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Young Children's Performance on a Task Sensitive to the Memory Functions of the Medial Temporal Lobe in Adults—The Delayed Nonmatching-to-Sample Task—Reveals Problems That Are Due to Non-Memory-Related Task Demands

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Delayed nonmatching-to-sample performance was examined in children and found to be poor from 12 months until almost 2 years even at 5-s delay, although 5 s is well within such children's memory capacity. After 12 months of age, performance did not differ by delay (5 or 30 s). Because children's problems seemed largely unrelated to the task's memory demands, the 2 final studies explored the role of other cognitive abilities (deduction of an abstract rule, speed of processing, and resistance to interference or distraction). Telling children the rule or quadrupling sample presentation time had little effect. Because a salient stimulus (the reward) might interfere with keeping one's attention on the sample, the reward was omitted during initial sample presentation. This helped; at the 5-s delay, 15-month-olds performed at least as well as 21-month-olds in the basic condition, and 12-month-olds performed almost as well. Implications for the cognitive abilities improving during the 2nd year and for the functions of the medial temporal lobe are discussed.

This article reports the developmental progression in young children's performance of the delayed nonmatching-to-sample task, a measure sensitive to the integrity of the medial temporal lobe in adult monkeys and human adults. One normally associates the medial temporal lobe with memory functions, but memory ability appears to bear little relation to why children cannot succeed on this task until relatively late. Therefore, Studies 3 and 4 addressed the question, "What cognitive requirement(s) of the delayed nonmatching-to-sample task make this task so difficult for children a year and a half or younger?" Our attempts to answer this question shed light on early cognitive development and, perhaps, on the functions of the medial temporal lobe.

Description of the Delayed Nonmatching-to-Sample Task

Each trial of this task consists of a familiarization phase, delay, and test phase. During familiarization, a sample object is presented at the midline; the subject displaces it to retrieve the reward underneath.[1] A brief delay follows. Next comes the test phase where the sample object is presented to the left or right and a new object is presented to the other side; the reward is hidden under the new object. Hence, subjects are rewarded for reaching to the novel object (the one that does not match the sample). Different objects are used on every trial, and the left–right positions of the sample and novel object are varied randomly or pseudorandomly over trials.

This task was first devised for use with monkeys. The reason that subjects are rewarded for reaching to the *non*matching object is that monkeys (Brush, Mishkin, & Rosvold, 1961; Gaffan, Gaffan, & Harrison, 1984; Harlow, 1950; Mishkin, Prockop, & Rosvold, 1962), like young children (e.g., Cohen & Gelber, 1975; Fagan, 1970, 1973; Fantz, 1964), have a natural preference for novelty; so this version of the task is much easier for them to learn than delayed *matching* to sample (Brush, Mishkin, & Rosvold, 1961; Gaffan, Gaffan, & Harrison, 1984; Harlow, 1950; Mishkin, Prockop, & Rosvold, 1962). The task was conceived as a straightforward measure of recognition memory for objects. The rationale was that given this demonstrated preference for novelty, if subjects remember the sample, their natural preference will lead them to reach for the new object when given a choice between the familiar sample and a new object. The testing procedure currently used, featuring different novel junk objects on every trial ("trial-unique objects"), was independently devised by Gaffan (1974) and by Mishkin and Delacour (1975). This procedure capitalizes on subjects' novelty preference in a way that the earlier procedure of using the same two stimuli on all trials could not (because when the same two stimuli are used repeatedly, no stimulus is novel after Trial 1).

Evidence Linking Success on the Delayed Nonmatching-to-Sample Task to the Integrity of Structures in the Medial Temporal Lobe

Structures in the medial temporal lobe (e.g., the hippocampus, entorhinal cortex, and perirhinal cortex) appear to under-

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[1] Historically, the reason for requiring subjects to displace the sample was to be able to certify that subjects had definitely seen the sample. If a subject touched the sample, the subject must have seen it, and the reward gave subjects some reason to touch the sample.

Table 1
Ages of Subjects in Study 1

Age (year)	Range (in weeks plus days)	Mean (in weeks plus days)
3	171 + 3–206 + 0	193 + 9 (3.7 years)
4	209 + 0–252 + 2	231 + 3 (4.5 years)
5	254 + 4–303 + 4	279 + 0 (5.4 years)

lie the memory ability required by the delayed nonmatching-to-sample task. Evidence for this is that lesions to the medial temporal lobe in monkeys produce deficits on the task (e.g., Mishkin, 1978; Murray, Bachevalier, & Mishkin, 1989; Zola-Morgan & Squire, 1986; Zola-Morgan, Squire, & Amaral, 1989a,b,c; Zola-Morgan, Squire, & Mishkin, 1982). Human adults made amnesic by damage to the medial temporal lobe are also impaired on the task (Squire, Zola-Morgan, & Chen, 1988). Macaques with medial temporal lobe lesions and amnesic adults perform the task well at brief delays (5–10 s), indicating that when memory demands are minimal these subjects can learn and perform the task. However, they fail at longer delays (15–60 s), and their performance progressively declines as the delay between familiarization and test increases.

Goals of the Present Set of Studies

This article addresses two questions: (1) What is the developmental progression in children's performance of the delayed nonmatching-to-sample task? Study 1 reports the performance of children 3–5 years of age (36 children; 12 each at 3, 4, and 5 years). Study 2 reports the performance of children 1–2½ years of age (84 children; 12 each at 12, 15, 18, 21, 24, 27, and 30 months). We began this research thinking that evidence concerning the progression in children's performance over age on this task would tell us something about the development of the memory function dependent on the medial temporal lobe. Our data indicate however that, although delayed nonmatching to sample is a sensitive measure of memory in adult monkeys and human adults, improvements in children's performance of the task appear to be largely unrelated to improved memory. We then began to investigate what the developmental progression in delayed nonmatching-to-sample performance indicated and why younger children were unable to succeed at the task.

This brought us to the second question the article is intended to address: (2) If memory is not the limiting factor, what other ability matures more slowly and accounts for why success on the delayed nonmatching-to-sample task does not usually appear until roughly 2 years of age? In Studies 3 and 4 the performance of 1–2½-year-olds was explored on experimental variations of the task designed to test hypotheses about the critical abilities required. The capacities we considered were (a) the ability to deduce the task's rule ("reach to the new object"), (b) speed of encoding, and (c) the ability to resist interference. To minimize the need to deduce the rule, we told the rule to half of the children in Study 3 (84 children tested; 12 at each of the same ages as in Study 2). Six children at each age were tested in the standard condition used in Study 2, and 6 children at each age were told the rule on three training pretrials. In the first condition of Study 4, we increased the presentation time of the sample fourfold during familiarization to minimize the requirement that subjects quickly encode the sample stimulus (24 children tested; 12 each at 12 and 15 months). In the second condition in Study 4, we did not reward children for displacing the sample during familiarization (although they were still rewarded during the test portion of each trial) to minimize interference between familiarization and test (24 children tested; 12 each at 12 and 15 months).

Study 1: Performance of 3–5-Year-Olds on the Delayed Nonmatching-to-Sample Task

Method

Thirty-six children (6 boys and 6 girls each at 3, 4, and 5 years of age) were tested. Their exact ages in weeks are given in Table 1. The children came from intact middle-class homes. The testing procedure closely resembled that used with amnesic patients (Squire et al., 1988) and monkeys (e.g., Zola-Morgan, Squire, Amaral, & Suzuki, 1989). Like amnesic patients and monkeys, the children were not told the principle determining which response would be correct. They were told only that we were going to hide a colored disk each time and wanted to see if they could find it. Preceding each trial, out of view of the child behind an opaque screen, the experimenter hid a disk under the object serving as the sample on that trial and positioned the sample at the midline. The screen was then removed, and the child was encouraged to reach and retrieve the colored disk. This ended the familarization period of the trial. The screen was replaced and a delay imposed.

During the delay, out of sight of the child, a colored disk was hidden under a new (nonmatching) object, and the new object and familiar sample were positioned to the right and left of the child's midline. After the delay, the screen was again removed, and the child was allowed to displace one object to find the colored disk. If the child reached incorrectly, he or she was not permitted to try again, but the experimenter removed the new object and showed the child where the disk had been.

Each child was first trained on the basic task with a 5-s delay, as is done with amnesic patients. The training trials continued until the child was correct on five trials in a row. Then the child was asked to state the rule he or she had been using to find the toy ("How did you know where to look?"), much as Squire and his colleagues (1988) had done with amnesic patients.

Following the training trials, 10 trials were administered at a 30-s delay and then 10 trials at a 60-s delay (delays similar to those used with amnesic patients and monkeys; e.g., the longest delay on which amnesic patients were tested was 60 s; Squire et al., 1988). The delays were administered in blocks rather than interspersed because of Squire's observation that amnesic patients may have done poorly even at short delays when trials at different delays were interspersed because the patients became so frustrated with the difficulty of the task at the longer delays.

A new pair of objects, drawn randomly from a pool of 75 junk objects, was used on every trial, as is done with amnesic patients and monkeys. The left–right position of the novel and familiar objects was varied across trials according to a pseudorandom schedule (Gellerman, 1933), as is done with amnesic patients and monkeys. The intertrial interval was approximately 5–10 s. All trials were administered in a single session in a private room in the children's nursery school. During the delay periods, the experimenter and child talked, read from a book, played games, ran around the room, counted the number of disks the child had accumulated, or counted the seconds until the delay would be over.

Results

Children at all ages succeeded at all delays. Children of 3 years took slightly longer to consistently succeed at the basic task (5-s delay) than did children of 4 and 5, but most children at all three ages caught on very quickly (the overall analysis of variance (ANOVA) for trials to criterion by age was not significant, $F(2, 33) = 2.38, p = .11$, although the orthogonal contrast for 3-year-olds vs. 4- and 5-year-olds was significant, $F = 4.68, p < .05$). Most children were correct on Trial 1 or 2 and were consistently correct thereafter. There were no significant age or sex differences in percentage correct at any delay. Nor was there any significant effect of delay or of type of delay period activity at any age. At all delays at all ages, the mean percentage correct was greater than 90% (see Table 2).

There was a striking age difference, however, in children's ability to state the principle determining where they would find the reward. Only three 3-year-old children (25%) could correctly state how they knew where to look for the reward. The typical verbal explanation given at this age was, "Because I know." By 4 years of age, 67% of the children could correctly state the principle determining the correct response (e.g., "Every time I see something new I know where to reach."). Interestingly, at 4 years, although not at 3 or 5 years, children sometimes stated the principle correctly in terms of turn-taking ("Because this one had a turn, and this one didn't" or "Everyone gets a turn"). By 5 years of age, all children (100%) correctly stated the rule. Thus, although there was no significant difference in performance, there was an age difference in children's ability to verbalize the rule they were using to guide their behavior; $F(2, 33) = 11.37, p < .001$; all linear contrasts were significant: 3- vs. 4-year-olds = 7.103, $p < .025$; 4 vs. 5-year-olds = 4.39, $p < .05$; 3- vs. 5-year-olds = 22.65, $p < .001$.

Discussion

There was no effect of delay; even the youngest children (3-year-olds) performed as well with 60-s delays as they had with delays of 5 or 30 s. This also suggests that the criterion of 5 consecutively correct responses to pass at the 5-s delay was sufficient. After passing criterion at the 5-s delay, these children went on to perform almost flawlessly at the longer delays.

There was also no effect of age. Most children throughout the 3–5 year age range succeeded on almost every trial from the outset or after only one trial of practice. There are a number of other studies that have also found no difference in recognition memory performance over the 3–5 year age range (e.g., Brown & Scott, 1971; Corsini, 1969; Parkin & Streete, 1988).

