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Local and overall reinforcement density as a determiner of self-control in preschool children: A preliminary analysis

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The present study was designed to examine children's sensitivity to reinforcer amounts and delays, and also to examine whether local and overall reinforcement density can predict children's choices in a self-control choice situation as in Ito & Nakamura (1998). Five and six years old children were exposed to a concurrent-chains schedule in which reinforcer amounts and/or delays were varied in the terminal links. Two independent variable-interval 10-s schedules were in effect during the initial links and delay periods were defined by fixed-time schedules terminating different numbers of points and cards (tokens) later exchangeable for cartoon characters used on seals (i.e., reinforcers). In the first part of the experiment, children were exposed to three different pairs of reinforcer amounts and delays and sensitivity to reinforcer amount and delay was determined separately based on the generalized matching law. Five-year-old children were more sensitive to reinforcer amount than to reinforcer delay and two out of four children were insensitive to reinforcer delay, whereas the 6-year-old children were more sensitive to reinforcer delay than to reinforcer amount. In the second part of the experiment, the children chose between immediate, smaller reinforcers and delayed, larger reinforcers, and choices of both the 5- and 6-year-old children were in accord with predictions based on local reinforcement density calculated by the ratio of reinforcer amount and delay rather than overall reinforcement density calculated by the ratio of reinforcer amount and total time. These results suggest that children aged 5 and 6 years can not integrate reinforcing events over a broader time horizon.

Key words : development, self-control, local and overall reinforcement density, concurrent-chains schedule, screen touch, token reinforcer, and children.

Much of research on human self-control and impulsiveness has been examined in a self-control choice situation in which both reinforcer amounts and reinforcer delays differ (e.g., Logue, King, Chavarro, & Volpe, 1990; Logue, Peña-Correal, Rodriguez, & Kabela, 1986; Millar & Navarick, 1984). In the standard self-control choice situation, preference for a smaller, immediate reinforcer over a larger, delayed reinforcer has been called "impulsiveness", whereas preference for a larger, delayed reinforcer over a smaller, immediate reinforcer has been called "self-control" (cf. Logue, 1988).

Although these studies have been concerned with adult humans, a few studies have examined children's responding in the standard self-control choice situation (Darcheville, Rivière, & Wearden, 1992, 1993; Logue, Forzano, & Ackerman, 1996; Sonuga-Barke, Lea, & Webley, 1989a, 1989b). Self-control in children has been supposed to be important in the socialization of children from a developmental point of view; choosing larger, more delayed reinforcers (i.e., self-control) is regarded as an index of child's normal development (cf. Mischel, Shoda, & Rodriguez, 1989). However, recent studies have shown that adult human participants tend to show impulsiveness rather than self-control if they obtain more reinforcers per session (i.e., overall reinforcement density) by choosing smaller, less delayed reinforcers (e.g., Flora & Pavlik, 1992; Ito & Nakamura, 1998; Logue, et al., 1990). These findings suggest that the conception of self-control should be reconsidered within the framework of the overall reinforcement density (ORD) view; that is, the molar conception of self-control refers to choosing an alternative producing a higher overall reinforcement density calculated with various time bases (cf. Rachlin, 1989). Similarly, the developmental view of self-control also remains to be examined to understand developmental aspects of self-control choices in children.

Sonuga-Barke et al. (1989a), using a concurrent-chains procedure, studied the effects of prereinforcer delay on children's choices in a self-control choice situation. In their study, children aged 4, 6, 9, and 12 years were given a choice between smaller, less delayed reinforcers and larger, more delayed reinforcers; that is, they chose between one token delayed 10 s and two tokens delayed 20, 30, 40, or 50 s. As a result, 6- and 9-year-old children showed a strong preference for the larger, more delayed reinforcer under all delay conditions, whereas 12-year-old children increasingly preferred the smaller, less delayed reinforcer as the delay to the larger reinforcer increased. To account for these results, they tentatively proposed a two-stage model of the development of self-control in children. The model states that during the first stage children's behavior is controlled by reinforcer amount, while in the second stage behavior is increasingly controlled by reinforcer density. This model proposes that children younger than 9 years old are insensitive to reinforcement density calculated by reinforcer amount and prereinforcer delay, but 12-year-old children are sensitive to reinforcement density. Further, Sonuga-Barke et al. (1989b), by using a similar procedure used in the above mentioned study and an adjusting-delay procedure (cf. Mazur, 1988), studied children's sensitivity to reinforcer density by independently manipulating reinforcer amount and delay. Children aged 6, 9, and 12 years were given a choice between three tokens delayed 30 s and two (or four) tokens delayed 25 s (or 65 s), in which changes in reinforcer density were brought about by manipulation of reinforcer amount or delay. All participants were sensitive to reinforcement density due to changes in reinforcer amount, but only three out of twelve participants aged 12 years showed sensitivity to reinforcement density due to changes in prereinforcer delay. These results were replicated using the adjusting-delay procedure. From these results, it was pointed out that there was a period of development during which children's poor performance in a self-control choice situation was due to an insensitivity to prereinforcer delay.

