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CHILDREN'S CHOICE: SENSITIVITY TO CHANGES IN REINFORCER DENSITY

EDMUND J. S. SONUGA-BARKE, STEPHEN E. G. LEA, AND PAUL WEBLEY

UNIVERSITY OF EXETER

Two experiments were carried out in which children's sensitivity to changes in reinforcer density (number of reinforcers per session) was measured in a choice paradigm. In Experiment 1, 24 girls (ages 6, 9, and 12 years) performed on concurrent-chain schedules of reinforcement. The initial links were variable-interval 10-s schedules. One terminal link always gave three tokens after 30 s, but the parameters associated with the other were varied. Independent manipulations of reinforcer size (two tokens or four tokens) and prereinforcement delay (25 s or 65 s) led to equal changes in the relative density of tokens that could be earned on the schedules. Subjects at all ages were sensitive to changes in reinforcer density brought about by changes in reinforcer size, whereas only 3 12-year-olds showed sensitivity to the changes brought about by manipulation of prereinforcer delay. In Experiment 2, titration procedures were used to test the extent of this insensitivity to delay in 32 6- and 12-year-old children. In these procedures, a repeated choice of the large reinforcer increased the delay to its delivery, and a repeated choice of the small reinforcer reduced the delay to the delivery of the large reinforcer. Whereas 6-year-old boys and girls tended to maintain a strong preference for the large reinforcer, so increasing the delay to its delivery, 12-year-olds tended to distribute their responses to both alternatives, thus producing a stable level of delay to the large reinforcer. The results from the two experiments support the idea of two stages in the development of adaptive intertemporal choice.

Key words: development, adaptation, insensitivity, concurrent-chain schedules, titration procedures, block press, children

Recently Logue, Peña-Correal, Rodriguez, and Kabela (1986, p. 172), asserted the existence of qualitative differences between human and animal choice. They suggested that "... humans, unlike pigeons, are sensitive to events as integrated over whole sessions and tend to maximize total reinforcement over whole sessions." From this position, the effects of "local" variables become conditional on the demands for optimal performance imposed by the operating "global" economic context (Sonuga-Barke, Lea, & Webley, in press).

This view is clearly controversial (for the opposite view see, e.g., Bangert, Green, Snyderman, & Turrow, 1985). It is important, therefore, to explore the predictions it makes. One such prediction is that when alternatives differ in reinforcer size and prereinforcement delay, and the number of choices available during an experimental session is constrained by time, choices should be determined by reinforcer density (i.e., the number of reinforcers that can be obtained during a particular period). When increases in prereinforcement delay to the larger reinforcer are not compensated for by a period of delay following the delivery of the smaller reinforcer, optimal performance requires sensitivity to changes in prereinforcement delay (Millar & Navarick, 1984).

Sonuga-Barke, Lea, and Webley (1989) studied the performance of children between the ages of 4 and 12 in this type of situation. They found that only the 12-year-old subjects exhibited the sensitivity to delay-induced changes in reinforcer density required for optimal performance in this situation. Children aged 6 and 9 years were insensitive to such changes; they chose the large reinforcer at all levels of delay. Four-year-olds were either indifferent between the two alternatives or tended to choose the small reinforcer.

Because manipulations of reinforcer density were delay induced, these results were seen as relating specifically to developmental differences in children's responses to delay. But reinforcer density can be manipulated in a number of different ways, and it may be that these findings expressed a more general insensitivity to changes in reinforcer density.

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Table 1

The total number of tokens that would be obtained in a 15-min session if one terminal link were obtained exclusively in Experiment 1. The calculations assume a 10-s delay in the initial link and a 5-s reinforcement period during which the tokens were dispensed.

Terminal-link delay	Tokens per reinforcement	Trials per session	Tokens per session
30	3	20	60
25	2	22.5	45
25	4	22.5	90
65	2	11.25	22.5
65	4	11.25	45

In the first experiment, changes in reinforcer density were brought about by independent manipulations of two terminal-link parameters: prereinforcement delay and reinforcer size. As before, experimental sessions were restricted to a certain length of time (a fact mentioned in the instructions given to subjects), and increases in prereinforcement delay were not compensated for with equal periods of postreinforcement delay. Thus, given the interdependent nature of delay, size, and reinforcer density, overall maximization required subjects to be sensitive to changes in both delay and reinforcer size.

EXPERIMENT 1

METHOD

Subjects

Twenty-four girls, 8 from each of the age groups studied (6, 9, and 12 years old), took part in the experiment. The subjects were recruited from local schools.

Apparatus

The experimental contingencies were implemented on a microcomputer (BBC Model B, Acorn Computers PLC). The computer monitor was housed in the portable module used by Sonuga-Barke et al. (1989). On the face of this module were a pair of response blocks, one red and one blue, and a token dispenser. The blocks were 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 solenoids and dispensed small brass tokens, 2 cm in diameter.

Procedure

Each experimental session lasted 15 min, during which time concurrent-chain schedules were in force. In the initial links of the chains, block responses were reinforced according to a pair of independent variable-interval (VI) schedules of reinforcement, with geometrically distributed interreinforcement intervals. Each schedule was associated with one of the two response blocks. After each token delivery, entry into the initial links was signaled by the monitor screen turning black and the appearance of the words "please choose the red or the blue block."

