olds, recovery was just that—a return of performance towards its initial value after systematic change in intervening sessions; a third 12-year-old showed a similar trend, although she did not reach the recovery criterion. The 4-year-old who showed "good recovery" (Subject 4 in Table 2) had in fact hardly shown any change in performance at all, remaining essentially indifferent between the two alternatives across all sessions. Because the remaining 4-year-olds (who did show variation in performance across sessions) did not show recovery of first-session data, we cannot be sure that these subjects came under the control of terminal-link delay at all, and the trend in preference across sessions in this group could simply be regarded as a session effect. Or it could be that increasing delay has an irreversible effect on these subjects' preferences.

In the 6- and 9-year-old groups, some subjects' initial performances were replicated but others were not. Those who did not show recovery (using the same criterion as above, two 6-year-olds and two 9-year-olds) showed evidence of a change in the variables controlling performance during the experiment, but the remaining subjects did not. At age 6, these changes in control tended to occur either during or at the end of the first session (for clear examples of between-session shifts see 6-year-old Subjects 3 and 4 in Table 2). These changes could be characterized as a shift in the relative rate of responding towards the schedule offering the large reward. For the 9-year-old subjects, the apparent changes in control occurred in the later stages (Sessions 4 or 5) and were characterized by increases in the relative rate of responding toward the schedule giving the smaller reward.

The subjects' answers to the questions posed at the end of each session support the hypothesis of changes in the variables controlling behavior, both between age groups and within the experiment for some age groups. The 4-year-olds all said that they preferred the large delayed reward in all sessions (even though they had in most cases chosen the small immediate reward more often), whereas the 12-year-olds claimed to prefer the small immediate reward in sessions when they had in fact tended to choose it. The best example of qualitative change in performance within the experiment is Subject 4 of the 9-year-old group. She maintained a strong preference for the larger more delayed reward until the middle of Session 4. At this point, she subsequently reported, she ". . . decided to do an experiment." This experiment involved counting the number of seconds in the delay periods that accompanied each reward alternative. After this "experimental" trial her preference shifted from the larger to the smaller reward. This shift in preference resulted in the relative rate of responding falling from 1.00 (i.e., absolute preference for the larger reward) during Session 3 to .65 in Session 4. A more dramatic change in performance occurred within Session 4: The relative rate of responding switched from 1.00 between token deliveries 5 through 10 to .11 during the rest of the experimental session. This change in performance was accompanied by a corresponding verbal reinterpretation of performance: At the end of Session 4 she reported, "I chose the blue one because it got through quicker and I could get more." This was typical of the kind of report given by 12-year-olds, who said, for example, "It (the blue block) doesn't take so long—I got

Table 3

The nature of the relation between initial-link relative response rate and age: *F* ratios at each level of delay to the larger reward.

Source of variation	*F*	Longer delay (s)			
		20	30	40	50
Age differences	3, 12	9.07*	6.52*	31.77**	15.08**
Linear age trend	1, 12	21.04**	4.00*	13.35**	2.72
Quadratic age trend	1, 12	3.46	15.40**	80.94**	41.55**

** $p < .001$, * $p < .05$.

more than if I pressed the red one" (Subject 4 after Session 4).

The effect of age, summarized by the means shown in Figure 3, was maintained irrespective of the position (left or right) or color (red or blue) of the block correlated with the reward. Because it was inherently a between-subjects effect, its reliability was tested by an analysis of variance. There were significant differences between age groups at each level of delay to the larger reward. The nature of the age trend was examined using orthogonal polynomials. The quadratic term accounted for an increasingly large percentage of the data variance, and the linear term for an increasingly small percentage, as the delay to the large reward increased across sessions. Table 3 shows the *F* values and significance levels corresponding to these effects.