However, this conclusion was limited in that three out of twelve 12-year-old children showed sensitivity to changes in prereinforcer delay. Moreover, it should be pointed out that in the Sonuga-Barke et al. (1989a, 1989b) studies, sensitivity to reinforcer amount and delay was estimated (not measured directly) from changes in choice proportions under two experimental conditions in which reinforcer amount or delay varied, while the other parameter was held constant. Therefore, this measure was limited in that it was based on changes in choice proportions in only two conditions (e.g., Ito, Nakamura, & Kuwata, 1997), and did not directly represent a degree of sensitivity to reinforcer amount and delay. In addition, the effects of reinforcer delay were confounded with rate of reinforcement in their studies because rate of reinforcement was not equated on the two alternatives by adding a timeout period to the shorter delay to compensate for the increase in delay to the larger reinforcer. Therefore, the results obtained in their procedure may reflect the effects of rate of reinforcement as well as the effects of prereinforcer delay *per se*. From these limitations, it seems necessary to assess sensitivity to reinforcer amount and delay more quantitatively in conditions with timeout periods for understanding of the development of children's self-control choice (cf. Sorama, Ito, & Saeki, 2007).

To assess sensitivity to reinforcer amount and delay, the following generalized matching equation (Baum, 1974) can be applied to the data obtained from more than three conditions:

$$\frac{R_1}{R_2} = k\left(\frac{A_1}{A_2}\right)^{S_a}\left(\frac{D_2}{D_1}\right)^{S_d} \qquad (1)$$

where A is reinforcer amount, D is delay to reinforcement, R is the number of responses to that alternative, and k, S_a and S_d are empirical constants. These parameters can be estimated by the logarithmic linear transformation of Equation (1). A bias is present when k is less than or greater than 1.0. The parameters S_a and S_d represent the sensitivity to variations in reinforcer amount and delay, respectively. Since the values of sensitivity to reinforcer amount and delay have been used as a quantitative measure of self-control in adult human participants (e.g., Ito et al., 1997; Ito & Nakamura, 1998; Logue et al., 1986, 1990), this measure can also be used to predict and describe children's self-control choices.

With respect to reinforcement density, Sonuga-Barke et al. (1989a, 1989b) varied reinforcement density by manipulating reinforcer amount or prereinforcer delay. In this manipulation, the ratio of reinforcer amount and prereinforcer delay (i.e., A/D) is supposed to represent a reinforcing value for each alternative as in the generalized matching equation. On the other hand, it is assumed from molar maximization that preference is determined based on total time (T) rather than prereinforcer delay (D) alone; total time is defined as the sum of the choice phase duration, prereinforcer delay, reinforcer access period, and postreinforcer delay (timeout period). Therefore, the ratio of reinforcer amount and total time (i.e., A/T) is supposed to represent a reinforcing value for each alternative according to molar maximization. The ratio of reinforcer amount and delay (A/D) as represented by the Sonuga-Barke et al. study is referred to as local reinforcement density, while the ratio of reinforcer amount and total time (A/T) is referred to as overall reinforcement density (e.g., Ito & Nakamura, 1998).

The present study, as a preliminary analysis, investigated whether preschool children aged 5 and 6 years are sensitive to reinforcer amount and delay to examine the notion that children aged less than 9 years are insensitive to changes in reinforcer delay (Sonuga-Barke et al., 1989a, 1989b). The present study also investigated whether children's self-control choices can be better predicted from local reinforcement density or overall reinforcement density. In the first part of the experiment, children's sensitivity to variations in reinforcer amount and delay was separately assessed based on Equation (1) for each participant by using a concurrent-chains schedule. In the present procedure, reinforcer amounts and delays were independently varied, while the other parameter was held constant. Unlike the procedure used by Sonuga-Barke et al., the present study used a timeout period following the shorter delay in order to equate rate of reinforcement on two alternatives. The second part of the experiment used sensitivity values obtained in the first part and assessed predictions based on local reinforcement density (LRD) and overall reinforcement density (ORD) in a self-control choice situation where reinforcer amounts and delays were varied together.