Feedback for a response on either block was given by the appearance of an arrow of corresponding color above the block. Reinforcement of initial-link responding consisted of access to the corresponding terminal link. At the start of each session the first response on either block was reinforced, and then initial-link values were increased after each of the first three token deliveries. After the third token delivery the initial-link schedules were VI 10 s. This shaping procedure (Sonuga-Barke et al., 1989) was introduced to limit the superstitious behavior that can be established in human subjects by chance reinforcement of random sequences of responding on schedules of long duration (Catania & Cutts, 1963; Lowe & Horne, 1985). On entry into the terminal link, the monitor screen turned white, and a small square corresponding in color to the block last pressed appeared in the center of the screen.

The terminal links differed both in delay and number of tokens. Schedule A always gave three tokens after 30 s, and Schedule B gave either four tokens after 25 s (Condition 4/25), two tokens after 25 s (Condition 2/25), four tokens after 65 s (Condition 4/65), or two tokens after 65 s (Condition 2/65). Token delivery took 5 s. Table 1 shows the number of tokens that would be earned if each terminal link were obtained exclusively during a 15-min period (assuming that all initial-link periods averaged 10 s). Under Condition 4/25 exclusive choice of Schedule B gave a higher reinforcer density than exclusive choice of Schedule A, whereas under the other conditions the opposite was the case. Manipulations of reinforcer size and delay led to equal decreases in reinforcer density associated with this alternative between Conditions 4/25 and

4/65 and Conditions 4/25 and 2/25 (see Table 1).

All subjects took part in five sessions. Condition 4/25 was in force during Sessions 1 and 5. For half the subjects in each age group the remaining conditions were presented in the order 2/25, 4/65, 2/65, whereas for the others they were presented in the order 4/65, 2/25, 2/65. 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 point counter appeared in the center of the screen and was incremented by that number. Reentry into the initial link followed immediately after the reinforcement period. After each experimental session the tokens earned were used to play a game in which the children could spend them on toys or sweets.

The color (blue or red) and the position (left or right) of the block associated with the large reinforcer were counterbalanced across subjects; each of the four possible combinations was assigned to 1 subject within each Age × Condition Order subgroup.

At the start of each experimental session subjects were given the following instructions:

> You are going to play a game where you can earn pennies to buy toys. You can do this by playing the machine over there [experimenter then points at the experimental apparatus]. In all you will have five goes on the machine, each go will last the same length of time. In between these goes you will be able to spend the tokens you earn on sweets and toys.

The child was then seated in front of the computer module and informed that,

> . . . you earn the pennies by pressing these two blocks. [The experimenter then pointed to the red and the blue blocks.] You can either press the red or the blue block.

The subject was then asked if she understood. If so, the experimenter said, "While you are playing the game I will go behind the screen and I will see you in a while." If not, the instructions were read again. At the end of each session subjects were asked to say which block they thought it was best to press.

Results

Table 2 shows the relative rate of responding to Schedule B from Token Delivery 4 to 14 in each experimental session. Of the 6-year-olds, 3 subjects were approximately indifferent between the two schedules on all sessions (Subjects 3, 5, 6). In addition, Subject 7 was approximately indifferent on all but Conditions 2/25 and 4/25. This indifference is evidence of these subjects' insensitivity to changes in both reinforcer size and prereinforcement delay. The other 4 subjects (1, 2, 4, and 8) responded more on the schedule offering the large

Table 2

The relative response rates to Schedule B between Token Deliveries 4 to 14 for each subject on each experimental session in Experiment 1. The schedules associated with the left block and the red block are indicated for each subject; (a) indicates the block associated with Schedule A and (b) indicates the block associated with Schedule B.

	Left block	Red block	Condition 1 4/25	2 2/25	3 4/65	4 2/65	5 (recovery) 4/25
6 years (Conditions 1, 2, 3, 4, and 5)							
S1	(a)	(a)	.87	.04	1.00	.00	1.00
S2	(b)	(b)	.83	.46	1.00	.30	1.00
S3	(a)	(b)	.51	.52	.50	.38	.49
S4	(b)	(a)	.93	.59	.94	.21	.98
6 years (Conditions 1, 3, 2, 4, and 5)							
S5	(a)	(a)	.56	.67	.50	.37	.39
S6	(b)	(b)	.36	.48	.64	.36	.45
S7	(a)	(b)	.35	.06	.50	.42	.75
S8	(b)	(a)	.85	.09	.97	.03	.98
9 years (Conditions 1, 2, 3, 4, and 5)							
S1	(a)	(a)	.52	.27	.65	.14	.67
S2	(b)	(b)	1.00	.01	1.00	.01	1.00
S3	(a)	(b)	.74	.03	.89	.00	.99
S4	(b)	(a)	.87	.42	.92	.05	.97
9 years (Conditions 1, 3, 2, 4, and 5)							
S5	(a)	(a)	.86	.02	.98	.02	1.00
S6	(b)	(b)	.56	.00	.95	.02	1.00
S7	(a)	(b)	.80	.03	.93	.02	.85
S8	(b)	(a)	.66	.07	.91	.04	.61
12 years (Conditions 1, 2, 3, 4, and 5)							
S1	(a)	(a)	.98	.00	.99	.00	1.00
S2	(b)	(b)	.98	.95	.01	.00	.99
S3	(a)	(b)	.80	.41	.98	.02	.82
S4	(b)	(a)	.99	.01	.69	.00	.93
12 years (Conditions 1, 3, 2, 4, and 5)							
S5	(a)	(a)	.98	.11	.99	.03	.91
S6	(b)	(b)	.49	.43	.55	.60	.33
S7	(a)	(b)	.94	.00	.08	.02	.98
S8	(b)	(a)	.98	.01	.99	.01	.99

reinforcer on most sessions (approximate indifference being exhibited by Subjects 2 and 4 under Condition 2/25). For Subjects 1 and 8 this involved a switch from approximately absolute preference for Schedule B in Conditions 4/25 and 4/65, when it gave four tokens per delivery and Schedule A gave three tokens, to absolute responding on Schedule A in Conditions 2/25 and 2/65, when Schedule B gave two tokens.