DISCUSSION

The performance of subjects at different ages was controlled by different aspects of the schedule parameters. The behavior of both 6- and 9-year-old subjects was insensitive to changes in prereward delay. At these ages behavior was controlled by reward size. Although the behavior of some 4- and all 12-year-old subjects was sensitive to changes in prereward delay, there were important differences between these two groups. First, the change in preference toward the smaller reward as the prereward delay increased was more marked for the 12-year-olds than for the 4-year-olds. In Session 1, all 4-year-old subjects were indifferent between the two alternatives, whereas 12-year-olds tended to choose the long-delay/large-reward option. Second, the 12-year-olds' verbal reports were consistent with their behavior, whereas those of the 4-year-olds were not—their verbal reports were consistent with the kind of behavior shown by 6- and 9-year-olds. Put together, these data suggest that the 12-year-olds' behavior was determined by a verbally expressible estimate of rate of reward, whereas that of the 4-year-olds tended to come under the control of delay in some way that was not mediated by language. Given the limitations of the present experiment, this has to be a tentative rather than a conclusive statement, but it is consistent with the present data, and it also resolves the apparent conflict between published results described in the introduction. Our 4-year-olds were impulsive in the way personality theorists such as Mischel (1981) have suggested, whereas our 12-year-olds chose a small immediate reward in a way that was in fact economically "mature," like the adult subjects of Millar and Navarick (1984).

One way of confirming that there are age differences in the variables controlling preference would be to use a procedure in which delay was manipulated independently of relative reward access. In this situation we would predict that 4-year-olds would establish a maladaptive preference for the short delay, whereas 12-year-olds would prefer the large reward.

Within the design of the present experiment, both the 4-year-olds and the 6- and 9-year-olds exhibited what might be called maladaptive or nonmaximizing performance, but they did so in different ways. The 4-year-olds' failure to maximize was most obvious in the sessions with shorter delays to the large reward. The 6- and 9-year-olds showed what in traditional terms would be described as high levels of impulse control in sessions with long delays to the large reward, but this was maladaptive in economic terms when that delay was at its longest. Finally, the 12-year-old children had developed that sensitivity to changes in delay necessary for effective economic action, at least within the choice paradigm and the range of values used in this experiment.

Thus we propose a two-stage account of development of performance within a self-control paradigm. In the present experiment, the relationship between the two stages is most clearly expressed by the inverted-U function relating age to relative response rate in Session 4, when the schedule leading to the large reward also gave the lower rate of reward. In this session 3 of the 4-year-olds and all 12-year-olds responded more to the schedule leading to the shorter delay, whereas all of the 6- and 9-year-olds preferred the large reward.

In the first stage, between 4 and 9 years, the child is learning *how* to wait for the larger reward. The factors to which development during this stage is related are well documented in the personality literature. They include sex (Trommsdorff & Schmidt-Rinke, 1980), intelligence (Hartig & Kanfer, 1973; Mischel & Metzner, 1962), and cognitive maturity, specifically in terms of the ability of subjects to form plans incorporating either "task-enhancing" or "temptation-inhibiting" components (Hartig & Kanfer, 1973; Miller & Karniol, 1976; Mischel & Ebbesen, 1970; Mischel, Ebbesen, & Ziess, 1972; Mischel & Moore, 1973; Mischel & Patterson, 1976; Patterson & Mischel, 1976; Toner & Smith, 1977). This development is shown by decreases in the level of control exerted by prereward delay, and so by a growing insensitivity to changes in that variable. In the second stage, a child learns *when* to wait for the larger reward. During this stage, reward value is redefined in terms of the rate at which rewards can be attained, rather than their size, and consequently subjects again become sensitive to changes in delay. This second stage has been studied much less often than the first.

This analysis is, of course, far from complete. It is possible that other variables may play a part in the developmental changes described. For instance, the content of instructions has been shown to be an important factor in determining human operant performance. In the present experiment, all subjects received the same instructions before the experiment and the same feedback during it, but it is impossible to be sure that this information would have the same effects on the behavior of a 4-year-old as on that of as 12-year-old. The 12-year-olds' improved performance could be due simply to increased sophistication in reading the numbers presented on the token counter. Alternatively, they may have interpreted the time constraint differently, even though the instructions were designed to ensure that all the children understood that they had a limited time in each session; Sonuga-Barke et al. (in press) have shown that if subjects think they are acting under a time constraint rather than a trial constraint, it affects their behavior under schedules of the sort used here. The origins of developmental trends in any operant performance can only be discovered gradually, through systematic replication, and can never be established finally in any single experiment involving age effects. On the other hand, we are confident that the structure of the present experiment, and the fact that time between experimental sessions was used to play a game in which subjects saved their tokens for a favorite toy, ensured that all children were motivated to maximize the number of tokens they received. The present results are at least consistent with the idea of two stages in the development of adaptive response to intertemporal choices.

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