METHOD

Participants

The participants were eight girls of two different ages (5 and 6 year olds); four children of each group served as participants (but one 6-year-old girl dropped out during the experiment because of illness). The age of the 5-year-old group ranged from 4 years and 11 months to 5 years and 5 months, while the age of the 6-year-old group ranged from 6 years and 2 months to 6 years and 4 months. They were recruited for participation from a kindergarten.

Apparatus

The experiment was conducted in a small room (3.6 m by 2.8 m). A 14-inch color CRT monitor with a touch panel (MicroTouch Systems Inc.) was placed on the desk, and was separated by a partition from a personal computer (NEC PC-9801U2) and the experimenter. The touch panel consisted of a capacitance screen and the maximum number of responses that could be detected per second was 44. A touch to the circles presented on the screen of the monitor was defined as a response. A personal computer, programmed to present stimuli (i.e., colored circles and counters) on the screen of the monitor, controlled the experiment and recorded events.

The screen of the monitor contained two colored circles and counters. Two colored circles, 5 cm in diameter, were located in the center of the screen and 11 cm apart (from center to center). A counter was located below each of the circles. A touch to the circles produced a brief beep as response feedback.

The partition contained an opening (3 cm × 10 cm) and a slide for delivering cards as tokens (see Figure 1). The cards were 4 cm × 6.5 cm and were delivered into a tray through the slide by the experimenter. The tray (10 cm × 10 cm) was located below the slide.

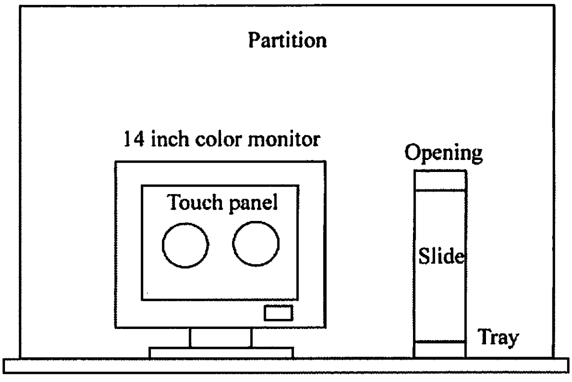

Figure 1. A display of the monitor and apparatus used in the present experiment.

Procedure

At the beginning of the experiment, participants were asked which of the five cartoon characters used on seals they preferred. At the start of each session, they were seated before the monitor and were then given the following instructions (in Japanese) as to what they were to do:

You may play a computer game. Your task is to earn as many cards as you can. Points will be accumulated on the counter and cards will be delivered into the tray from the opening (the experimenter pointed to the tray and opening). Each play is 15 min in duration. You may play two times. At the end of each play, you can exchange cards accumulated on the tray with cartoon character seals you preferred. You may touch two circles on the screen to earn cards, but you have to touch with a forefinger (the experimenter pointed to the circles). A brief beep sound will be provided if a response is effective. The play will begin when two white circles come on. While you are playing the game, I will go behind the partition.

If a participant did not understand the instruction, the above instructions were repeated until the participant understood them.

A concurrent-chains schedule was employed with two independent variable-interval, variable-interval (VI, VI) schedules (i.e., choice phase). During the choice phase, the two circles with its counter were presented on the screen of the monitor. Each circle was colored with white (the background color of the screen was black). After entry into either of the terminal links (i.e., delay period), only the circle not selected was darkened and the other circle was lit with either blue or red. Entry into either of the terminal links was arranged by two independent VI 10-s VI 10-s schedules (see Figure 2). Each interval of the VI tape was derived from the distribution of Fleshler and Hoffman (1962). As each interval in one of the VI schedules timed out, the timer stopped and reinforcement was assigned to the appropriate side. A 3-s changeover delay (COD) was used. In this COD procedure, 3 s had to elapse after a changeover response from the right to the

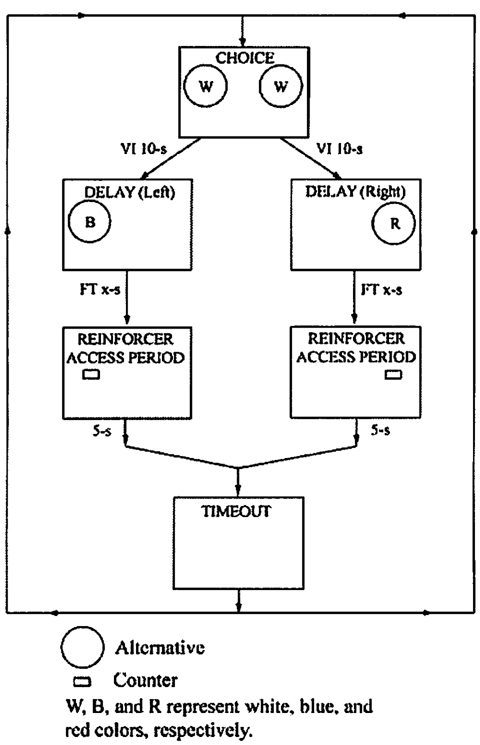

Figure 2. A schematic diagram of the concurrent-chains procedure used in the present experiment.