There was a difference in this age range in children's ability to state the rule that governed correct performance. Although children of 3 years picked the correct choice on almost every trial, they could not verbalize how they knew which choice was correct. Children of 4 and 5 years, on the other hand, chose

Table 2
Performance in Study 1 on the Delayed Nonmatching-to-Sample Task by Age and Delay

	5-s delay					
Age (years)	Mean no. trials to criterion	Mean no. errors to criterion	% passing criterion	% correct	30-s delay (% correct)	60-s delay (% correct)
3	1	1	100	93	96	96
4	0	0	100	98	99	97
5	0	0	100	94	95	95

Note. Number of trials to criterion = number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion of correct performance. $n = 12$ in each cell; $N = 36$.

correctly *and* could verbalize the principle governing their choices. This is consistent with the findings of others demonstrating a progression between 3 and 5 years of age in the ability to verbalize a rule, even though the youngest children act consistently in accord with the rule.

For example, Wimmer, Hogrefe, and Perner (1988) showed or told children the contents of a box or deprived children of this information. Then they asked each child what was in the box and how the child knew this. They found that all children of 3 and 4 years who were shown or told a box's contents responded correctly when asked what was in the box. Children of 4 years were also able to tell the experimenter how they knew this. "In contrast, 3-year-olds were quite incompetent [at that]. Eight of the ten 3-year-olds consistently failed the justification question" (Wimmer et al., 1988, p. 387). We, too, found that children of 3–5 years knew the right answer (that is, they responded correctly on >90% of the trials), but the 3-year-olds could not explain how they knew that.

Similarly, in a study of children's understanding of causality, Bullock and Gelman (1979) found that even children of 3 years could correctly select the side that caused Snoopy to jump up. However, the 3-year-olds were unable to explain how they knew that that choice was correct, whereas almost all of the 5-year-olds could provide at least a partial explanation. "While children as young as 3 years behave as though they use an assumption of unidirectional order in reasoning about causality, it is only the older children who show some ability to articulate this belief" (Bullock & Gelman, 1979, p. 89).

Amnesic adults are also unable to state the correct rule for the delayed nonmatching-to-sample task (at least over the first several hundred trials), even though they perform correctly on the task at short delays after very few trials. All subjects in Test 2 of Squire et al. (1988), including amnesics, performed well on delayed nonmatching to sample during training and test at the 5-s delay; however only 1 amnesic patient was able to consistently state the principle determining the correct response. Thus, children of 3 years of age and adult amnesic patients demonstrate that it is possible to perform at high levels on this task and yet have no conscious access to what determines a correct response.[2]

[2] After the first several hundred trials, when amnesic patients are performing even better, performance does begin to correlate with their ability to state the rule (Squire et al., 1988).

Table 3
Characteristics of Subjects in Study 2

Variable	Age (months) 12	15	18	21	24	27	30
Mean age in weeks + days	53 + 1	66 + 1	79 + 1	93 + 0	105 + 4	117 + 4	130 + 5
Age range in weeks + days	51 + 4– 54 + 6	65 + 0– 67 + 4	78 + 0– 80 + 0	91 + 3– 93 + 1	104 + 3– 106 + 5	116 + 0– 119 + 0	128 + 1– 132 + 4
Mother's mean age (years)	33.33	33.00	31.25	31.17	31.25	31.50	31.75
Father's mean age (years)	35.00	34.50	33.25	34.75	35.00	33.67	32.16
Mean of mother's years of education	16.00	15.00	15.00	16.50	15.75	16.25	16.50
Mean of father's years of education	16.16	15.25	15.58	16.00	15.83	17.50	17.25
Mean no. siblings	1.17	0.83	0.75	0.50	1.25	1.00	1.00
Subjects without siblings (%)	21	42	50	50	25	17	17
Mothers not working (%)	33	50	42	50	42	33	17
Mothers working part-time (%)	50	21	50	42	25	25	83
Mothers working full-time (%)	17	30	8	8	33	42	0

Note. n = 12 subjects in each age group.

We may have failed to find an effect of either delay or age in Study 1 because the task was too easy for 3- to 5-year-olds. At all ages, at all delays, performance was very close to ceiling. Therefore in Study 2, we tested younger children (ages 12–30 months) on the task to see if in this younger age group performance would improve with age and if the length of delay would affect performance.

Study 2: Performance of 1–2½-Year-Olds on the Delayed Nonmatching-to-Sample Task

Method

Eighty-four infants and toddlers were tested (6 boys and 6 girls each at 3-month intervals between 12 and 30 months of age). Their exact ages as well as information on their backgrounds are given in Table 3. All the children were healthy, full-term, and from middle-class homes.

In addition to these 84 subjects, we tried to test 5 other children but were unable to use their sessions. This happened either because the children were too interested in the stimuli themselves, rather than in the rewards (3 children: a 12-month-old girl, a 15-month-old boy, and a 30-month-old girl), or because they lost interest in "our game," and the testing session could not be completed (2 children: a 24-month-old girl and a 30-month-old boy).

The testing procedure used with the infants and toddlers in Study 2 was very similar to that used with children of 3–5 years in Study 1. The infants and toddlers were not told the principle determining which response would be correct. They were told only that we would hide a reward and wanted to see if they could find it. The rewards were food (e.g., a Cheerio, raisin, or piece of cookie), marbles (which could be collected and rattled in a cup or rolled down a ramp), pennies (which could be placed in a windup bank), or tiny plastic animals (which could be collected or given a ride in a truck). Each stimulus was presented on a small wooden base (7.3 × 7.3 × 3.5 cm). Embedded in each base was a well (4 cm in diameter and 1.6 cm in depth), and the reward was hidden in the appropriate well. Each subject was seated in a toddler chair by a toddler-size testing table (70 × 65 × 50 cm).

Preceding each trial, out of view of the subject behind an opaque screen, the experimenter hid a reward in the well of the object serving as the sample on that trial. The sample, with the well underneath it, was then positioned at the midline at the rear of the testing table. At the beginning of each trial, the opaque screen was removed, and the experimenter pushed the sample object atop its well forward toward the subject, encouraging the subject to reach and retrieve the reward. After the subject displaced the sample and retrieved the reward, the sample object and well were removed, the opaque screen lowered, and a delay imposed.

The test phase of each trial followed the delay. The opaque screen was removed and two objects (the sample and a new object) were first presented at the rear of the table out of reach (61 cm away from the front of the table) at the midline and were not pushed forward until the subject had clearly seen both stimuli. Then the stimuli, each sitting on its own wooden base, were pushed diagonally forward, one to the left and one to the right (7.5 cm distance from midline), so that they were equidistant from the subject and just within reach. The stimuli were kept at this distance to discourage the subject from reaching simultaneously for both objects.

Subjects were trained on the basic task using a 5-s delay until they passed the criterion of five correct responses in a row. Testing then continued with a 30-s delay between familiarization and test up to a maximum of 25 trials in a session. There was one exception to this: Subjects who reached criterion at the 5-s delay only after 19–22 trials were tested at the 30-s delay for 8–10 trials, up to a session total of 30 trials. That is, because they took so long to pass criterion, they were given up to 5 more trials than the other subjects so that we could have a minimum number of trials on which to assess their performance at 30 s. Subjects who failed to pass criterion at the 5-s delay or who passed in ≥ 23 trials were not tested at the 30-s delay. The intertrial interval was approximately 10 s. All trials were administered in a single session in our laboratory, with the child's parent present in the room during testing.

If the subject reached incorrectly, the experimenter removed the other object and called the subject's attention to where the reward had been but did not allow the subject to have the reward. New junk objects were used on every trial, but they were not chosen at random as in Study 1. Instead, the stimuli were arranged in fixed pairs (see Figure 1 for sample pairs). These same pairs of objects were used in every testing session in the same order, with half of the children in each Age × Sex group receiving one member of the pair as the sample, and half of the children receiving the other member of the pair as the sample. Thus, for example, for half of the children the correct choice (the novel object) was presented on the left in Trial 1, and for half it was presented on the right for Trial 1, although the actual object on the left or right was the same for all subjects (only whether it was novel or had served as the sample varied). The objects within a pair were roughly matched in size and in preference, as revealed by pretesting with infants and toddlers throughout the age range used in Study 2. Several stimuli were rejected during pretesting because the infants or toddlers found them too interesting. Earlier work had revealed that even

Figure 1. Examples of the pairs of stimuli used for testing delayed nonmatching to sample with children.

infants of 6 months will succeed on delayed nonmatching to sample with delays of at least 60 s if the stimuli serve as their own reward (i.e., if nothing is hidden underneath them, but instead the subject is allowed to explore the stimulus itself; Diamond, 1990a, 1992). Given that finding, we were exceedingly careful in all studies reported here to try to make sure that all subjects were going for the rewards (and not for the stimuli themselves). Any subjects who seemed to be more interested in the stimuli than in the rewards were eliminated from the analyses (see description of unusable subjects above). All testing sessions were filmed on videotape.

Results

Performance at the 5-s delay. Performance on the delayed nonmatching-to-sample task improved significantly over the age range of 12–30 months. This can be seen in the significant main effect for age in the ANOVA for each dependent variable; number of trials to criterion at the 5-s delay: $F(6, 77) = 4.41, p < .001$; number of errors to criterion at the 5-s delay: $F(6, 77) = 4.36, p < .001$; percentage correct at the 5-s delay: $F(6, 77) = 4.23, p < .001$; and the percentage of children passing criterion at the 5-s delay: $F(6, 77) = 2.41, p = .035$.

There was, however, very little improvement from 12 to 18 months. Percentage correct at the 5-s delay remained at 67% for infants of 12, 15, and 18 months (see Table 4). Number of trials to criterion at the 5-s delay remained at 11–12 and number of errors to criterion remained at 6–7 throughout this age range. ANOVAs for the age range of 12–18 months

Table 4
Performance in Study 2 on the Delayed Nonmatching-to-Sample Task by Age and Delay

	5-s delay				
Age (months)	Mean no. trials to criterion	Mean no. errors to criterion	% passing criterion	% correct	30-s delay (% correct)
12	12	6	58	67	67[a]
15	12	7	67	67	63[b]
18	11	6	67	67	81[b]
21	6	3	92	80	80[c]
24	4	2	100	87	86[c]
27	2	1	100	85	90
30	4	2	92	84	86[c]

Note. Subjects who never passed criterion at the 5-s delay or who took more than 22 trials to pass 5 s were not tested at 30 s. No. trials to criterion = number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion for correct performance. $n = 12$ except where noted. [a] $n = 7$. [b] $n = 8$. [c] $n = 11$.