The reason for the indifference exhibited by some of the 6-year-olds is unclear. Their verbal reports tended to suggest that indifference was limited to motor behavior, because all subjects reported a clear preference for the alternative with the large reinforcer. This dissociation between verbal and motor responses is common in studies of conditioning with young children and is said to represent immature verbal control of behavior (Bem, 1967; Bentall, Lowe, & Beasty, 1985; Luria, 1961).

The 9-year-olds' behavior was far more homogeneous, with high rates of responding on the schedule with the large reinforcer in most sessions (Subjects 1 and 6 were approximately indifferent between the two alternatives under Condition 4/25 as was Subject 4 on 2/25). This response distribution was maintained irrespective of delay level so that, like some of the 6-year-olds, these subjects responded more on the schedule with the large reinforcer but lower reinforcer density under Condition 4/65, thereby failing to maximize the amount of reinforcement.

Five of the 12-year-old subjects (1, 4, 5, 7, and 8) exhibited high relative rates of responding on the schedule with the large reinforcer under Conditions 4/25 and 2/25, whereas Subjects 2 and 3 did so only under Condition 4/25. In Condition 4/65, Subjects 1, 3, 5, and 8 maintained a high level of responding to the schedule offering the large reinforcer. Subjects 2 and 7 responded more to the schedule giving the small reinforcer but the higher reinforcer density. Subject 4's responding fell towards indifference. Subject 6 was indifferent between alternatives under all conditions.

Most subjects reverted to first-session levels of performance in Session 5. One 6- and one 9-year-old's performance on Session 1 was substantially different from that on Session 5.

One way of assessing age-related changes in sensitivity to changes in delay and reinforcer size is to compare the relative rate of responding under two experimental conditions in which amount or delay varies but the other parameter remains constant. For instance, finding the difference in the relative rate of responding for Schedule B under Conditions 4/25 and 2/25 would give a measure of a subject's sensitivity to the change in reinforcer size. The mean values for this measure (4/25 and 2/25) were: 6-year-olds, +.29; 9-year-olds, +.64; and 12-year-olds, +.65. For Conditions 4/65 and 2/65, the corresponding values were +.51, +.87, and +.58. Overall, subjects at all ages were sensitive to changes in reinforcer size, although 6-year-olds tended to be less sensitive than 9- and 12-year-olds. Similarly, a comparison of choice under Conditions 4/25 and 4/65 gives a measure of sensitivity to changes in delay. The mean values for this measure (4/25 and 4/65) were: 6-year-olds, −.09; 9-year-olds, −.14; and 12-year-olds, +.23. For Conditions 2/25 and 2/65, the corresponding values were +.11, +.07, and +.15. These results suggest that 6- and 9-year-old subjects were insensitive to the differences in delay, whereas the 12-year-old subjects were sensitive to some extent, particularly in those conditions in which Schedule B provided four tokens per reinforcement.

DISCUSSION

The results from the present study extend the findings of Sonuga-Barke et al. (1989). Between the ages of 6 and 9, subjects were sensitive to changes in reinforcer density brought about by decreases in reinforcer size only. As in the previous study, they were insensitive to changes due to increases in delay. Of the 12-year-olds, 3 subjects showed some level of sensitivity to changes in delay. We interpret this finding as supporting the view, expressed by Sonuga-Barke et al. (1989), that childhood maladaptivity on these types of tasks is the result of a systematic deficit in their ability to adapt to delay rather than a general insensitivity to parameter manipulations.

A smaller proportion of 12-year-olds exhibited a sensitivity to delay-induced changes in reinforcer density than in the study of Sonuga-Barke et al. (1989). A possible explanation is that the pseudorandom order of presentation of delay levels, adopted in the present experiment but not in the previous one, increased the demands placed on the subjects and so inhibited the assimilation of information about the changing nature of the experimental environment.

EXPERIMENT 2

The results from Experiment 1 suggest that children between the ages of 6 and 9 years are insensitive to delay-induced increases in reinforcer density, whereas children of age 12 are at least partially sensitive. In Experiment 2 the limits of this insensitivity and the extent of the resulting maladaptivity were tested using a titration procedure.

Recently, a number of studies have used titration procedures to study choice (Mazur, 1988). Rather than preference being described as a function of predetermined reinforcer parameters, parameter values are described as a function of a predetermined level of preference (usually indifference). Typically, a titration procedure involves the repeated presentation of a choice between a standard schedule and an adjusting schedule. Choice of the adjusting schedule causes the adjusting parameter to be moved upwards by one unit, whereas choice of the standard schedule causes the adjusting parameter to be moved downwards by one unit. A subject who achieves stability and thus distributes responses equally to the two schedules is said to be indifferent between them. But clearly, titration procedures also provide a test of insensitivity to changes in schedule parameters.