left circle, or *vice versa* before a subsequent response made it possible to enter into the delay period. The next response on the appropriate circle initiated the delay period defined by a fixed-time (FT) schedule. During the delay period, a touch to the screen produced no scheduled consequences and no feedback beep. After the delay, the reinforcer access period (5 s) was in effect, during which either the left or the right side counter was presented on the screen and a prescribed point (i.e., one point was worth one card) was accumulated on the respective side counter. The experimenter delivered a prescribed number of cards into the tray during the reinforcer access period. A timeout period followed the shorter delay. Timeout periods were used to equate overall rates of reinforcement on two alternatives. During timeout periods, the screen was darkened and a touch to the screen produced no scheduled consequences and no feedback beep.

The experiment consisted of four conditions, that is, baseline, reinforcer amount, reinforcer delay, and self-control choice conditions. In baseline, reinforcer amount was one card (one point) and reinforcer delay was 5 s for both alternatives. Before the baseline condition, participants were exposed to a shaping procedure in which the values of the initial-link VI schedules were increased from 1 s to 10 s over five cycles (trials). After this shaping procedure, the baseline condition began. The baseline condition was presented once. For the reinforcer amount condition, three different pairs of reinforcer amounts of one vs. two, one vs. three and one vs. five cards were studied and, for the reinforcer delay condition, three different pairs of reinforcer delays of 5 s vs. 10 s, 5 s vs. 20 s, and 5 s vs. 40 s were studied. Each condition was presented once in a random sequence for the reinforcer amount and delay conditions. For the self-control choice condition, only one combination of reinforcer amount and delay was studied for each subject except for one participant (P 64), who dropped out at this condition because of illness. In these conditions, the side to which the larger amount and the shorter delay were assigned was counterbalanced across participants.

The self-control choice condition was presented once after participants were exposed to the reinforcer amount and delay conditions. In the self-control choice condition, the participants of the two different age groups were given a choice between larger, more delayed and smaller, less delayed reinforcers; that is, the participants chose between two alternatives consisting of three cards delayed 15 s and one card delayed 5 s except for two participants. These values were arranged so as to make a prediction of indifference between two alternatives under the assumption that values of sensitivity to reinforcer amount (S_a) and delay (S_d) are equal to 1.0; that is, based on Equation (1), the ratio of responses would be $(3/1)^{1.0}$ $(5/15)^{1.0}$ = 1.0 (i.e., indifference) in this combination of reinforcer amount and delay. In two exceptions, one participant (P53) of the 5-year-old group chose between three cards delayed 50 s and one card delayed 5 s, while one participant (P63) of the 6-year-old group chose between five cards delayed 20 s and one card delayed 5 s.

To derive predicted choice proportions for the larger, more delayed reinforcers from the generalized matching law (i.e., LRD), the values of sensitivity to reinforcer amount and delay obtained in previous conditions were used and the bias parameter of Equation (1) was assumed to be 1.0 for simplicity. For example, in the case of P53, the value of the ratio of responses for two alternatives was calculated to obtain the predicted choice proportion; that is, $R_1/R_2 = (3/1)^{.73}(5/50)^{.03} = 2.08$, yielding a predicted value of .675 (i.e., preference for the larger, more delayed reinforcer), given that $S_a = .73$, $S_d = .03$, $A_1 = 3$, $A_2 = 1$, $D_1 = 50$ s, and $D_2 = 5$ s.

On the other hand, the following three values were used to derive the predicted choice proportions from the ORD; (1) the sum of the prereinforcer delay, the reinforcer access period, and the postreinforcer delay (i.e., a timeout period) for each alternative, (2) the averaged initial-link duration, and (3) the reinforcer amount (i.e., the number of cards) for each alternative. By using these values, overall reinforcement density can be calculated for each alternative. The predicted choice proportions for the larger, more delayed reinforcer were calculated by dividing the overall reinforcement density for the larger reinforcer by the total reinforcement density for the two alternatives. For example, again in the case of P53, the mean duration of the initial link was 5 s. Therefore, total time for the alternative producing the larger reinforcer would be 5 + 50 + 5 = 60 s, while for the alternative producing the smaller reinforcer, this value would be 5 + 5 + 5 + 45 = 60 s. Then, reinforcement density was obtained by the ratio of the reinforcer amount and total time; that is, 3/60 and 1/60, yielding a predicted value of $(3/60)/(3/60 + 1/60) = .75$ (i.e., preference for the larger, more delayed reinforcer).