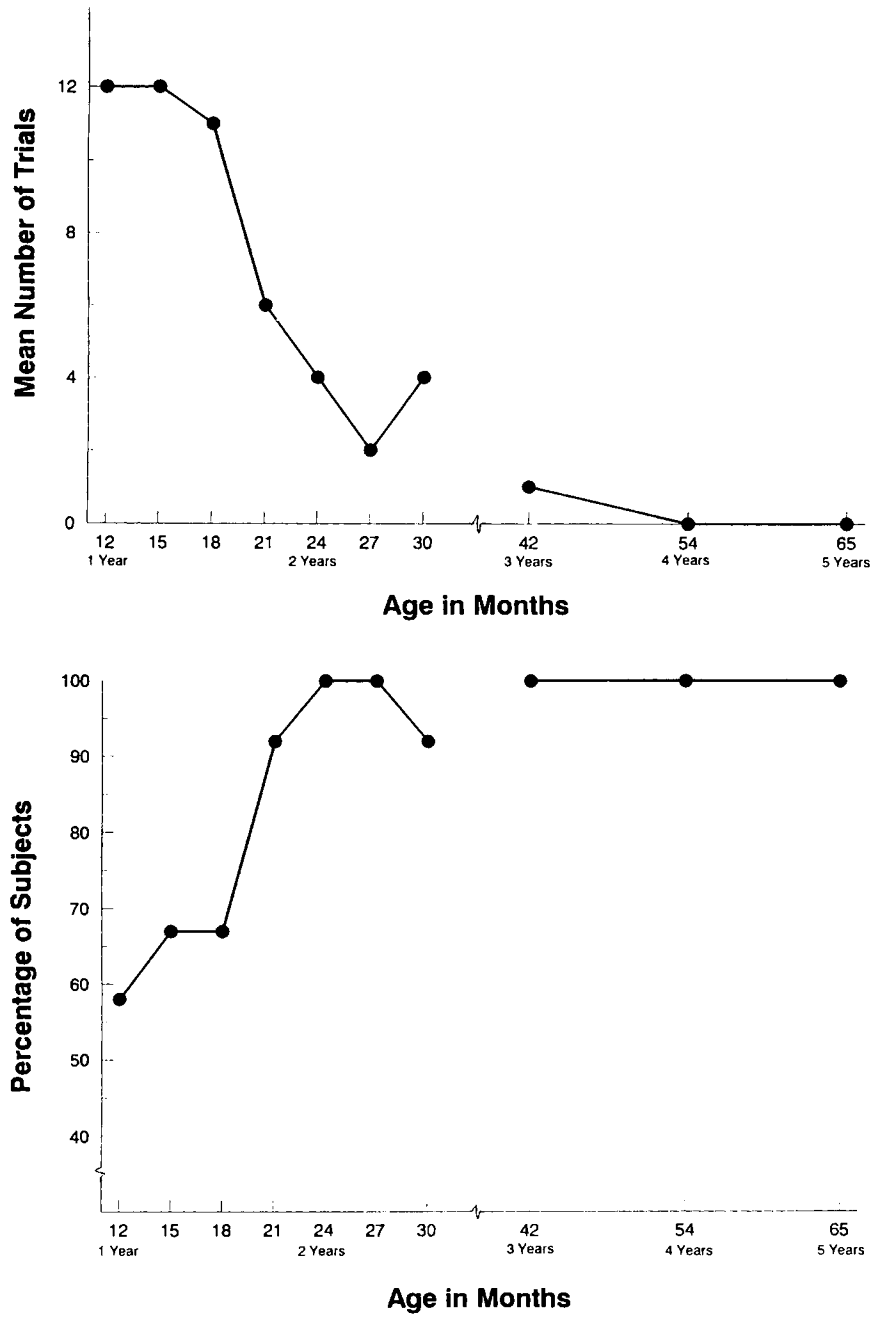

Figure 2. Percentage of subjects at each age passing criterion at the 5-s delay (bottom). Mean number of trials to criterion at the 5-s delay by age (top). $n = 12$ at each age. Subjects aged 3–5 years are from Study 1. Criterion = five correct responses in a row.

yielded no significant main effect for age for any of the dependent variables.

On the other hand, there was an impressive improvement on the task by 21 months of age (see Table 4 and Figure 2). The percentage of subjects succeeding at the 5-s delay jumped from 67% to 92%; orthogonal contrast (18 vs. 21 months) = 5.56, $p < .02$. Percentage correct at the 5-s delay jumped from 67% to 80%; orthogonal contrast (18 vs. 21 months) = 2.96, $p = .09$. Number of trials needed to reach criterion at the 5-s delay dropped from 11 to 6; orthogonal contrast (18 vs. 21 months) = 6.00, $p < .02$.

From 21–30 months, there was little further improvement on the task: There were no significant main effects for age in the ANOVAs for any of the dependent variables for the subset of children between the ages of 21–30 months; e.g., number of trials to criterion at the 5-s delay: $F(3, 44) = 1.44$, *ns;* percentage correct at the 5-s delay: $F(3, 44) = 0.90$, *ns.*

There was considerable individual variability among infants at 12, 15, and 18 months. Many children at these ages never reached criterion within the 25 trials of testing. On the other hand, for those who did pass criterion (and over half of them did), the mean number of trials to do so was only 5, 6, and 6 trials respectively at 12, 15, and 18 months of age (see Table 5).

There were no significant main effects for sex nor were there any significant Sex × Age interactions. There was also no significant effect for type of reward used.

There was no systematic pattern to the errors made by the children. One might have thought that the effect of rewarding subjects for reaching to the sample during the first part of each trial (when the sample was presented alone) might have been to teach subjects that they should reach to the sample when given a choice between that and something new during the second half of each trial. However, subjects rarely erred by consistently reaching back to the sample. If preference for the familiar sample is defined as reaching for the sample during the test phase on 4 out of the first 5 trials, then only 1 infant showed such a preference at 12, 15, 21, 24, and 30 months, and none did so at 18 or 24 months. Only 1 infant (a 15-month-old) reached to the sample on 8 of the first 10 trials. The lack of systematic choice of the familiar sample can also be seen in the percentage of correct responding by the infants who failed to ever reach criterion. As shown in Table 5, they were performing at, or slightly better than, chance, whereas consistent choice of the familiar sample would have resulted in well below chance performance. This roughly chance performance can also be seen in the first two columns of Table 4. For example, it took infants of 12–18 months 10 to 11 trials on average before they began to consistently reach to the new object. Over those 10 to 11 trials, they made an average of 5 to 6 errors (i.e., they erred about half the time).[3]

There was some evidence of a bias to reach to the object on the right or the left, especially at 12 months of age. This largely disappeared by 21 months. For example, on at least 4 of the first 5 trials, 4 infants of 12 months reached to the choice on the right, and 4 reached to the choice on the left. Of the 5 children of 12 months who failed to pass criterion, 3 were in this group of 8 children with a position preference. Of the 9 children of 15–18 months who failed to pass criterion, only 3 showed any evidence of a position preference.

Performance at the 30-s delay. There was no overall effect of length of delay (see Figure 3). That is, the children who succeeded at 5 s tended to succeed at 30 s in that same session and to show performance comparable at the 30-s delay to their performance at the 5-s delay. For example, when the percentages of correct responses at the 5-s and 30-s delays were compared, the difference was not significant; matched pairs $t(67) = 0.48$, *ns.*

This overall finding, however, masks an effect at the two youngest ages. Only 58% and 67% respectively of 12- and 15-month-olds in our study were tested at the 30-s delay because a subject had to pass criterion at the 5-s delay to qualify for testing at the longer delay. This subset of infants performed significantly worse at the 30-s delay than they had at the 5-s delay; matched pairs $t(14) = 1.91, p < .05$.[4]

This was not true for any of the older ages. For each age from 18 to 30 months considered separately or for children of

Table 5
Performance at 5-s Delay in Subjects Who Succeeded and Subjects Who Failed in Passing Criterion

	Passed criterion			Never passed criterion		
Age (months)	Mean no. trials	% correct	*n*	Mean no. trials	% correct	*n*
12	5	75	7	23	56	5
15	6	75	8	24	48	4
18	6	75	8	24	55	4
21	4	83	11	25	64	1
24	4	87	12	—	—	0
27	2	85	12	—	—	0
30	3	84	11	25	60	1

Note. Total number of subjects at each age = 12. At 24 and 27 months, no subject failed to pass criterion at the 5-s delay.

18–30 months considered together, there was no significant difference between performance at the 5-s and 30-s delays; e.g., matched pairs $t(52) = 0.15$, *ns.* Even a more stringent comparison of performance only during the last 10 trials at 5 s versus performance at 30 s yielded no significant differences; e.g., matched pairs $t(52) = 1.27$, *ns.*

Because of the poorer performance of 12- and 15-month-olds at the 30-s delay, there was a significant improvement over age in percentage correct at the 30-s delay, $F(6, 61) = 4.46$, $p < .001$. However, when only the ages from 18 to 30 months are considered, the difference in performance at the 30-s delay by age is no longer significant, $F(4, 48) = 0.95$, *ns.*

There were no significant differences between the performance of boys and girls at the 30-s delay nor were there any significant Sex × Age interactions. There was also no significant effect on performance at the 30-s delay of type of reward.

Comparison of performance in Study 2 versus Study 1. There was no significant difference between the performance of the 30-month-olds in Study 2 and the 3-year-olds in Study 1 on any dependent measure. Even though there were no significant differences from 21 to 30 months (Study 2) or from 3 to 5 years (Study 1) on any dependent measure, when all the subjects between the ages of 21 months and 5 years were entered into the same analysis, there was a significant main effect for age on two dependent measures; percentage correct at the 5-s delay: $F(6, 77) = 2.32, p = .04$; and percentage correct at the 30-s delay: $F(6, 74) = 3.09, p < .01$. Over the large age range from 1 year (9 months) to 5 years (5 months), however, there was no significant difference in number of trials or errors to criterion

[3] Other evidence that rewarding subjects for displacing the sample during familiarization does not teach them to reach to the sample again during the test phase comes from the well-replicated finding that delayed nonmatching to sample is much easier for subjects than is delayed matching to sample, where subjects are supposed to reach to the sample again during the test phase (in children: Overman, 1990; Diamond, Wusinich, & Levy, 1994; in adult monkeys: e.g., Brush et al., 1961; Gaffan, Gaffan, & Harrison, 1984; in infant monkeys: Bachevalier, 1990).

[4] This difference is not significant for the 15-month-olds considered alone, but it is significant for the 12- and 15-month-olds considered together as a group and for the 12-month-olds alone.

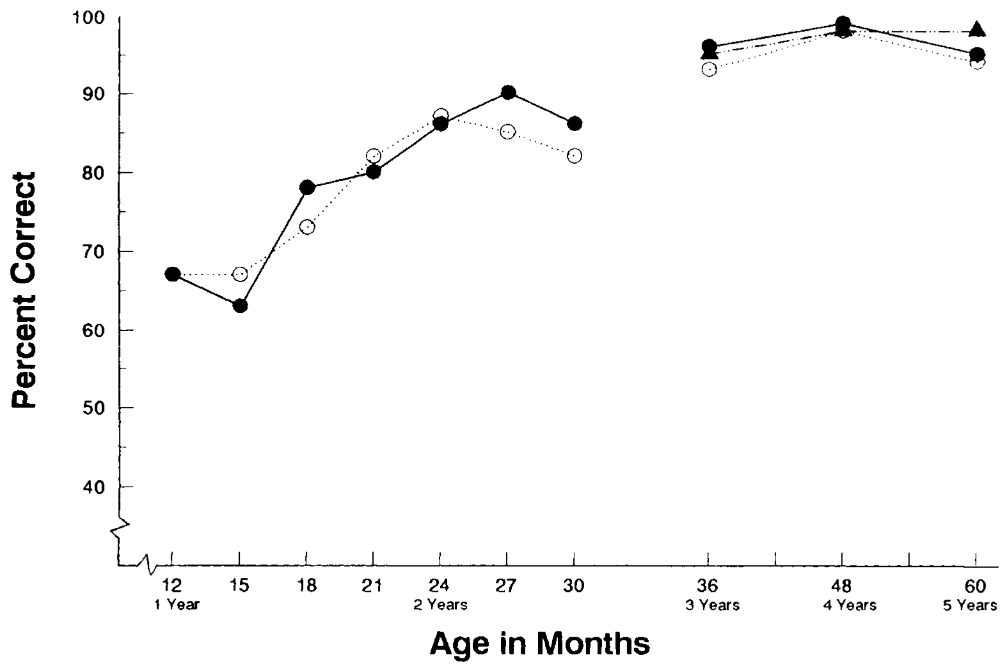

Figure 3. Percentage of correct responses by delay and age. $n = 12$ at each age. Subjects aged 3–5 years are from Study 1. Only subjects in Study 1 were tested at the 60-s delay. Open circles indicate delays of 5 s, solid circles, 30 s; and solid triangles, 60 s.

at the 5-s delay or in the percentage of subjects passing criterion at the 5-s delay.

Discussion

Subjects of 12–18 months of age had a difficult time with the delayed nonmatching-to-sample task. Forty-two percent of the 12-month-olds and 33% of those 15 and 18 months of age were never able to perform correctly on five trials in row even at the brief 5-s delay. Those who did manage to do this only succeeded on an average of 75% of the trials at the 5-s delay. Their grasp of the task was evidently too fragile to sustain even this level of performance over subsequent trials when the delay was increased to 30 s. Subjects of 18 months continued to perform well, but subjects of 15 months began to have problems, and subjects of 12 months performed significantly worse on the later trials at the increased delay than they had at the 5-s delay. At the ages when many children are still unable to succeed at the task with a brief delay, and those who do pass criterion at the brief delay are still performing below 80% correct; length of delay (and presumably the memory demands imposed by delay) may make a difference. This is consistent with the results reported in the only other study of delayed nonmatching to sample in children (Overman, Bachevalier, Turner, & Peuster, 1992). Overman et al. (1992) found that infants 12–15 months of age performed more poorly on the task at delays of 30 s than at delays of 10 s. We are unable to tell from our data, however, whether the decline in performance was due to the increased delay or to an inability to sustain a high level of performance. It is possible that the youngest subjects would not have been able to sustain good performance over more trials even if those trials had continued to be at the 5-s delay.