In Experiment 2, responses to the adjusting schedule were reinforced with two tokens and those to the standard schedule by one token. In addition, a response to the adjusting schedule increased the length of delay associated with that schedule, whereas a response to the standard schedule reduced the length of delay associated with the adjusting schedule. If it is the case that children's performance on intertemporal choice tasks is determined solely by reinforcer size (and so is insensitive to changes in prereinforcement delay), then these subjects should maintain a strong preference for the adjusting schedule (two tokens) throughout the experimental session, irrespective of the length of delay associated with that alternative. Because these subjects will usually not respond on the standard schedule, the adjusting schedule should be associated with very long delays.

A second issue is also addressed here: What are the reasons for insensitivity to delay? One possibility is that young children are insensitive to differences in delay simply because they do not detect them. To investigate this, the performance of subjects on the titration procedure was compared in situations with different computer displays during the prereinforcement delay period. For some subjects, changes in the graphic structure were related to the passage of time in an orderly and systematic way. This was designed to highlight three things: the difference in delay length between the standard and the adjusting schedules, the difference in length of delay between the adjusting schedules of different trials (i.e., the changes in the adjusting delay), and finally the passage of time within each delay period. For the remaining subjects, the changes in form were not related to the passage of time in this way but occurred at random. Thus, none of the previous emphases was given.

METHOD

Subjects and Apparatus

Thirty-two subjects took part, 8 boys and 8 girls from each of the two ages studied (6 and 12 years). These subjects were recruited from local schools. The apparatus was the same as in Experiment 1.

Procedure

Each subject received four experimental sessions, each lasting 20 min, during which time a titration procedure was in force. This consisted of a standard schedule, the delay parameters of which remained the same throughout the experiment, and an adjusting schedule, the delay parameter of which changed after each reinforcement. Each schedule was associated with one of the two response blocks. After each token delivery, two colored arrows (one red and one blue) appeared at the bottom of the monitor screen above the response block corresponding to its color. The first response on either block was reinforced by entry into the outcome phase of the schedule. Entry into this phase was signaled by the disappearance of the two arrows and the appearance of a display corresponding in color to the block pressed.

Subjects at each age group were divided into two groups, a clock condition and a no-clock condition. These differed in the display presented during the delay period of either the standard or the adjusting schedule. In the clock condition, the display consisted of a stimulus that changed in an orderly way with the passage of time within each delay period. Up to 43 concentric colored squares of decreasing size were drawn from the outer edge of the screen.

The number of these squares present at any time was inversely related, and the size of the black square in the middle of the screen was directly related, to the length of delay remaining. During the delay period, one square was drawn every 3 s, so that the amount of the screen colored in around the edge of the display increased, and the amount of the remaining black square at the center of the screen decreased. Thus, at the start of the delay component of the standard schedule, in which 10 s were to elapse before reinforcer delivery, 40 of the 43 squares were present. At the end of the delay period the last square drawn completed the filling-in process, and the black square disappeared. This kind of display allowed subjects to compare the lengths of delay associated with the adjusting and the standard schedules and between adjusting schedules on different trials.

The alternative screen display, presented to subjects in the no-clock condition, differed as follows. At the start of each delay period, the entire screen was filled in with concentric squares so that no black square remained in the center of the screen. The passage of time during each delay period was not related to systematic changes in the graphic display. The changes that did occur involved highlighting, in white, a random selection of the concentric squares drawn on the screen for a random length of time. These changes in display continued until reinforcement.

At the start of the first experimental session, 10-s delays were in force on both the standard and adjusting schedules. On the standard schedule this delay was followed by the delivery of a small reinforcer (one token) and on the adjusting schedule it was followed by the delivery of a large reinforcer (two tokens). Responses during the terminal link had no consequences. At the end of the outcome phase the appropriate number of tokens was dispensed. The two arrows appeared immediately after reinforcer delivery as the initial link was reentered, and a choice could again be made.

The adjustment was geometric; the delay parameter for each of the two adjusting schedules was multiplied by 1.3 after every reinforcer delivered from the adjusting schedule and divided by 1.3 after every reinforcer delivered from the standard schedule. The two values for delay on the adjusting schedules were carried over from the end of each session to the start of the next.

To ensure that subjects sampled both alternatives, forced-choice trials were introduced. These were programmed to occur on the second trial and then every 10th trial. On these trials, only the choice alternative not presented on the previous trial was available, and only the corresponding arrow was presented.

Two pairs of standard (SA and SB) and adjusting schedules (AA and AB) were in operation. These pairs of schedules operated independently of each other, so that a response on the standard block when SA was in force led to a decrement in the AA delay parameter associated with the adjusting block, whereas when SB was in force on the standard block, the same response resulted in a decrement in the AB delay parameter associated with the adjusting block. After each reinforcement, the computer program selected a pair of schedules in a random manner, and this pair remained in force until the next reinforcement. This interlocking staircase approach (Cornsweet, 1962) was used to disguise the way in which the values of the variable parameter associated with the adjusting schedules were ordered. If subjects in a titration procedure detect this aspect of the schedule, they can attempt to maximize reinforcement by driving the adjusting interval down to its minimum level by repeatedly choosing the standard schedule and then alternating between the two schedules (Lea, 1976). In this situation, revealed indifference would not correspond to indifference as expressed in nontitration situations and would be an artifact of the experimental procedure.

The color (blue or red) of the block initially associated with the large reinforcer available from the adjusting schedule was counterbalanced across subjects. In addition, for some subjects the color of the block associated with the adjusting schedule was changed after the second experimental session to demonstrate experimental control. Only those subjects who showed an exclusive preference for the block associated with the adjusting schedule were treated in this way.