The order of the conditions is shown in Table 1. Each session was 15 min in duration and two 15-min sessions were conducted per day. The experiment was conducted over four days. At the start of each session, the participants were exposed to four forced-cycles (trials) in which both alternatives were presented and the available terminal link was assigned quasi-randomly, with equal probability (i.e., two right and two left alternatives), to the right or to the left except for baseline condition. These forced-choice cycles were not included in a 15-min session and never used in data analysis. Since each condition was presented once, the maximum number of cycles per condition differed across conditions and participants; for the reinforcer amount condition, it ranged from 45 to 60 cycles, while it ranged from 18 to 45 cycles for the reinforcer delay condition. In the self-control choice condition, the maximum number of cycles also depended on the delay values used and ranged from 15 to 45 cycles. The participants received the cards earned and exchanged them with cartoon character seals at the end of each session.

RESULTS

Table 1 shows the number of responses to both left and right circles, choice proportions, and the order of conditions for each participant. Choice proportions were obtained by dividing the initial-link responses for the larger of two reinforcers or the shorter of two delays by the total initial-link responses. Choice proportions increased, not so systematically,

Table 1. Values of rainforcer amount (A) and delay (D) for the left (l) and right (r) circles, number of choice responses, choice proportions for the larger, or less delayed reinforcers and sequence of conditions for each participant.

Participant	Age	Order	Amount (card)		Delay (sec)		Choice responses	Choice prop.
	years / months		Al	Ar	Dl	Dr	left / right	
P51	4 / 11	1	1	1	5	5	568 / 447	.440
		2	1	2	5	5	322 / 415	.563
		4	1	3	5	5	150 / 198	.569
		3	5	1	5	5	541 / 80	.871
		6	1	1	5	10	231 / 160	.591
		7	1	1	20	5	171 / 245	.589
		5	1	1	40	5	104 / 128	.552
		8	3	1	15	5	89 / 27	.767
P52	5 / 1	1	1	1	5	5	87 / 115	.569
		6	2	1	5	5	99 / 63	.611
		5	1	3	5	5	63 / 104	.623
		7	1	5	5	5	42 / 79	.653
		2	1	1	5	10	95 / 121	.440
		4	1	1	5	20	75 / 76	.497
		3	1	1	40	5	27 / 36	.571
		8	1	3	5	15	25 / 28	.528
P53	5 / 4	1	1	1	5	5	235 / 251	.516
		4	1	2	5	5	103 / 120	.538
		3	3	1	5	5	199 / 112	.640
		2	1	5	5	5	81 / 282	.777
		6	1	1	5	10	137 / 128	.517
		7	1	1	20	5	68 / 79	.537
		5	1	1	40	5	35 / 39	.527
		8	1	3	5	50	10 / 30	.750
P54	5 / 5	1	1	1	5	5	864 / 528	.379
		2	1	2	5	5	742 / 874	.541
		4	1	3	5	5	86 / 1205	.933
		3	5	1	5	5	636 / 207	.754
		6	1	1	5	10	718 / 461	.609
		7	1	1	20	5	551 / 714	.564
		5	1	1	40	5	203 / 950	.824
		8	3	1	15	5	318 / 200	.614

Table 1. Continued

Participant	Age years / months	Order	Amount (card) Al	Ar	Delay (sec) Dl	Dr	Choice responses left / right	Choice prop.
P61	6 / 2	1	1	1	5	5	256 / 114	.308
		6	2	1	5	5	181 / 130	.582
		5	1	3	5	5	115 / 133	.536
		7	1	5	5	5	86 / 119	.580
		2	1	1	10	5	169 / 96	.362
		4	1	1	20	5	90 / 105	.538
		3	1	1	5	40	156 / 123	.559
		8	1	3	5	15	30 / 41	.577
P62	6 / 3	1	1	1	5	5	315 / 207	.397
		3	1	2	5	5	103 / 108	.512
		2	3	1	5	5	203 / 122	.625
		5	5	1	5	5	193 / 172	.529
		6	1	1	10	5	182 / 180	.497
		4	1	1	5	20	114 / 139	.451
		7	1	1	5	40	393 / 12	.970
		8	3	1	15	5	49 / 274	.152
P63	6 / 4	1	1	1	5	5	93 / 86	.480
		4	2	1	5	5	102 / 104	.495
		2	1	3	5	5	80 / 109	.577
		5	1	5	5	5	42 / 138	.767
		3	1	1	10	5	127 / 121	.488
		7	1	1	20	5	20 / 76	.792
		6	1	1	5	40	111 / 9	.925
		8	1	5	5	20	9 / 51	.850
P64	6 / 4	1	1	1	5	5	251 / 108	.301
		6	2	1	5	5	181 / 121	.599
		5	1	3	5	5	120 / 138	.535
		7	1	5	5	5	66 / 109	.623
		2	1	1	5	10	153 / 86	.640
		4	1	1	20	5	49 / 70	.588
		3	1	1	40	5	54 / 194	.782