In any case, after 15 months of age (and, indeed, overall even including the 12- and 15-month-olds), there was no effect of length of delay within the limits of the delays tested. Children who succeeded at the 5-s delay succeeded at the 30-s delay in the same session and with a percentage of correct responses at least as high as they had achieved at the 5-s delay. Thus, the performance of 18-month-olds at the longer delay (81% correct) was almost indistinguishable from their performance at the shorter delay (79% correct). The same was true for subjects between the ages of 21 and 30 months. Although our criterion of five consecutively correct responses at the 5-s delay may have seemed lenient, it appears to have been sufficient to establish when a child of 18 months or more had mastered the task. Over the next several trials, even though the delay was increased sixfold, performance remained at a high level. These results are consistent with those of Bachevalier (1990), who found no difference in the performance of infant monkeys over delays of 10–120 s. The results also agree with those from other studies of recognition memory in children of this age, where excellent recognition has been consistently found across delays (e.g., Daehler & Bukatko, 1977). The only discrepant finding is that of Overman et al. (1992), who found that children of 18–20 and 22–32 months performed worse when the delay was 30 s than when the delay was only 10 s.

There was little improvement in delayed nonmatching-to-sample performance between 12 and 18 months of age. Then, between 18 and 21 months performance improved significantly. The improvement by 21 months was relatively abrupt. This can be seen most clearly perhaps in the percentage of subjects passing criterion (see Figure 2; 67% at 15 or 18 months and 92% at 21 months). Note how very late in infancy success on this task first appears; after all, 21 months is almost 2 years of age. Even with a delay of only 5 s, and up to 25 trials of testing, over 40% of the 12 month-olds and one-third of the 15- and 18-month-olds never passed criterion. Similar results have been obtained using daily longitudinal testing and using single session, cross-sectional testing (Overman, 1990; Overman et al., 1992). Whether subjects began testing at 12 months of age or months later, Overman and his colleagues found that performance generally remained poor until about 20–21 months of age.

This is in sharp contrast to infants' performance on many other tests of memory. For example, on the AB̲ hiding task infants can successfully remember where a toy has been hidden after a delay of 5 s by 10–11 months of age (Diamond, 1985, 1990b); they can show deferred imitation over delays of at least 24 hours by the age of 9 months (Meltzoff, 1988); and on the visual paired comparison (preferential looking) task infants show evidence of recognition over delays of 10–15 s by only 4 months of age and over much longer delays by 5 months (e.g., Caron, Caron, Minichiello, Weiss, & Friedman, 1977; Fagan, 1970; Pancratz & Cohen, 1970). The comparison of performance on the delayed nonmatching-to-sample and visual paired-comparison tasks is particularly compelling because both tasks are formally quite similar and appear to impose the same requirements on visual recognition memory (see Diamond, 1990a, 1992; McKee & Squire, 1993).

Why should success on the delayed nonmatching-to-sample task appear so very late (not until almost 2 years of age) with so very brief a delay (5 s) when we have much evidence from many sources that infants considerably younger than 21 months can remember information for 5 s and for a great deal longer? We suggest that although the delayed nonmatching-to-sample task requires memory, as shown by the impaired performance of adult monkeys and human adults with damage to the medial temporal lobe structures important for memory and by the progressive deterioration in their performance as a function of delay, the developmental progression of improved performance on this task does *not* chart a developmental progression in memory. Our reasons for this conclusion are the following.

First, success appears very late. Children can display recognition memory after a 5-s delay long before 21 months of age.

Second, there is almost no Delay × Age gradient. It was not until 21 months that subjects showed a significant improvement in delayed nonmatching-to-sample performance at the 5-s delay. If the developmental progression in performance were charting the development of memory ability, then one might expect to find success first at the shorter delay, and at a later age success at the longer delay. However, the significant improvement in performance at the 30-s delay also occurred at 21 months, and there were no significant changes in performance at either delay before or after this age.

Third, within a given child there is little variation in performance by delay. Even among 21-month-olds, performance with delays of 30 s was fully comparable to performance with delays of 5 s. Once a child could solve the task, the child could solve it at both long and short delays. This is all the more striking when one considers that the delay-period activity was more distracting during the 30-s delays than during the delays of 5 s. One does not need to do much to use up 5 s; indeed, there is little time to do anything. However, during the 30-s delays, in order to keep the children occupied, they rolled their marble reward down a ramp and through a maze in which wheels turned and parts moved or inserted their penny reward into one of several windup banks that did special things upon receipt of the penny.

There are two objections that might be raised to these conclusions. First, there was a difference in performance at delays of 5 and 30 s among 12–15-month-old subjects. It is possible that the small improvements in performance between 12 and 15 months were due, in part, to improved memory. However, the difference in performance from 12 to 15 months was not significant and does little to explain why performance was so poor until 21 months. For subjects of 15 and 18 months considered separately or together, there was no significant difference between performance at delays of 5 and 30 s. Why did so many of these subjects perform so poorly even with a delay of only 5 s? For those 15- and 18-month-olds who succeeded at the 5-sec delay, why did their performance show no decline when the delay was increased to 30 s?

Second, the other objection that might be raised is that our 30-s delay was too brief to challenge the subjects. We might have seen a difference in performance over delay if we had used longer delays. There are two responses to this. First, delays of only 15 s have been sufficient to impair the performance of amnesic patients (Squire et al., 1988, Experiment 1B) and of adult monkeys with lesions to the medial temporal lobe; hippocampus + amygdala + adjacent cortical tissue (e.g., Zola-Morgan & Squire, 1985); hippocampus + perirhinal cortex + anterior entorhinal cortex (Squire & Zola-Morgan, 1991); and perirhinal cortex + the parahippocampal gyrus excluding the hippocampus and entorhinal cortex (Zola-Morgan, Squire, Amaral, & Suzuki, 1989c) on this same task. Thus, if the developmental improvement in performance on the delayed nonmatching-to-sample task was thought to indicate something about the development of the memory ability dependent on these medial temporal lobe structures, a delay of 30 s should have been sufficiently long. Second, the problem for the younger subjects seems to be largely independent of delay in that they were correct on only 67% of trials at the 5-s delay. Performance did not significantly improve even with delays of 5 s until 21 months.

Our conclusion that the memory requirement of the delayed nonmatching-to-sample task is not the limiting factor in why success on the task appears so relatively late in infancy is consistent with other evidence that recognition memory is quite robust early in development and changes little over age. For example, Olson concluded in his review, "A variety of studies have shown either no developmental changes at all or very small ones very early in development. . . . Such experiments argue for viewing picture recognition performance as a basal, developmentally invariant aspect of the memory system" (Olson, 1976, p. 248). Our conclusion is also consistent with recent evidence that in primates, as opposed to rodents, the hippocampus may mature quite early in development (see Diamond, 1990a, for a discussion of this evidence). That is, the neural substrates for the memory ability required by this task

Table 6
Ages of Subjects in Study 3 According to Standard Condition and Told-the-Rule Condition

Age (months) and condition	Mean (in weeks plus days)	Range (in weeks plus days)
12		
Standard	53 + 1	52 + 3–54 + 0
Told rule	53 + 1	52 + 0–54 + 6
15		
Standard	66 + 3	65 + 6–67 + 4
Told rule	65 + 1	65 + 1–66 + 5
18		
Standard	79 + 0	78 + 2–80 + 0
Told rule	79 + 2	78 + 2–80 + 4
21		
Standard	93 + 1	92 + 0–93 + 6
Told rule	92 + 6	91 + 6–93 + 6
24		
Standard	105 + 4	104 + 1–107 + 2
Tole rule	105 + 5	104 + 4–106 + 6
27		
Standard	117 + 6	117 + 0–119 + 0
Told rule	117 + 3	114 + 5–119 + 6
30		
Standard	130 + 2	128 + 1–131 + 6
Told rule	131 + 2	129 + 0–134 + 2

Note. $n = 6$.

appear to be in place fairly early. Behavioral evidence is consistent with this: The visual paired comparison task is formally very similar to delayed nonmatching to sample and has been shown to depend on the same medial temporal lobe memory system as does delayed nonmatching to sample (in humans: McKee & Squire, 1993; in infant monkeys: Bachevalier, 1990; in adult monkeys: Saunders, 1989). Human infants and infant monkeys show evidence of recognition memory over delays of 10–600 s on the visual paired-comparison task very, very early in the first year of life (in humans: e.g., Fagan, 1973, 1990; in monkeys: Bachevalier, 1990).

If young children have sufficiently good memory ability to succeed at a task like delayed nonmatching to sample with a 5-s delay, then they must be failing the delayed nonmatching-to-sample task at that delay for some other reason. Studies 3 and 4 were designed to investigate what that other reason might be.

Study 3: Performance of 1–2½-Year-Olds on the Delayed Nonmatching-to-Sample Task When Told the Rule or When They Must Deduce It

Study 3 was designed to test the hypothesis that the critical ability accounting for why success appears so relatively late on the delayed nonmatching to sample task might be the ability to deduce the task's rule ("reach to the new object"). M. Mishkin (personal communication, 1992) has suggested that an inability to figure out the abstract rule implicit in the delayed nonmatching to sample task might be the key variable. To minimize the need to deduce the rule, we gave half the children three training trials where we told them the rule; we told them to choose the new object, the one they hadn't seen before. For the other children tested, Study 3 was a replication of Study 2, as the testing materials and procedures were identical.

Method

Eighty-four infants and toddlers were tested (12 subjects, 6 boys and 6 girls,[1] at each 3-month interval between 12 and 30 months of age inclusive; the same ages as in Study 2). Six subjects at each age were tested on the standard condition, and 6 subjects at each age received training trials prior to testing where they were told the rule governing correct performance on the task. Their exact ages are in Table 6. Their backgrounds were comparable to those of the subjects in Study 2; detailed information on this is available on request. All children were healthy, full-term and from middle-class homes.

In addition to these 84 subjects, we tried to test another 7 children but were unable to use their sessions because the children were too interested in the stimuli themselves (rather than in the rewards; 3 children), because they lost interest in "our game" and the testing session could not be completed (2 children), because they were not interested in any of our rewards (1 child), or because they were too cranky to permit testing (1 child).

The procedure used in the standard condition here is identical to that used in Study 2. The procedure in the "told the rule" condition varied only in that it included three training trials. Each of these trials was exactly like a test trial except that just before the pair of objects was presented the experimenter said, "The trick to this game is to always pick the *new* object. Reach to the thing you haven't seen before." On training Trials 2 and 3, the same instructions were given preceded by the word "remember." Once testing began, the procedure in the told-the-rule condition was identical to that in the standard condition.

Results

Performance in the standard condition. The results for the standard condition in Study 3 largely replicated the results found in Study 2. Indeed, there were no significant differences in performance by condition (Study 2 vs. the standard condition in Study 3), by Age × Condition, or at any individual age when we compared the results here to those in Study 2.

As in Study 2, performance improved over age (see Table 7). This can be seen by the significant main effect for age for most dependent measures; number of trials to criterion at the 5-s delay: $F(6, 35) = 2.34, p < .05$; number of errors to criterion at the 5-s delay: $F(6, 35) = 2.19, p = .07$; percentage of children passing criterion at the 5-s delay: $F(6, 35) = 4.20, p = .003$; percentage correct at the 5-s delay: $F(6, 35) = 3.41, p < .01$; percentage correct at the 30-s delay: $F(6, 28) = 2.30, p = .06$. As in Study 2, there was no effect of sex, no interaction of Sex × Age, and no effect of reward.