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 that machine over there [experimenter then pointed to the apparatus]. In all, you will have four goes on the machine, it is important that you remember that you have only 20 min-

> utes in which to earn your pennies on each of these goes.

The child was then positioned in front of the apparatus and told,

> Two arrows will come up on the screen; when they do, you can press one of these two blocks; that is how you earn your points. Because the type of toy that you can buy depends on how many tokens you can earn it is important to try to get as many tokens as possible, isn't it? I will now go behind this screen. Before I go I would like to remind you that you have just 20 minutes to earn your tokens.

The experimenter then went behind the screen and had no more contact with the subject until the end of the session. After each experimental session, subjects were asked "Which block did you like the best?" and "Was there any difference between what happened when you pressed the red block compared with when you pressed the blue block?" In most cases all sessions were completed on the same day. After each experimental session, the tokens were used to play a game in which the children could spend them on toys or sweets.

RESULTS

The main dependent variable used was the longest acceptable adjusting delay (LAD). This was defined as the longest delay period associated with one choice of the adjusting schedule that was followed by another choice of that schedule on the following trial. For instance, suppose that a subject chose the adjusting schedule and received a delay of 20 s, and then chose that alternative on the following trial but chose the standard schedule on a third trial. The LAD would be 20 s for those three trials. This type of measure was used in preference to more traditional measures (such as the mean or the median length of adjusting delay) because it allowed delay-insensitive and delay-sensitive behavior to be more clearly distinguished. Large LADs were associated with delay-insensitive behavior and small LADs with delay-sensitive behavior.

Figure 1 A to D plots the largest LAD value for each group of 10 choices of the adjusting schedule for each subject. The performances of 7 of the 8 6-year-old girls were very similar (SGC 6 being the exception). A strong preference for the large reinforcer, associated with the adjusting schedule, was established during the first experimental seession and was maintained up to the end of the experiment. For 6 of the 8 subjects (the exceptions being SGC 6 and EGC 6), choices of the standard key were made only on the forced-choice trials. This was the case even when the block associated with the adjusting schedule was changed from red to blue or vice versa. This response distribution led to a continuous increase in the length of the delay period before the large reinforcer associated with both adjusting schedules, apparent in the increasingly large LAD values exhibited by these subjects. These results suggest that for these subjects, *no* level of delay presented here was considered unacceptable. In other words, subjects appeared to be completely insensitive to the changes in delay produced by their response distribution.

Only Subjects SGC 6 and EGC 6 consistently responded on the standard schedule for any length of time during the experiment. In each case these bursts led to a drop in the LAD value recorded. There were no appreciable differences in the behavior of subjects in the clock and the no-clock conditions.

Two of the 6-year-old boys (DBN 6 and MBN 6) were also insensitive to increases in delay to the large reinforcer associated with the adjusting schedule. The performance of 2 other subjects (RBC 6 and TBN 6) was similar to that of SGC 6. Both subjects emitted bursts of responding on the standard schedule towards the end of the experiment, resulting in a reduction in the LAD value.

The performance of the remaining 4 subjects in this group was more difficult to interpret. Subjects KBC 6, CBC 6, and ABN 6 established a strong preference for the adjusting schedule during the first two sessions of the experiment. During these sessions the adjusting schedule was associated with the blue block for Subjects ABN 6 and CBC 6 and the red block for Subject KBC 6. At the start of the third session; the blocks were changed over. Where the adjusting schedule was associated with the blue block during the second session, it would be associated with the red block during the third session, and vice versa. After this change, Subjects CBC 6 and KBC 6 continued to respond on the same block as before, even though now it was associated with the standard schedule and it gave only one token per trial. This distribution of responses had the effect of decreasing the LAD values. After a period of continued preference for the small reinforcer, Subjects CBC 6 and KBC 6 gradually

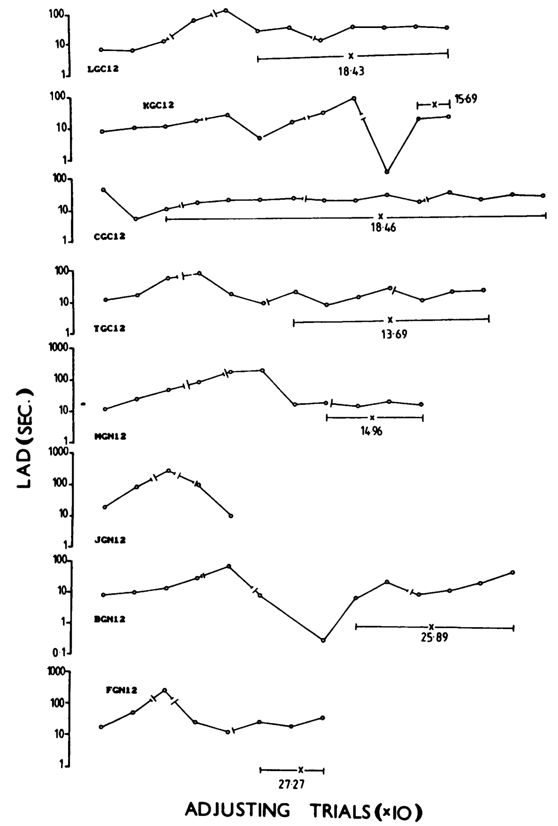

Fig. 1A. The longest acceptable adjusting delay (LAD) value for each group of 10 choices of the adjusting schedule for each subject in Experiment 2. The end of each session is signified by a break in the graph. Subjects are identified by three letters and a number: The first letter refers to subject's name; second to gender (B, boy; G, girl), and third to display condition (C, clock; N, no clock). The number refers to the child's age. A rough estimate of final sensitivity is shown for appropriate subjects: the mean largest LAD value calculated across stable LAD sets. Note that the y axis is log transformed to allow for economy in data presentation.