Note. In baseline, choice proportions for the right circle were presented, while choice proportions for the larger, more delayed reinforcers were presented in the self-control condition.

with increases in the ratio of two reinforcers (i.e., reinforcer amount and delay).

Figure 3 shows the logarithm of the ratio of responses during the initial links as a function of the logarithm of the ratio of reinforcer amount or delay for each participant of the 5-year-old and 6-year-old groups. The solid lines show a least-squares fit to the data. The dashed lines show the locus of perfect matching between the response ratio and reinforcer amount (or delay) ratio. The value of r^2 is the coefficient of determination. A linear regression was applied to the log-transformed data.

In all participants, the slopes of the function for the reinforcer amount condition were steeper than those of the function for the reinforcer delay condition. As for the 5-year-old group, the values of the slope obtained ranged from .21 to 1.37 for the reinforcer amount condition, and from .03 to 0.86 for the reinforcer delay condition. For two participants (P 52 and P53), the slopes of the function were close to zero (or flat) for the reinforcer delay condition, showing that these participants were insensitive to variations in reinforcer delay.

As for the 6-year-old group, contrary to the results obtained in the 5-year-old group, the slopes of the function for the reinforcer amount condition were less steep than those of the function for the reinforcer delay condition in three out of four participants of the 6-year-old group. The values of the slope obtained ranged from .41 to .77 for the reinforcer amount condition, and from .56 to 1.66 for the reinforcer delay condition. These results indicate that most participants of the 6-year-old group, contrary to the 5-year-old group, are more sensitive to variations in reinforcer delay than to variations in reinforcer amount.

For the 5-year-old group, a linear regression applied to mean data over all participants yielded the functions: $y = .76x - .05$ ($r^2 = .88$) for the reinforcer amount condition and $y = .28x - .04$ ($r^2 = .92$) for the reinforcer delay condition. For the 6-year-old group, different functions were obtained: $y = .65x - .19$ ($r^2 = .93$) for the reinforcer amount condition and $y = 1.11x - .31$ ($r^2 = .91$) for the reinforcer delay condition.

As a comparison of different groups of age, a Mann-Whitney U test was applied to the difference in the slopes of the best-fitting lines, indicating that the difference was significant ($U = 1$, $p < .05$) for the reinforcer delay condition, but it was not significant for the reinforcer amount condition. Thus,