As in Study 2, there was no significant difference in performance at delays of 5 and 30 s, either comparing performance on all the trials at 5-s to those at 30-s; paired $t(34) = 0.26$, *ns*, or comparing performance on just the last 10 trials at 5-s to those at 30-s; paired $t(34) = 1.07$, *ns*. Unlike the results for Study 2, performance at the 30-s delay did not differ significantly from performance at the 5-s delay even for subjects of 12–15 months.

As in Study 2, there were no significant improvements in performance between 12 and 18 months or between 21 and 30 months of age. As in Study 2, the largest improvement in performance occurred between 18 and 21 months on all

Table 7
Performance in Study 3 on the Delayed Nonmatching-to-Sample Task by Age, Delay, and Condition

	5-s delay								30-s delay (% correct)	
	Mean no. trials to criterion		Mean no. errors to criterion		% passing criterion		% correct			
Age (months)	Standard condition	Told rule	Standard condition	Told rule	Standard condition	Told rule	Standard condition	Told rule	Standard condition	Told rule
12	12	17	6	8	67	33	72	63	64[a]	73[b]
15	15	10	9	9	67	83	63	69	65[c]	62[c]
18	13	9	7	5	50	83	70	76	81[d]	76[a]
21	7	5	3	4	83	100	79	83	90[a]	81
24	3	4	1	2	100	100	87	89	85	88
27	2	1	1	2	100	100	87	91	86	92
30	4	3	2	1	100	100	85	83	85	93

Note. Subjects who took more than 22 trials to pass at the 5-s delay were not tested at 30 s. No. trials to criterion = number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion for correct performance. $n = 6$ except where noted.
[a] $n = 5$. [b] $n = 2$. [c] $n = 4$. [d] $n = 3$.

dependent measures except percentage correct at 30 s (where the largest improvement was between 15 and 18 months). However, because of the smaller number of subjects in Study 3, the difference in performance between 18 and 21 months only reached a significance level of $p = .10$ on four of the five dependent measures in Study 3.

The subjects at ages 12, 15, and 18 months who had passed criterion at the 5-s delay in Study 2 had done so in very few trials (5, 6, and 6 trials respectively at each age). The same results were found here (4, 7, and 6 trials respectively).

The results concerning any systematic pattern to the errors are similar to those for Study 2. One might conclude that the effect of rewarding children for reaching to the sample when the sample is presented alone at the outset of a trial would be to train the children that the correct response, even when another choice is available, is to reach to the sample. However, as in Study 2, our subjects did not err by consistently reaching back to the sample. If a tendency to reach for the familiar sample is defined as reaching for the sample when it was presented paired with a new object on four out of the first five trials or on four of the next five trials, then only 1 infant (a 30-month-old) in either condition of Study 3 showed such a preference.

There was some evidence of a bias to reach to the object on the right or the left, especially at 12 months of age. As in Study 2, this largely disappeared by 21 months, and most of the subjects who showed a side preference passed criterion; so a position bias cannot account for so many younger subjects failing the task.

Comparison of performance in the told-the-rule and standard conditions. In the told-the-rule condition, subjects were given three training trials where they were told, "The trick here is to pick the *new* object; reach to the one you haven't seen before." It appears that subjects ≥ 15 months of age probably understood these instructions (although see Discussion below). At all ages from 15 to 30 months, performance on the three training trials was significantly better than chance and did not differ over age; see Table 8; $F(5, 30) = 0.56$, *ns.* If one is willing to grant that children of 2½ years probably understood these instructions, then one would probably need to grant that 15-month-old subjects understood also, as the performance of these two groups was quite similar. On the other hand, many subjects (even at 2½ years of age) were wrong on one of these three trials, so the evidence is not as strong as one might like that our instructions were, in fact, understood (see Discussion below). Subjects of 12 months performed roughly at chance (56%) on these three trials and probably did not understand the verbal prompt.

Giving subjects the three training trials had little effect on performance during the test trials. There were no significant differences on any of the five dependent measures between performance in the told-the-rule condition versus the standard condition for the two groups as a whole, for the two groups beginning at 15 months (when the first evidence of any understanding of the verbal prompt was evident), for any individual age, or for any pair of ages (see Table 7). Although the differences were not large enough to be significant, average performance in the told-the-rule condition tended to be marginally better at the 5-s delay than in the standard condition, beginning at the youngest age where any understanding of our verbal prompt was evident (15 months). Subjects in the told-the-rule condition performed marginally better on three of the four dependent measures of performance at the 5-s delay at 15 months, 100% of these measures at 18 months, and 75% at 21 months. (After 21 months, 100% of the subjects

Table 8
Performance in Study 3 on Three Training Trials in the Told-the-Rule Condition

Age (months)	% correct
12	56
15	78
18	78
21	78
24	78
27	72
30	83

passed criterion at the 5-s delay even in the standard condition.) After the point where the 5-s delay became trivial (i.e., after 21 months), performance at the 30-s delay was consistently better when children had been told the rule than in the standard condition, although this did not quite reach statistical significance; $t(33)$ for subjects 24–30 months of age = 1.93, p = .06.

Performance during the training trials bore little relation to performance of the same subjects during the test trials. The correlation between percentage correct on training and test trials (5-s delay on all these trials) was $r = .27$, $p = .08$; the correlation between percentage correct during training and the number of trials that subjects needed to pass criterion at the 5-s delay was $r = .24$, $p = .10$. In short, there werc no significant correlations between performance during training and performance during test.

Performance improved in the told-the-rule condition over age, as it did for the standard condition (see Table 7). There was a significant main effect for age on each of the five dependent measures. As was true for the standard condition, thcre were no significant sex differences, no Sex × Age interactions, no effect of reward, and no effect of delay length. There was no significant difference between performance at the 5- and 30-s delays, overall or at any age, either comparing performance on all the trials or on just the last 10 trials at the 5-s delay. Similarly, as was true for the standard condition, the difference in how a subject performed at the 5- and 30-s delays also did not change significantly over age.

The younger subjects who passed criterion in the told-the-rule condition appeared to need more trials to do so than subjects of the same age in the standard condition in either Study 2 or Study 3, although these differences were not statistically significant. At 12 and 15 months, position preferences on the first 5 and 10 trials were as common in the told-the-rule condition as in the standard condition. After 15 months, slightly more children tended to show a position preference here than in the standard condition (18 months: 2 children showed a position preference here on 8 of the first 10 trials; 21 months: 2 children on 4 of the first 5 trials; 24, 27, and 30 months: 1 child showed a position preference on 4 of the first 5 trials).

Discussion

It had been suggested that young subjects fail the delayed nonmatching-to-sample task because they cannot figure out the rule governing correct performance. So, for half of the subjects in Study 3, we told them the rule. This did not significantly affect performance. The direction of our effects suggests that telling children the rule may have slightly aided performance. However, this slight effect can by no means account for why children of 12–18 months perform so poorly on the task.

Others have found that as long as testers continue to instruct young school-age children, the children perform better, but once the instruction ceases, so does the improvement in performance. For example, children perform better on memory tasks if they rehearse during the delay, and younger children (who do not spontaneously rehearse) perform better if they are prompted to use this strategy. However, as soon as the prompting stops, so does the use of the strategy, and so does the improvement in performance (e.g., Hagen, Hargrove, & Ross, 1973; Keeney, Cannizzo, & Flavell, 1967). The pcrformance of the previously prompted children becomes indistinguishable from that of children who never received instruction, just as we found that performance of children in the told-the-rule condition was indistinguishable during the test trials from that of children in the standard condition. Unlike these studies in children of 6–7 ycars, however, we found that children of 12–30 months did not even perform that well while we were prompting them (M = 76% correct). Their performance during the test trials (when the prompting ceased) was not significantly worse than their performance on the training trials; paired $t(41) = 0.63$, *ns*.

Other studies, with children in the same age range as studied here, have also found that cven during the time testers are telling young children the rule, the children still act incorrectly. DeLoachc (1986) told children of 21 and 27 months that "the candy is in the box with this [thing, picture] on top. Remember this [thing, picture], because that is where the candy is hiding" and periodically repeated this to remind the children (p. 133). She found that these reminders did not improve performance even on the trials immediately following them. Similarly, Zelazo and Reznick (1991) reminded 32-month-old children of the rules governing correct performance on a sorting task at three points during the task. These instructions did not aid performance at all, even on the trials immediately following them. Zelazo and Reznick (1991) concluded, "It does not seem to be the case that poor sorting performance reflects an inability to remember the rules" (p. 732). It is interesting to note that when Squire et al. (1988) placed a card stating the rule for the delayed nonmatching-to-sample task in front of amnesic patients while they were performing the task, the patients still performed poorly. Here, however, the explanation offered is that, although the patients no longer needed to figure out or remember the rule, they still needed to remember what the sample object had been on the current trial, and when the delay was several seconds or more, they forgot.

More recently, Zelazo, Frye, and Reznick (in press) and P. D. Zelazo (personal communication, 1993) have demonstrated that even when the children themselves indicate what the rule is at the outset of a trial, the children still act incorrectly. Here, children of 3 years were to sort a deck of cards (red triangles and blue circles) by color and then by shape. (Half of the children were to sort by shape and then by color.) Children of 3 years did well on the first sorting criterion but had difficulty switching, despite the experimenter's instructions indicating the sorting rule had changed and what the current rule was. After a child erred five times, the experimenter went over the rule with the child thusly, "Remember we're playing the shape game, and in the shape game the circles go here and the triangles go there. Now, where do the circles go in the shape game?" The child pointed correctly. "Where do the triangles go in the shape game?" The child pointed correctly. The experimenter then handed the child the next card to be sorted and asked, "Where does this red triangle go?" Amazingly, children sorted it by color! Zelazo and his colleagues (in press) found that this happened trial after trial. Despite demonstrating knowledge of the rule and of how the rule applied on the current trial, children of 3 years erred repeatedly.

Thus, the results of other studies are consistent with the results of Study 3. At the ages when most children fail the delayed nonmatching-to-sample task, telling children the rule determining correct performance has little effect on their behavior. Children do not act in accordance with the rule even when there is good evidence that they know the rule. The results of Tyrrell, Stauffer, and Snowman (1991) may also be relevant here, as they found that infants of only 7 months appear to be able to respond based on an abstract relationship (same or different), rather than simply on the basis of the concrete characteristics of a stimulus. If, in fact, 7-month-olds can respond at this level of abstraction, then it is perhaps more likely that 12-month-olds should be able to deduce a rule at a similar level of abstraction ("Choose the stimulus different from the sample."). During each familiarization period, Tyrrell and colleagues allowed infants to look at a unique pair of two identical toys (e.g., *AA*) or two dissimilar toys (e.g., *BC*). During the abstract preference test, infants were presented with the choice of looking at a pair of identical objects (e.g., *DD*) or a pair of dissimilar objects (e.g., *EF*). Infants of 7 months showed a novelty preference at the level of abstract relationship; they looked preferentially at the pair of stimuli in a relationship to one another different from the pair presented during familiarization (i.e., those who had seen *AA* looked more at *EF*, and those who had seen *BC* looked more at *DD*), even though all objects presented during familiarization were novel.

At this point, we eliminated two of the hypotheses for why success on the delayed nonmatching to sample appears so late in development. In Study 2, we found evidence that the memory requirements of the task appeared not to be the problem. In Study 3, we found that difficulty deducing the rule required by the task was probably not the problem either.

Study 4: Performance of 12- and 15-Month-Olds on the Delayed Nonmatching-to-Sample Task When Given a Long Time to Encode the Sample or When Given No Reward for Reaching to the Sample During Familiarization

If memory and deductive reasoning are not the limiting factors, what other more slowly maturing ability accounts for why success on the delayed nonmatching-to-sample task appears so relatively late? The abilities we considered in Study 4 were speed of encoding and the ability to resist interference.