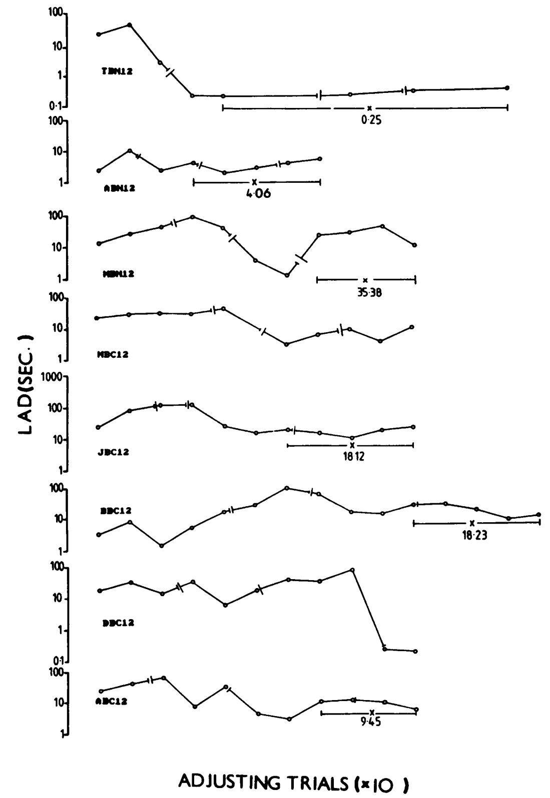

Fig. 1B. Results for additional subjects in Experiment 2. See Figure 1A for details.

reasserted a strong preference for the block associated with the large reinforcer and so increased the LAD value toward the end of the experiment. Subject ABN 6 was the only subject in this age group to establish that stable response distribution required for adaptive behavior within the limits of the present experimental paradigm. This was achieved by distributing responses evenly between the two response alternatives. The performance of the final subject (TBC 6) in this group was neither insensitive nor sensitive to changes in delay on the adjusting schedule. At no time during the experiment did he exhibit a preference for either alternative in words or actions.

Unlike the 6-year-olds, most of the 12-year-old subjects established a stable response distribution between the two alternatives by the end of the experiment (the exceptions being JGN 12 and TBN 12). This was exhibited in the stability of the LAD values across sets of adjusting trials. These results suggest that all subjects reached a point at which the delay value associated with the adjusting schedule was unacceptable.

Other aspects of the 12-year-old subjects' performance were similar. To aid description, their performance will be described in three parts:

1. There was an initial period of total insensitivity to the increases in delay and a consequent increase in LAD values across adjusting trials as subjects established a preference for the schedule associated with the large reinforcer. Eventually, delay reached a level which these subjects found unacceptable. At this point,

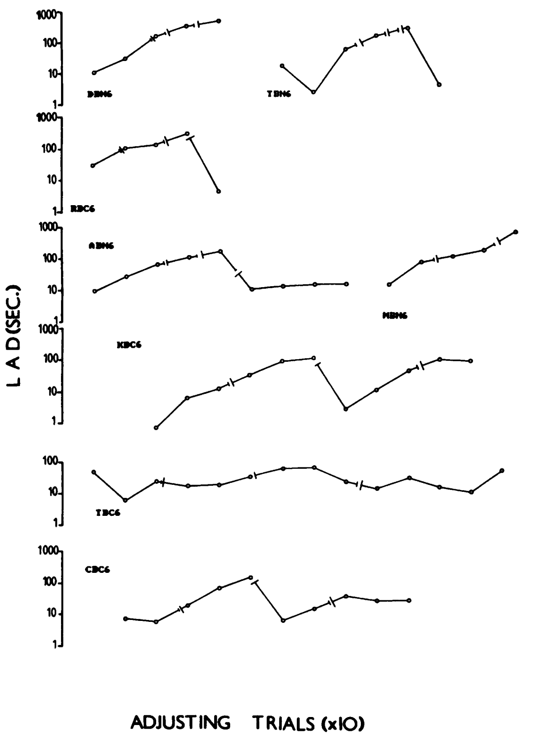

Fig. 1C. Results for additional subjects in Experiment 2. See Figure 1A for details.

subjects stopped responding on the adjusting schedule and responded repeatedly on the standard schedule associated with the small reinforcer.

2. This preference for the standard schedule led to a reduction in the delay parameter associated with the adjusting block and consequently to a reduction in LAD values.

3. Finally, subjects distributed responses approximately evenly between the two alternatives and maintained a stable LAD value.

There were individual differences in the extent of the changes that occurred as children passed through these three stages. For instance, there were differences in the number of trials before the limits of insensitivity to changes in delay were reached. KGC 12 was presented with 100 adjusting trials before she reached this point, whereas CGC 12 only needed 15. There were also differences in the length of delay associated with that point. For JGN 12 this value was 275.6 s, whereas for CGC 12 it was 48.3 s.