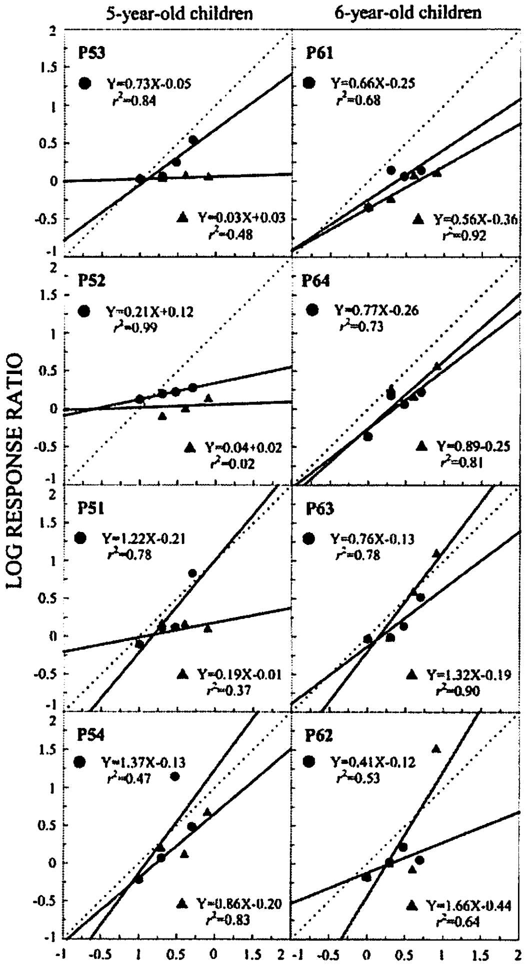

Figure 3. The logarithm of the ratio of responses as a function of the logarithm of the ratio of reinforcer amounts or reinforcer delays for the 5-year-old and 6-year-old groups. The dashed lines show the locus of perfect matching between the response ratio and reinforcer amount or delay ratio. The filled circles show the data from the reinforcer amount condition, whereas the filled triangles show the data from the reinforcer delay condition. The solid lines show a least-squares fit to the data.

the present results demonstrate that sensitivity to variations in reinforcer delay is higher in children of the 6-year-old group than in those of the 5-year-old group, and that children of both groups are equally sensitive to variations in reinforcer amount.

Figure 4 shows the obtained choice proportions for the larger, more delayed reinforcers, and the predicted choice proportions from the local reinforcement density (LRD) and overall reinforcement density (ORD) for each participant. As shown in Figure 4, in most cases, obtained choice proportions were in accord with the predictions from the LRD; for the 5-year-old group, obtained choice proportions were consistent with predicted choice proportions from the LRD in three out of four children, while for the 6-year-old group, obtained choice proportions were also consistent with the predictions from the LRD in two out of three children. Therefore, across children of two different groups of age, choice proportions were in accord with the LRD predictions in five out of seven cases. For 5-year-old children, percent differences of obtained from predicted choice proportions were smaller for the LRD predictions than for the ORD predictions; mean absolute percent difference was 4.7% for the LRD predictions, whereas it was 9.5% for the ORD predictions. For 6-year-old children, mean absolute percent difference was 19.9% for the LRD predictions, whereas it was 26.2% for the ORD predictions. For two participants of 6-year-old group whose choice proportions were consistent with the LRD predictions, however, mean absolute difference was 5%, close to the mean difference obtained in the 5-year-old group. These results clearly demonstrate that choice proportions for the larger, more delayed reinforcers are

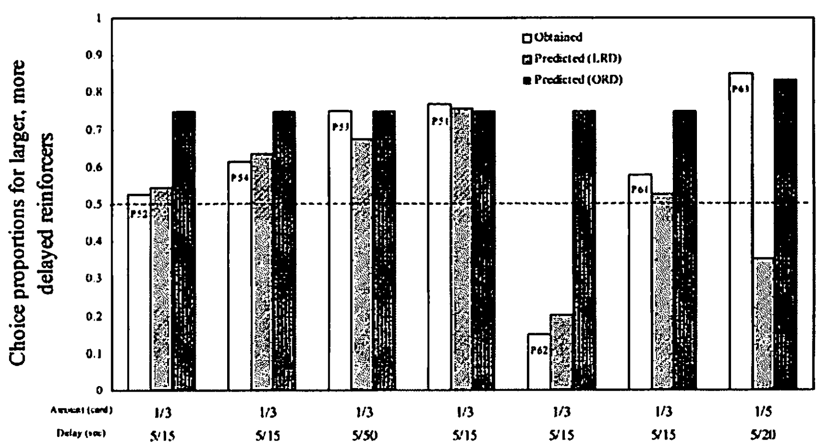

Figure 4. The obtained and predicted choice proportions for the larger, more delayed reinforcers under the self-control choice condition for each subject. The predictions are derived from the overall reinforcement density (ORD) and the local reinforcement density (LRD).

quantitatively well predicted from the LRD view in the present self-control choice condition.

DISCUSSION

The present study, using a concurrent-chains procedure, investigated children's sensitivity to variations in reinforcer amount and delay by varying the ratio of two reinforcers for each reinforcer dimension (i.e., amount and delay), while the other dimension was held constant. The present study found that all four participants of the 5-year-old group were more sensitive to reinforcer amount relative to reinforcer delay, and two out of four participants were insensitive to reinforcer delay. This finding is consistent with the notion of development of self-control that as children age, they become sensitive to reinforcer delay, as well as to reinforcer amount, and take account of both dimensions of reinforcers, thereby they tend to show self-control (Darcheville et al., 1993; Sonuga-Barke et al., 1989a, 1989b). As shown in Figure 3, two of the 5-year-old participants (P52 and P53) seem to take account of reinforcer amount only in the present choice situation because they were insensitive to reinforcer delay. Therefore, the present results obtained in the 5-year-old group confirm and extend the previous findings of Sonuga-Barke et al. (1989a, 1989b) to the situation where each sensitivity value for reinforcer amount and delay was determined based on Equation (1) and data obtained from four conditions (including baseline).