Information-processing time decreases dramatically with age; younger children need much longer to process a stimulus than older children. Studies of visual paired comparison have often found that if the sample is presented only briefly subjects do not look preferentially to the novel stimulus (e.g., Caron et al., 1977; Hunter & Ames, 1975, 1988; Lasky, 1980; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). This is analogous to subjects not reaching preferentially to the novel stimulus on the delayed nonmatching-to-sample task. Moreover, the time needed to encode the sample decreases with age during infancy (e.g., Caron et al., 1977; Hunter & Ames, 1975, 1988; Rose et al., 1982; Werner & Perlmutter, 1979), so if the sample is presented briefly, younger children would be more adversely affected than older children.

In the first condition of Study 4, we increased the presentation time of the sample to 20 s during familiarization (when the sample is presented alone at the outset of the trial). In the standard delayed nonmatching-to-sample task, the subject sees the sample for only a few seconds (2–5 s). It is possible that infants need more than 2 to 5 s to process the information about the sample. The first condition was designed to test that hypothesis.

In the second condition of Study 4, we did not reward subjects for displacing the sample during familiarization (although they were still rewarded during the test portion of each trial for displacing the new object) to minimize interference from the reward between familiarization and test. During familiarization on the standard delayed nonmatching-to-sample task, the subject first displaces the sample stimulus and then retrieves the reward. It is possible that receiving the reward after displacing the sample interferes with remembering what the sample was.

We know that when monkeys are tested on the delayed *matching*-to-sample task (Gaffan, Shields, & Harrison, 1984), they perform better when they do not receive a reward for displacing the sample during familiarization. The delayed matching-to-sample task is identical to delayed nonmatching except that during the test phase subjects are rewarded for displacing the sample again, not the new object. Both Gaffan, Shields, & Harrison (1984) and Mishkin (personal communication, 1992) have argued that the reason performance is aided by this no-reward during-familiarization condition is that the standard delayed matching-to-sample task requires subjects to learn two contradictory rules: When the sample is presented alone during familiarization, it is new. The subject has never seen it before. Thus, during familiarization the following rule applies: "Reach to a new object." During the test phase, however, when the now familiar sample is paired with a new object, the subject is rewarded for reaching to the sample again in the delayed matching-to-sample task. Thus, during the test phase, the rule "Reach to the familiar object," applies.

Gaffan, Shields, & Harrison (1984) and M. Mishkin (personal communication, 1992) reasoned that having to learn two contradictory rules was confusing and that this could be alleviated by placing no reward under the sample during the familiarization. In this no-reward-during familiarization condition, subjects still had to touch the sample during familiarization, but they were not rewarded for doing so. Here, subjects were rewarded for reaching to the sample only during the test phase; hence the only relevant rule would be "Reach to the familiar object." Subjects found this version of delayed matching to sample far easier to master (Gaffan, Shields, & Harrison, 1984).

We reasoned, however, that rules only become relevant when there is choice. When the sample is the only stimulus presented, subjects neither reach to it because it is new, nor because of any other characteristic of the sample, but because it is the only thing available. "Reach to the new object" implies "do not reach to something else," and during familiarization there is no something else. Hence, we reasoned that the only time a rule becomes relevant in the delayed matching-to-

Table 9
Ages of Subjects in Study 4 in the Long-Presentation Condition and the No-Reward-During-Familiarization Condition

Age (months) and condition	Mean (in weeks plus days)	Range (in weeks plus days)
12		
Long	53 + 4	52 + 2–55 + 0
No reward	53 + 2	52 + 0–53 + 6
15		
Long	67 + 1	65 + 4–71 + 1
No reward	66 + 1	64 + 1–67 + 6

Note. $n = 12$.

sample task is during the test phase (when two stimuli are presented); that rule is "reach to the familiar object;" and this is true whether subjects are rewarded during familiarization or not. We reasoned further that Gaffan, Shields, & Harrison (1984) manipulation of no-reward-during-familiarization aided performance because it removed the interference caused by the reward. In this no-reward-during-familiarization condition, subjects' attention was not diverted from the sample by the treat underneath it.

No one has argued that subjects are required to learn two contradictory rules on the delayed nonmatching-to-sample task. Hence, if subjects were to perform delayed nonmatching to sample better when there was no reward during familiarization, that would support our interpretation of why this manipulation helps, as opposed to the interpretation offered by Gaffan, Shields, & Harrison (1984) and M. Mishkin (personal communication, 1992).

Method

Forty-eight infants were tested (24 subjects each, at 12 and 15 months of age). Twelve subjects (6 boys and 6 girls) at each age were tested with the sample presented for a long time (the long-presentation condition) and 12 subjects (6 boys and 6 girls) at each age received no reward for reaching to the sample when the sample was presented alone (the no-reward-during-familiarization condition). Their age ranges and means are in Table 9. Their backgrounds were very similar to those of the subjects in Studies 2 and 3. All subjects were healthy, full-term, and from middle-class homes.

In addition to these 48 subjects, we tried to test another 16 infants but were unable to use their sessions. Most of these infants (75%) were in the long-presentation condition. Many 15-month-old subjects (3 girls and 4 boys) would not sit still during the long initial presentation of the sample. (This is one reason we did not include still older subjects in this experiment.) Other subjects in the long-presentation condition were omitted from the analyses because they were more interested in the stimuli than in the rewards (3 girls of 15 months; we know that infants of only 6 or 9 months can succeed when the stimuli themselves are the rewards; Diamond, 1990a, 1992), they were not interested in any of our rewards (1 girl of 15 months), or they lost interest in the task and could not be enticed to finish (1 boy of 15 months). Four subjects in the no-reward-during-familiarization condition were unusable because they were more interested in the stimuli than in the rewards (2 girls of 15 months), they were too shy and would not displace the stimuli (1 girl of 12 months), or they lost interest in the task and could not be enticed to finish (1 boy of 12 months).

The procedure in both conditions closely resembled the standard delayed nonmatching-to-sample condition of Studies 2 and 3, with one aspect of the procedure modified in each condition. In the long-presentation condition, we presented the sample during familiarization for 20 s. Each trial began with the sample, on top of a well containing the reward, presented at the midline outside of the infant's reach. The experimenter moved the sample back and forth, trying to keep the infant's attention fixed on the sample. If the infant looked away from the sample, the experimenter drew the infant's attention back to the sample by tapping the sample and well on the tabletop or by saying, "Look at this" and describing the object. If an infant looked up at the experimenter, the experimenter brought the sample into the infant's line of sight and then brought it back down to the table, drawing the infant's eyes back down. After 15–18 s, the sample and well were pushed forward, and the infant was allowed to retrieve the reward. The experimenter then removed the sample and well. The sample was thus available in this condition for approximately 20 s, as opposed to the 2–5 s during which it was available in the standard condition.

In the no-reward-during-familiarization condition, the sample was presented alone at the midline, with no well or reward underneath it during familarization. To ensure that the infant had seen the sample, the infant had to move the sample or briefly pick it up, but no subject was allowed more than 2 to 3 s with the sample. Total presentation time was 2 to 5 s.

Results

Performance in the long-presentation condition. To check whether this manipulation succeeded in directing infants' attention to the sample for a longer period of time than in the standard condition, we coded from the videotape the amount of time infants fixated the sample in the long-presentation condition and in the standard condition in Study 2 at comparable ages (12 and 15 months of age; *ns* at all ages in all conditions = 12). In the long-presentation condition, the mean time fixating the sample during familiarization was 15 s; the range was 7–20 s on individual trials and the range in mean fixation time over subjects was 10–18 s. In the standard condition, the mean time fixating the sample during familiarization was 4 s; the range was 2–6 s on individual trials and 3–5 s for the means of each subject. Thus, subjects looked at the sample approximately 4 times longer in the long-presentation condition.

There was no significant age difference (12 versus 15 months) in the long-presentation condition on any dependent measure or on fixation time to the sample. There was a sex difference, however. Girls performed better (see Table 10). They required almost half as many trials and made half as many errors as boys before passing criterion at the 5-s delay. More girls passed criterion, and girls were correct on a higher percentage of the trials at the 5-s delay than were boys. There were no significant Age × Sex interactions. Girls fixated the sample longer during familiarization (M = 17 s) than did boys, who were more fidgety (M = 13 s), but this difference did not reach significance.

As in Study 2, those infants of 12 and 15 months who performed better than many of their peers and managed to pass criterion with a delay of 5 s, performed significantly worse when the delay was increased to 30 s; paired $t(16) = 3.53, p = .002$.

Giving subjects more time to familiarize themselves with the sample did not significantly improve performance on the

Table 10
Comparison of the Performance in Study 4 of Boys and Girls in the Long-Presentation Condition

Variable	Boys	Girls	$F(1)$ for orthogonal contrast	$p \leq$
5-s delay				
Mean no. trials to criterion	11.50	6.33	4.84	.04
Mean no. errors to criterion	6.08	2.58	7.31	.01
% passing criterion	66.67	91.67	5.00	.04
% correct	62.87	79.58	12.78	.002
30-s delay				
% correct	63.96 ($n = 6$)	65.76 ($n = 11$)	0.50	*ns*

Note. $n = 12$ in each cell at 5 s. Only subjects who passed criterion at the 5-s delay in fewer than 23 trials were tested at 30 s; hence the lower *ns* at 30 s. *F* values are based on the contrasts from analyses of variance with Age, Sex, and Age × Sex as independent variables. No. trials to criterion = number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion for correct performance.

delayed nonmatching-to-sample task by most measures (see Table 11). There was no significant difference on any dependent measure at either the 5- or 30-s delay, overall or at either age, between performance here and performance at comparable ages in Study 2, where the standard condition was administered. Although none of these differences was statistically significant, infants in the long-presentation condition performed better than infants in the standard condition on all dependent measures of performance at the 5-s delay. The across-the-board lack of significance was true for boys but not for girls. Girls given a long time to observe the sample were correct on significantly more trials at the 5-s delay; $t(10) = 2.11, p = .05$; and required fewer trials to pass criterion at the 5-s delay than girls given the sample for only 2–5 s, although the latter difference was not quite significant; $t(10) = 1.96, p = .07$. No other dependent measure showed any significant difference between the girls in the long-presentation and standard conditions. Within the long-presentation condition, there was one significant correlation between how long the sample was fixated and performance; percentage correct at the 5-s delay was higher among subjects who had fixated the sample longer ($r = 0.40, p < .05$).

Performance in the no-reward-during-familiarization condition. There was no significant age difference (12 vs. 15 months), no sex difference, and no significant Sex × Age interaction in this condition on any dependent measure. As in the standard and long presentation conditions, performance of the 12 and 15 month old infants was significantly better at the 5-s delay than at the 30-s delay; paired $t(20) = 3.1, p < .01$.

Performance was significantly better in this no-reward-during-familiarization condition than in the standard condition of Study 2 (see Table 11). Infants were correct on significantly more trials at the 5-s delay; $t(46) = 2.82, p < .01$; and required significantly fewer trials to reach criterion at this delay; $t(46) = 2.69$, $p < .01$, when they received no reward during the familiarization phase of each trial. Infants also made fewer errors at the 5-s delay and more of them passed criterion, but neither of these differences quite reached significance; $t(46) = 1.81$, $p = .08$; $t(46) = 1.73$, $p = .09$, respectively. There was no significant difference in performance at the 30-s delay; $t(30) = .92$, *ns;* see Table 11.

Comparison of performance in the long-presentation and no-reward-during-familiarization conditions. There was no significant difference between performance in the long-presentation condition and performance in the no-reward-during-familiarization condition, although the difference in percentage correct at delays of 5 s just missed being significant, $t(46) = 1.91$, $p = .06$. Even though none of these differences was statistically significant, on every dependent measure (including percentage correct at the 30-s delay) and at both ages, infants in the no-reward-during-familiarization condition performed better than infants in the long-presentation condition (see Table 11). There was no significant interaction between condition and sex, except for percentage correct at the 5-s delay. Males in the long-presentation condition were correct on sig-

Table 11
Performance in Study 4 on the Delayed Nonmathcing-to-Sample Task by Age, Delay, and Condition

	12-month-olds			15-month-olds		
Variable	Standard condition	Long presentation	No reward during familiarization	Standard condition	Long presentation	No reward during familiarization
5-s delay						
Mean no. trials to criterion	12	10	6	12	9	6
Mean no. errors to criterion	6	5	4	7	5	3
% passing criterion	67	75	83	67	83	92
% correct	67	74	78	67	69	82
30-s delay						
n	7	8	10	8	9	11
% correct	67	66	73	63	61	67

Note. $n = 12$ in each cell at 5 s. Only subjects who passed criterion at the 5-s delay in fewer than 23 trials were tested at 30 s; hence the lower *ns* at 30 s. No. trials to criterion = number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion for correct performance. Standard condition data are from Study 2.