A rough estimate of indifference is provided by taking the mean LAD over the stable period

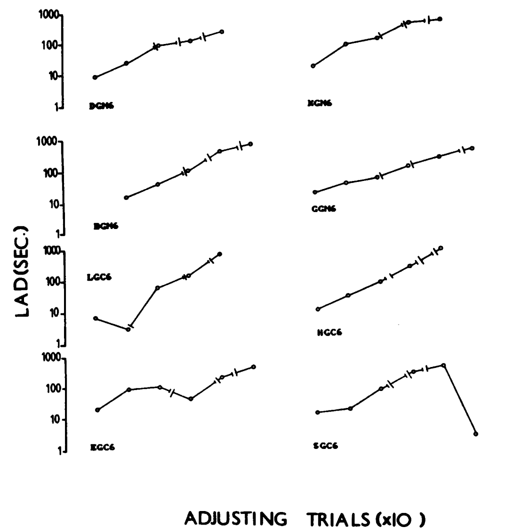

Fig. 1D. Results for additional subjects in Experiment 2. See Figure 1A for details.

of responding occurring during the third segment. These stable periods, along with the corresponding LAD values, are indicated for appropriate subjects in Figure 1A to D.

The only boy who did not conform to the usual pattern was TBN 12. His performance progressed through the first of the three stages discussed above. During the period of accommodation he drove the adjusting schedules to their lowest values and maintained them there until the end of the final session. As was mentioned above, this type of response distribution represents the optimum strategy in this titration situation.

To evaluate the effect of age and sex (which are inherently between-subject variables) on delay-sensitive behavior, the effects of these variables, along with that of display condition (clock and no clock) on the largest LAD, were assessed using an ANOVA. Because 9 of the 6-year-olds did not reach the limit of their insensitivity, this value will underestimate the extent of the 6-year-olds' insensitivity. There was a significant effect of age, $F(1, 24) = 53.70$, $p < .001$, with older children having shorter LADs, and of sex, $F(1, 24) = 7.93$, $p < .05$, with boys having shorter LADs. There was also a significant interaction between subjects' age and sex, $F(1, 24) = 7.32$, $p < .05$, with young girls having longer LADs.

Table 3 shows the number of tokens earned by the subjects of each group over the entire experiment. Again, the effects of age, sex, and type of display were tested using an ANOVA. There were significant effects of age, $F(1, 24) = 35.28, p < .01$, with younger children earning fewer tokens; of gender, $F(1, 28) = 6.05, p < .05$, with boys earning more tokens; and of display type, $F(1, 24) = 5.32, p < .05$, with those in the clock condition earning more tokens. Of the possible interactions, only the three-way interaction was significant, $F(1, 24) = 5.24, p < .05$.

Discussion

These results support and extend the findings of Experiment 1. They point to the existence of a period of development during which subjects' maladaptive performance during intertemporal choice was due to an insensitivity to delay-induced changes in reinforcer density. Most of the 6-year-old subjects were completely insensitive to the increases in delay to the large reinforcer associated with the adjusting schedule, and so failed to establish a stable LAD value. The performance of these subjects, like that of most 6- and 9-year-olds in Experiment 1, was controlled by reinforcer size rather than delay or reinforcer density.

The verbal expressions of preference offered by those subjects who did not maintain their preference for the adjusting schedule suggested that they chose the standard schedule because of the aversiveness of waiting. Two subjects explained the changes by saying that ". . . it took too long" (SGC 6), and that ". . . I got bored pressing the red one" (EGC 6).

According to traditional theories of the development of intertemporal choice (Mischel, 1981), these results appear to indicate a quite exceptional level of self-control in the 6-year-old subjects, for the girls in particular. Some of these subjects apparently valued the large reinforcer more than the small one, even when it was preceded by a *10-min* delay period. Such an account clearly misrepresents the 6-year-olds' performance. One can see that in the present titration paradigm this insensitivity to increases in delay, which in other contexts may be described as self-control, led to extreme maladaptivity. In this respect it seemed that the 6-year-old subjects were both more self-controlled and less adaptive than the 12-year-old subjects. They earned fewer tokens because they were prepared to wait much longer for the large reinforcer.

The performance of all but 1 of the 12-year-old subjects was adaptive in the sense that it came under the control of changes in reinforcer density by the end of the experiment. Consequently, the 12-year-old subjects earned a greater number of tokens than did their 6-year-old counterparts (although in traditional terms they might have been called impulsive; on the other hand, Ainslie, 1975, has suggested that for a response to be called impulsive it must produce "specious reward"). By the end of the experiment, all of these subjects reported, in one way or another, that they were trying to choose the schedule that gave the higher reinforcer density.

Although this view has an intuitive appeal, with a more complex and adaptive response to delay following from a simple and maladaptive one, there is an alternative explanation for the 12-year-olds' response to delay. For instance, in Experiment 2, the 12-year-olds' shift in responding towards the standard schedule offering a small less delayed reinforcer could have been made either to increase the number of trials per session, and so maximize overall reinforcement, or to avoid the longer prereinforcement delay associated with the adjusting schedule. In the present experiment it would have been helpful to have a condition in which changes in prereinforcement delay on the adjusting schedule were compensated for by the inclusion of a postreinforcement delay on the standard schedule. Under these conditions, subjects who were attempting to maximize overall number of tokens would need to show a greater preference for the adjusting schedule than that found in the present experiment.