The present study also found that all four participants of the 6-year-old group were sensitive to reinforcer delay as well as to reinforcer amount. This finding is inconsistent with the notion that children aged less than 9 years are insensitive to reinforcer delay (Sonuga-Barke et al., 1989a). Why did children aged 6 years show sensitivity to reinforcer delay in the present choice situation? To address this question, we may look at the procedural differences between the present study and the Sonuga-Barke et al. study. The present study used a forced choice procedure at the beginning of each condition (but only four cycles) and a timeout procedure, while Sonuga-Barke et al. did not use these procedures. Moreover, the present study measured sensitivity to reinforcer amount and delay directly by varying the ratio of reinforcer amount or delay, while they estimated (not measured directly) sensitivity from changes in choice proportions across two conditions in a self-control choice situation. This procedure of measurement of sensitivity may explain the difference between the present results and Sonuga-Barke et al.'s results. In any case, the present procedure provided a quantitative measure of sensitivity to reinforcer amount and delay and proved it to be useful in showing the difference in sensitivity to reinforcer amount and delay between two different ages. Based on the preliminary results of the present study, it seems that a period of development during which children's insensitivity to reinforcer delay was evident may be less than 6 years.

Sensitivity values based on Equation (1) have been used as a quantitative measure of human as well as animal preferences (Chavarro & Logue, 1988; Ito, 1985; Ito & Nakamura, 1998; Ito & Oyama, 1996; Logue, Rodriguez, Peña-Correal, & Mauro, 1984; Logue et al., 1986, 1990; Omino, 1993; Omino & Ito, 1993). For example, Ito and Nakamura (1998), using adult humans as participants, studied humans' sensitivity to reinforcer amount and delay in a concurrent-chains procedure. As in the present study, they arranged four different pairs of reinforcer amount or delay (including baseline condition) and determined sensitivity to reinforcer amount and delay separately for each participant. They found that adult humans were sensitive to both reinforcer amount and delay, but more sensitive to reinforcer amount relative to reinforcer delay. This finding supported the previous findings obtained in studies with adult humans (e.g., Logue et al., 1986, 1990), although schedule parameters used were different across studies. However, these findings are inconsistent with the present finding that children aged 6 years are more sensitive to reinforcer delay relative to reinforcer amount. Why did children aged 6 years show a higher sensitivity to reinforcer delay relative to reinforcer amount? Considering the results obtained in the 5- and 6-year-old groups, it may be that the ability to estimate time intervals improves as children age, and thus children become sensitive to reinforcer delay at this stage of development (e.g., Darcheville et al., 1992). However, we do not have enough data to address this question at present. Therefore, this question remains to be examined in future research.

The present study also investigated the predictability of self-control choice from the local reinforcement density (LRD) and overall reinforcement density (ORD) views, and demonstrated that children's self-control and impulsiveness were quantitatively better predicted by the LRD rather than the ORD. Although the present study did not arrange the self-control choice condition so as to make different predictions from the LRD and ORD, in most cases, the preliminary results of the present study showed that children aged 5 and 6 years were sensitive to local reinforcement density (LRD) calculated by reinforcer amount and delay. This finding is inconsistent with the findings obtained in studies with adult humans (Flora & Pavlik, 1992; Ito & Nakamura, 1998; Logue et al., 1990), but consistent with results, with pigeons, obtained by Logue, Smith, and Rachlin (1985), who showed that pigeons were less sensitive to postreinforcer delay than to prereinforcer delay. The inconsistency between the present preliminary results with preschool children and the results with adult humans indicates that adult humans can integrate events over a broader time base (i.e., total time), whereas children aged 5 and 6 years can integrate events only over a narrower time base (i.e., prereinforcer delay), similar to the case of pigeons. This suggests that the notion of the development of self-control should be reconsidered within the framework of the local and overall reinforcement density (cf. Rachlin, 1989). For example, the two-stage model of development of self-control choice proposed by Sonuga-Barke et al. (1989a) may be stated differently that at the first stage children's behavior is controlled by local reinforcement density calculated by reinforcer amount and delay (i.e., a narrower time base), while in the second stage behavior is increasingly controlled by overall reinforcement density calculated by reinforcer amount and total time (i.e., a broader time base). However, more extensive examinations of various conditions which make different predictions between the LRD and ORD are required to understand the development of self-control in preschool children. Future research should attempt to examine whether or not children older than 6 years are sensitive to changes in overall reinforcement density as is the case with adult humans.

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