Table 12
Comparison of the Performance of Children of 15 Months in the No-Reward-During-Familiarization Condition and the Performance of Children of 21 Months in the Standard Condition of the Delayed Nonmatching-to-Sample Task

		21-month-olds	
Variable	15-month-olds: No reward during familiarization	Standard condition Study 2	Standard condition Study 3
5-s delay			
n	12	12	6
Mean no. trials to criterion	6	6	7
Mean no. errors to criterion	3	3	3
% Passed criterion	92	92	83
% Correct	82	80	79
30-s delay			
n	10	11	5
% Correct	67	80	90

Note. No. trials to criterion = number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion for correct performance.

nificantly fewer trials at the 5-s delay than were males in the no-reward-during-familiarization condition; orthogonal contrast: $F(1) = 5.20, p = .03$; for females, percentage correct at the 5-s delay did not differ significantly by condition.

Some subjects showed systematic reaching biases, as have subjects in earlier conditions. If preference for the familiar sample is defined as reaching for the sample during the test phase on 4 out of the first 5 trials, then three 12-month-olds (2 in the long-presentation condition and 1 in the no-reward condition) and one 15-month-old (in the long-presentation condition) showed a tendency to reach back to the familiar stimulus. None reached to the sample during the test phase on 8 of the first 10 trials. There was also some evidence of position preferences. As found for the previous conditions, infants showing a right or left bias were no more likely to fail to pass criterion than other infants.

Discussion

Toddlers given four times longer to encode the sample stimulus did not perform significantly better than toddlers of the same age tested on the standard delayed nonmatching-to-sample task. The direction and consistency of the effects suggest, however, that presenting the sample for a longer time may have slightly aided performance, very much like telling children the rule in Study 3 may have helped slightly. An inability to quickly encode the sample stimulus cannot account for why children do not consistently succeed on the delayed nonmatching-to-sample task until roughly 21 months of age because the effect is simply too small.

This conclusion is consistent with the results of others. Fagan (1973) found that infants ≥5 months of age could succeed on the visual paired-comparison task even after minimal exposure to the stimulus and in the absence of overt habituation. Bachevalier (1990) found that infant monkeys who looked at the sample stimuli for only 2 to 5 s during familiarization looked significantly longer at the novel stimuli in the visual paired-comparison task as early as at least 2 weeks of age. Consistent with our results, Bachevalier (1990) found that, although time fixating the sample was comparable on the delayed nonmatching-to-sample task, monkeys could not consistently succeed on delayed nonmatching-to-sample until about 4 months of age.

The no-reward-during-familiarization condition, alone among the variations of the delayed nonmatching-to-sample task tested in the present set of studies, significantly improved performance. Children were able to succeed at the 5-s delay at a younger age when they received no reward for reaching for the sample during familiarization. *Here, children of 15 months performed at least as well as those of 21 months in the standard condition.* On every measure of performance at the 5-s delay, 15-month-old subjects in the no-reward-during-familiarization condition performed as well or better than subjects of 21 months in the standard condition (see Table 12). Indeed, even children of 12 months performed much like children of 21 months in the standard condition. Thus, although good performance on the standard delayed nonmatching-to-sample task is not evident until about 21 months, simply by omitting the reward during the familiarization portion of each trial, we were able to obtain this level of performance by 12–15 months at the 5-s delay.

There was a limit to this effect, however. It did not extend to performance at the longer delay. Subjects of 15 months in the no-reward-during-familiarization condition still performed like subjects of 15 months in the standard condition when the delay was increased to 30 s. More 15-month-olds made it to the 30-s delay when tested with no-reward, but among those who passed criterion at the 5-s delay, performance was unaffected at the 30-s delay by whether or not a reward was present during familiarization. Performance here was significantly worse than that of 21-month-olds tested with a delay of 30 s in the standard condition.

Performance of infants of 12 to 15 months on the no-reward-during-familiarization condition of delayed nonmatching to sample is similar to the performance of monkeys and human adults with medial temporal lobe damage on the standard delayed nonmatching-to-sample task, i.e., good performance at very brief delays (e.g., 5 s) and significantly worse performance at longer delays (e.g., 30 s). This is the only instance over the course of the four studies reported here where we saw this pattern of performance.

We were not the first to omit the reward during familiarization. Gaffan, Shields, & Harrison (1984) used this procedure with monkeys tested on delayed matching to sample; it helped their subjects, too. Gaffan et al. had reasoned that this beneficial effect was due to eliminating the need for subjects to master two contradictory rules (see above). We reasoned that the no-reward-during-familiarization procedure aids performance because the last thing subjects see before the delay is the sample, without having their attention drawn away from the sample by a reward. The interpretation offered by Gaffan, Shields, & Harrison cannot account for the ameliorative effect reported here on delayed nonmatching to sample because on this task subjects are never required to learn two contradictory rules. The rule "reach to the thing you haven't seen before" is the only rule relevant to the task whether or not a reward is present during familiarization. On the grounds of parsimony and because we see no compelling reason why the no-reward-during-familiarization manipulation should aid performance on these two very similar tasks for different reasons, we take these results as a disconfirmation of the hypothesis offered by Gaffan and colleagues. Indeed, we would argue that the delayed matching-to-sample task does not require subjects to learn two rules, even in the standard condition. Rather, monkeys and children find the task much harder than delayed nonmatching because delayed matching requires that subjects resist their natural preference to reach to the new thing and instead reach back to the familiar sample (see Diamond, 1990a). On the other hand, in delayed nonmatching to sample, subjects are rewarded for doing precisely what they are predisposed to want to do.

Further evidence that the critical difference between nonmatching and matching is the advantage conferred on the former by the natural preference for novelty is the similarity in the ages at which children solve these two tasks when this preference is absent. Oddity tasks require subjects to select the stimulus that does not match the others, but all stimuli are presented simultaneously so none is more familiar or novel than any other. Matching tasks require subjects to select the stimulus that matches the sample, all stimuli presented simultaneously with the sample set apart from the choice stimuli. Under these circumstances, children solve oddity and matching tasks at about the same age (about 5 years of age; oddity: e.g., Brown & Lloyd, 1971; Gollin, Saravo, & Salten, 1967; Gollin & Shirk, 1966; matching: e.g., Levin & Hamermesh, 1967; Levin & Maurer, 1969; Silleroy & Johnson, 1973).[5]

Alvarez-Royo, Zola-Morgan, and Squire (1992) found that monkeys with lesions of the medial temporal lobe performed as well as controls on delayed nonmatching to sample when the reward was omitted during familiarization. Unfortunately, in the Alvarez-Royo et al. (1991) study, no-reward-during-familiarization was confounded with length of delay. When the reward was omitted during familiarization, the delay was only 0.5 s. When the reward was present during familiarization, the delay was 60 to 180 s. We predict that, holding delay constant, even monkeys with lesions of the medial temporal lobe would perform significantly better on delayed nonmatching to sample with no-reward-during-familiarization than on the standard delayed nonmatching-to-sample task.

It has been shown in monkeys that performance improves if there is less distraction between the initial portion of a trial and the test phase. Such evidence is consistent with our interpretation that receiving a reward during familiarization (i.e., between the initial sample presentation and test) distracts subjects and thereby impairs performance. For example, on the delayed matching to sample task (D'Amato, 1973; D'Amato & O'Neill, 1971; Etkin, 1972) as well as on other tasks (e.g., delayed response: Malmo, 1942) monkeys perform substantially better if the experimenter simply turns the lights off during the delay. This suggests that any interference, such as looking around at things in the room, might impair performance. However, there is also evidence that recognition memory is quite robust in young infants despite the presence of distraction from, say, stimuli interspersed between sample and test (e.g., Bornstein, 1976; Caron & Caron, 1968; Fagan, 1971; Martin, 1975).

The present results would also be consistent with at least one other interpretation. If a reward defines the end of a trial, then allowing subjects to retrieve a reward during familiarization as well as during the test phase might make it difficult for subjects to perceive where a trial begins and ends. They might see this as single-item trials alternating with two item trials, without perceiving the relation between the familiarization phase and the test phase of each trial. Omitting the reward during familiarization would then aid performance, not because it reduces interference, but because it makes trial boundaries clearer. Although the present results cannot distinguish between these two interpretations, the trial boundary hypothesis could be tested by demarcating the beginning and end of a trial more clearly (e.g., by a larger difference between within-trial and between-trial delays). If the trial boundary hypothesis is correct, children should perform better here even if they receive a reward during both familiarization and test.

General Discussion

Overview of the Developmental Progression

The developmental progression in children's performance on the delayed nonmatching to sample task and on various modifications of the task is summarized in Table 13. On the standard delayed nonmatching to sample task, children first performed at $\geq 70\%$ correct by 18 months of age (both at delays of 5 and 30 s), at $\geq 80\%$ correct by 21 months (at delays of 5 and 30 s), and at $\geq 90\%$ after 2½ years and by at least 3 years (at delays of 5, 30, and 60 s). At none of these ages was there any difference in performance by delay. However, at the youngest age tested (12 months) performance significantly declined when the delay was increased from 5 to 30 s. In general, performance changed little between 12 and 18 months of age and between 21 and 30 months, but there was a substantial improvement between 18 and 21 months. Telling children the rule for correct performance or giving them a long time to familiarization themselves with the sample had little effect on performance.

Presenting the sample by itself during familiarization, without a reward beneath it, enabled subjects of 12–15 month to perform significantly better on the task at the 5-s delay. Using this procedure, by the youngest age tested (12 months), infants were performing at $> 70\%$ correct at the 5-s delay and by 15 months they were performing at $> 80\%$ correct. Indeed, at delays of 5 s, 15-month-old subjects performed at least as well here as do 21-month-old subjects on the standard delayed nonmatching-to-sample task. However, this procedure had little effect on performance at delays of 30 s. Subjects of 12 and 15 months who managed to succeed at the 5-s delay in the no-reward-during-familiarization condition performed significantly worse when the delay was increased to 30 s, and performed comparably at this increased delay to subjects of the same age on the standard delayed nonmatching-to-sample task.

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[5] Note that there is no delay whatsoever here, but success does not appear until children are roughly 5 years of age.