Providing a display that was designed to aid the perception of the passage of time seemed to have little effect on the sensitivity of the 6-year-olds to increases in delay. There are two possible explanations for this. First, the display provided in the clock condition might not have been an effective means of emphasizing delay. A comparison of the verbal reports of 6-year-olds in the clock and no-clock groups suggest that this was not the case. Each child in the clock condition commented on the difference between the screen display for adjusting and standard schedules. When these subjects were asked what they thought this meant, 3 of them related it to changes in the length of delay before the large reinforcer. For instance, HGC 6 said it was "longer to the

Table 3
The number of tokens earned by each subject at each age group during the four experimental sessions of Experiment 2.

Age 6				Age 12			
Male subjects	Tokens	Female subjects	Tokens	Male subjects	Tokens	Female subjects	Tokens
Clock							
CBC	293	EGC	132	ABC	326	CGC	422
KBC	328	SGC	184	JBC	309	TGC	398
RBC	131	HGC	148	DBC	397	KGC	385
TBC	388	LGC	71	BBC	378	LGC	331
M	285.00		133.75		352.50		384.00
No clock							
DBN	113	KGN	94	MBN	375	BGN	409
MBN	115	BGN	156	DBN	295	JGN	147
TBN	217	GGN	144	ABN	254	MGN	279
ABN	239	DGN	103	TBN	520	FGN	212
M	171.00		124.25		361.00		261.75

pennies on that one." At the same time none of the subjects in the no-clock condition reported making such an observation.

The second explanation is that although the subjects in the clock condition could describe the changes in delay, this did not affect their choice of the adjusting schedule. This suggests that younger children's maladaptive performance on these tasks is not caused by an inability to verbalize the changes in choice parameters. A number of subjects who reported that there were differences in delay between the two situations still went on to choose the alternative associated with the adjusting schedule, and so pushed the value of the delay parameter up over 10 min.

GENERAL DISCUSSION

These findings can be seen as supporting the two-stage model of the development of adaptive performance on intertemporal choice tasks proposed by Sonuga-Barke et al. (1989). They suggested that during the first stage the child's behavior is increasingly controlled by reinforcer size as the child learns *how* to wait for the larger reinforcer. In the present experiments, many of the 6-year-old subjects responded more on the schedule offering the large reinforcer irrespective of reinforcer density or delay. During the second stage the child learns *when* it is most profitable to wait. During this stage we see the development of that sensitivity to changes in reinforcer density necessary for adaptive performance. In the experiments reported here, many 12-year-old subjects responded more on the alternative offering the greater reinforcer density irrespective of the associated levels of reinforcer size and prereinforcement delay.

The finding that the 6-year-old subjects in the present experiments exhibited a sensitivity to changes in reinforcer size only, raises two issues. The first relates to previous reports of adult impulsiveness. A number of studies have shown that, when presented with a choice between a large delayed reinforcer and a small immediate reinforcer, some adults exhibit a strong preference for the small immediate reinforcer (e.g., Millar & Navarick, 1984; Navarick, 1985). This choice has been described as impulsive because it was associated with a lower density of reinforcement (a postreinforcement delay was included after the delivery of the small immediate reinforcer) (Navarick, 1986). It has often been assumed that these findings of human impulsiveness are due to some form of reinforcer discounting, an automatic reduction in the value of future reinforcers.

The finding that children as young as 6 years old show very little sensitivity to changes in delay suggests that impulsiveness in adults, with their greater intellectual and linguistic abilities, might not be the result of discounting at all. One alternative explanation is that adult impulsiveness is due to miscalculation rather than discounting. That is to say, during attempts to maximize reinforcement, subjects fail to give equal weight to all periods of scheduled delay when calculating reinforcer density. In particular, some subjects might not take into account the role of delay periods other than prereinforcement delay (e.g., initial-link interval or postreinforcement delay period).

The second issue of interest raised by this finding relates to the determinants of the insensitivity of the 6-year-olds to changes in prereinforcement delay. The failure of 6-year-olds to develop a sensitivity to delay under the clock condition suggests that their insensitivity to prereinforcement delay was not due to a failure to discriminate changes in delay. There are a number of alternative possibilities. Cognitive developmentalists might argue that these children's performance was governed by limitations of cognitive functioning. Such limitations might, for instance, result from deficiencies in the child's conception of time, stemming from an inability to incorporate a number of related parameters such as speed and distance (Piaget, 1969), or from young children's confusion over relational terms (Siegel, 1978). Sonuga-Barke (1987) has argued that changes in the controlling relations between behavior and its consequences in the choice paradigm studied here might be the product of changes in children's response to social contingencies. On a wider level, this type of approach views development as a process in which age-related changes in performance are due to the reorganization of the nature of control by social agents rather than a reorganization of a child's cognitive structures.

From this position, the child's failure to choose the small immediate reinforcer in the appropriate situation is not seen as an expression of an inability to recognize relative delay duration or an inability to assess reinforcer density. Rather, this failure to choose is seen as a more positive expression of a period during economic socialization when the child sees the large delayed reinforcer as more attractive. Within western culture much is made of the virtues of patience, thrift, and forbearance (Lea, Tarpy, & Webley, 1987, pp. 214–216). From a behavioral point of view, these words signal social reinforcement for waiting for more valued, and perhaps more difficult-to-attain, material reinforcers, even when less valued reinforcers are available with less effort and are, perhaps, valuable in an economic sense. Although deciding between these possible explanations is beyond the scope of the present study, the issues raised by developmental differences in schedule performance make these questions important topics for future research.

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