Table 13
Summary of the Developmental Progression on the Standard Delayed Nonmatching-to-Sample Task and Its Variations

		Delayed nonmatching to sample				
Task characteristic	Visual paired comparison[a]	Stimulus = reward[b]	No reward during familiarization[c]	Told rule[d]	Long presentation[e]	Standard[f]
Task procedures						
General						
Stimuli	3-D objects	3-D objects	3-D objects	3-D objects	3-D objects	3-D objects
Response required	Looking	Reaching	Reaching	Reaching	Reaching	Reaching
Told-the-rule condition	Not applicable	Not applicable	Must deduce	Told rule	Must deduce	Must deduce
During familiarization phase						
Presentation time	> 30 s	> 30 s	2–5 s	2–5 s	15 s	2–5 s
Reward under sample?	No	No	No	Yes	Yes	Yes
During delay and test phases						
Length of delay	10 s–10 min	10 s–10 min	5 and 30 s	5 and 30 s	5 and 30 s	5 and 30 s
Reward hidden under stimulus?	No	No	Yes	Yes	Yes	Yes
Results						
Age at which begin to choose novel stimulus ≥ 70% of time						
at 5-s delay	—	—	≤ 12 months[g]	18 months	> 15 months[h]	18–21 months
at 10-s delay	≤ 4 months[g]	≤ 6 months[g]	—	—	—	—
at 30-s delay	—	—	> 15 months[h]	18 months	> 15 months[h]	18 months
at 60-s delay	6 months	≤ 6 months[g]	—	—	—	—
at 10-min delay (600 s)	9 months	≤ 6 months[g]	—	—	—	—
Age at which begin to choose novel stimulus ≥ 80% of time						
at 5-s delay	—	—	15 months	21 months	?[h]	21 months
at 10-s delay	6 months	≤ 6 months	—	—	—	—
at 30-s delay	—	—	?	21 months	?[h]	18–21 months
at 60-s delay	9 months	9 months	—	—	—	—
at 10-min delay (600 s)	?[h]	9 months	—	—	—	—
Age at which begin to choose novel stimulus ≥ 90% of time						
at 5-s delay	—	—	> 15 months[h]	> 30 months[h]	?[h]	> 2½ and ≤ 3 years
at 10-s delay	?[h]	12 months	—	—	—	—
at 30-s delay	—	—	?[h]	?[h]	?[h]	> 2½ and ≤ 3 years
at 60-s delay	?[h]	12 months	—	—	—	—
at 10-min delay (600 s)	?[h]	> 12 months[h]	—	—	—	—
Earliest age at which performance at 30- and 5-s are both ≥ 80%	—	—	> 15 months	21 months	> 15 months[h]	21 months
Earliest age at which performance at 60- and 10-s are both ≥ 80%	9 months	9 months	—	—	—	—

Note. 3-D = three-dimensional. Empty cells indicate not studied.
[a]Diamond, 1990a, 1992. [b]Diamond, 1990a, 1992. [c]Study 4. [d]Study 3. [e]Study 4. [f]Studies 2 and 3. [g]Performed at least this well at youngest age tested. [h]Did not perform at this level even at oldest age tested.

When the rewards are eliminated altogether during both familiarization and test, and subjects are allowed to explore the stimulus objects instead, infants are ≥ 70% correct at all delays (10 s–600 s) by the earliest age at which they can reach for free-standing objects (Diamond, 1990a; 1992). Already by this young age (6 months), they reach correctly to the new object ≥ 80% of the time at delays of 10 and 15 s. By 9 months, they reach correctly ≥ 80% of the time at all delays (a level of performance comparable to that of children of 21 months on the standard delayed nonmatching to sample task). By 12 months, they are correct on 90% of the trials at delays of 10 sec and 1 min, and on 85% of the trials at all other delays.

Does the Developmental Progression Reflect the Development of Recognition Memory?

What can we conclude from the pattern of results? First, children do not succeed on the standard delayed nonmatching-to-sample task until surprisingly late. Many children do not pass criterion with a delay of only 5 s until 21 months of age. We say this is late because of the wealth of evidence that children can recognize what they have seen after delays of 5 s and after much longer delays at least 9–12 months earlier, and the delayed nonmatching-to-sample task has been thought of as a straightforward test of recognition memory.

This has led us to question whether this task really is as straightforward as once thought and whether the developmental progression in children's performance reflects the development of recognition memory. Clearly, delayed nonmatching to sample appears to require the recognition memory ability subserved by the medial temporal lobe. We know this from the plethora of ablation studies in macaques and from adults made amnesic by damage to the medial temporal lobe. But is memory the only ability required by the delayed nonmatching-to-sample task, and is the memorial requirement of the task the reason most children do not begin to succeed on the task until almost 2 years of age?

Consider, for example, the visual paired-comparison task. Formally, it is virtually identical to delayed nonmatching to sample (sample presented during familiarization, then a delay followed by a choice between the sample and a new stimulus during the test phase). The evidence appears strong that visual paired comparison requires the same medial temporal lobe memory system as does delayed nonmatching to sample based on work in adult monkeys (Saunders, Aigner, & Frank, 1990), infant monkeys (Bachevalier, 1990), and amnesic adults (McKee & Squire, 1993). However, *by only 4 months of age* infants choose the novel stimuli in the visual paired-comparison task 70% of the time after delays of 10 s with stimuli like those used in delayed nonmatching to sample (Diamond, 1990a; 1992; see Table 13), and at even earlier ages when the stimuli are pictures or faces (e.g., Fagan, 1990). By 9 months of age, infants tested on the visual paired comparison task with three-dimensional stimuli choose the novel stimulus 80% of the time with delays of 10 to 60 s. Indeed, this level of performance can be obtained on the delayed nonmatching to sample task simply by removing all extrinsic rewards (Diamond, 1990a; 1992; see Table 13). Inability to remember for 5 s does not appear to be the limiting factor in why most children do not succeed on the standard delayed nonmatching to sample task until 21 months of age.

Development of What Other Ability Might Underlie the Observed Developmental Progression

All of these tasks rely to some extent on the subject's natural preference for novelty. Certainly, delayed nonmatching to sample should be easier for any subject to master if that subject's natural inclination happened to be to choose the novel stimulus. Visual paired comparison and delayed nonmatching to sample (stimulus = reward) are administered to infants under 1 year; we administered the standard delayed nonmatching-to-sample task to toddlers and young children 1–5 years of age. If a preference for novelty is present in the younger age group but not in the older group this might account for why subjects 12–18 months of age have such difficulty with the task. We can rule out this possibility, however, because Daehler and his colleagues have demonstrated robust novelty preferences in children from 12 to 40 months of age. In every age and sex group from 12 to 38 months (Daehler & O'Connor, 1980) and from 17 to 40 months (Daehler & Bukatko, 1977), Daehler and his colleagues have found a significant preference for the novel stimulus after a brief familiarization period with the sample stimulus.

We are back to the question, then, if the 5-s delay is too brief and 21 months of age too old for inadequate memory to be the central reason for why success on delayed nonmatching-to-sample appears so late, what *is* the central reason? What ability is required for the standard delayed nonmatching-to-sample task, but not required for delayed nonmatching when the stimulus is the reward or for the visual paired comparison task?

The answer is not yet clearly known, but we can now eliminate some of the possibilities. When there are clear rewards, it is possible to be wrong. It has become an explicit testing situation. During delayed nonmatching to sample (stimulus = reward) and visual paired-comparison, subjects simply do what comes naturally (directing their attention to new things rather than old, familiar ones). When rewards are involved, subjects may try to think about what one "should" do. It is possible that the latter situation requires the *ability to deduce an abstract rule* or the ability to demonstrate during *explicit testing* something which can readily be shown implicitly during play. Telling subjects the rule in Study 3, however, did little to help their performance. Therefore, we tentatively conclude that the critical limitation for young children on the task is not inability to figure out the rule governing correct performance.

When Diamond (1992) used the stimulus objects themselves as the only reward (in delayed nonmatching to sample [stimulus = reward]), the purpose was to give subjects a chance to get bored with (i.e., habituated to) the sample stimulus, so that their novelty preference would lead them to reach for the new object if they still remembered the sample. Therefore, subjects were given a long time with the sample during familiarization. It is possible that subjects succeed later on the standard delayed nonmatching-to-sample task because it requires *faster speed of processing* to encode the visual properties of the sample in the much briefer time allotted. To test this, we gave half of the subjects in Study 4 a long time to familiarize themselves with the sample. This helped little. Therefore, a slow rate of encoding does not seem to be the critical limitation of young children on this task. It is unlikely that our longer presentation time was still too brief, as we lost many subjects to boredom with this longer presentation and had a difficult time maintaining the visual attention of most of the remaining subjects.

It is possible that part of the answer to what accounts for why success on the standard delayed nonmatching-to-sample task appears so much later than success on the visual paired-comparison task or on delayed nonmatching to sample (stimulus = reward) is slow development of the *ability to resist interference.* Allowing subjects to have a reward after displacing the sample during the familiarization phase of each trial may require that subjects be able to maintain their attention on the sample sufficiently well to remember what it was, despite the distraction provided by the reward; it requires an ability to resist interference, which is not necessary when there are no rewards. When we eliminated the reward during familiarization in Study 4, this significantly helped 12–15 month olds succeed at the brief, 5-s delay, although it did not affect their performance at the longer, 30-s delay. It did not succeed in boosting performance all the way to the levels observed on delayed nonmatching to sample (stimulus = reward), but it made a significant difference. Thus, the development of the ability to resist interference may be one of the keys to the observed developmental progression in delayed nonmatching-to-sample performance. Or, the manipulation may have helped because it made the link between the two portions of a trial more clear. It is also possible that, despite our efforts to discourage subjects from treating the stimuli themselves as the reward and despite our eliminating any subjects who were clearly more interested in the stimuli than in our reward, this manipulation may have helped because children tended to focus more on the stimuli and less on the rewards. They may have tended toward treating the stimuli themselves as the reward. In any case, this manipulation does demonstrate that even in a formal testing situation, where there are rewards during the test phase and it is clear when one is right or wrong, it is possible for infants of 12–15 months to succeed at the task when a brief delay is used.

We believe that this set of data provides an important lesson for those interested in brain–behavior relationships in development. Here, we have taken a task that had been solidly linked to the medial temporal lobe memory system by dozens of studies in adult monkeys and also by work with adult patients. We used the same task with children, not an analogous task, but the very same one. We found a developmental improvement on the task with age. Often at this point one concludes that because task *x* is linked to neural system *y*, and children improve on task *x* over a certain age range, that neural system *y* must be maturing over that age range. Indeed, that is the conclusion that Bachevalier and Mishkin (1984) drew when they found a similar developmental progression on this task in infant monkeys. However, the conclusion that improved performance on the task with age provides some indication of the progressive maturation of the medial temporal lobe memory system appears to be unjustified. It appears unjustified primarily because variations in task parameters have a different effect on human and simian adults with brain damage than they do on human and simian infants and children.

Adult monkeys with lesions of the medial temporal lobe and amnesic human adults have little difficulty succeeding on delayed nonmatching to sample and other tasks with delays as brief as 5 to 10 s or less; their performance worsens as the delay increases (e.g., Alvarez-Royo, Zola-Morgan, & Squire, 1992; Overman, Ormsby, & Mishkin, 1990). Their excellent performance at brief delays (showing that they can learn the task) and their progressive deterioration with increasing delay has provided strong support for the hypothesis that the reason they have difficulty with the task is probably because of its memory requirements. Young children, on the other hand, fail delayed nonmatching to sample at even the briefest delays (5 s), and children of 15 months or more show no deterioration in performance with increasing delay.

The lesson to be learned from this is that it is not enough to find a developmental progression on a task that has been linked to a particular neural system; one must also investigate the causes for success and failure. Memory is one of the abilities required for success on the delayed nonmatching-to-sample task, but it is not the only ability required. In adults, who have developed all the requisite abilities, if their memory system is impaired, they fail. However, it appears that young children fail the delayed nonmatching-to-sample task because of the late emergence of some ability other than recognition memory.

Finally, although it is clear that the development of recognition memory probably does not underlie the development of successful performance on the task, it is not as clear whether maturation of the medial temporal lobe is necessarily unrelated. For a long time, most of the discussion of the functions of the hippocampus and related structures in the primate has centered around the role of this system in explicit memory. This may be too narrow a conception of the functions of this system, however. Although it is rarely emphasized, both monkeys and human adults with damage to the medial temporal lobe require more trials to master the delayed nonmatching-to-sample task (to pass criterion at the initial brief delay) than do control subjects; e.g., in monkeys: 360 trials to criterion versus 40 (Zola-Morgan & Squire, 1985); in adults: 1 trial to criterion versus 29 (Squire et al., 1988). This is similar to our finding that younger children required more trials to pass criterion. It is possible that the medial temporal lobe plays some role in enabling one to figure out what the task is about or in the reference memory required for the task. Amnesic adults also have difficulty articulating the rule for correct performance on the task, even when they are performing well (like our 3-year-old subjects) and are not helped by having a cue card containing the rule in front of them (much as telling our subjects the rule helped them little). It is possible that these findings indicate something important about the functions of the medial temporal lobe that has not received sufficient attention thus far.

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