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Early Developments in the Ability to Understand the Relation Between Stimulus and Reward

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Delayed nonmatching to sample (DNMS) is used to test the recognition memory function dependent on the medial temporal lobe. Children cannot succeed on this task until about 21 months. Because robust recognition is present well before then, the late emergence of another ability must account for the late success on DNMS. Evidence is presented here that the critical late-maturing competence is the ability to grasp the relation between stimulus and reward—that is, to understand that the stimulus is a symbol or marker for the reward. Infants of 9 and 12 months were tested on 3 conditions of DNMS. A sample object was presented. After a delay, the sample and a novel object appeared; choice of the novel object was rewarded. In the standard task, the reward was in a well beneath the stimulus. In the verbal-reward condition the reward was not a separate object but was praise and applause. In the Velcro condition, the reward, although a separate and separable object, was attached to the base of the stimulus. Most infants at both ages succeeded in the verbal-reward and Velcro conditions but not in the standard condition.

In the delayed nonmatching to sample (DNMS) task, a sample object is presented. A delay follows, then the familiar sample is presented alongside a novel object. The correct choice is to select the novel object, that is, the object that does not match the previously presented sample—hence the task's name, *delayed nonmatching to sample.* Infants (Cohen & Gelber, 1975; Fagan, 1970, 1973; Fantz, 1964) and monkeys (Brush, Mishkin, & Rosvold, 1961; Gaffan, Gaffan, & Harrison, 1984; Harlow, 1950; Mishkin, Prockop, & Rosvold, 1962) have a natural preference for novelty. Thus, they are inclined to select the correct choice in DNMS (the novel object) if they remember what the sample looked like. A number of laboratories have used the DNMS task for many years as a test of recognition memory subserved by the medial temporal lobe (e.g., Meunier, Hadfield, Bachevalier, & Murray, 1996; Mishkin, 1978; Squire, Zola-Morgan, & Chen, 1988; Zola-Morgan, Squire, & Amaral, 1989a, 1989b; Zola-Morgan, Squire, & Mishkin, 1982).

Children generally cannot succeed on DNMS, even with delays of only 5 or 10 s, until they are 21 months old (Diamond, 1990; Diamond, Towle, & Boyer, 1994; Overman, 1990; Overman, Bachevalier, Turner, & Peuster, 1992). Because success on DNMS depends on the medial temporal lobe and because children cannot succeed on the task until relatively late (almost 2 years of age), it was not unreasonable for some researchers to conclude that the recognition memory function dependent on the medial temporal lobe must mature late (Bachevalier & Mishkin, 1984).

However, that conclusion appears to be incorrect. The recognition memory requirements of the DNMS task are evidently not the limiting factor in why success appears relatively late in development. Children can remember something for 5 s well before 21 months. Indeed, infants can remember what they have seen for 5–10 s (the delays used for DNMS), and for periods far longer than that, well before they are 21 months old. Infants under 12 months of age have demonstrated impressive recognition memory on a host of tasks such as visual paired comparison (e.g., Fagan, 1971, 1973, 1990; Pancratz & Cohen, 1970; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982), A-not-B (e.g., Diamond, 1988; Fox, Kagan, & Weiskopf, 1979), delayed response (Diamond & Doar, 1989), deferred imitation (e.g., Meltzoff, 1988, 1990), elicited imitation (Mandler & McDonough, 1995), visual habituation (Baillargeon, 1987), and conjugate reinforcement (e.g., Rovee-Collier, 1990, 1997). Indeed, when we administered a version of the visual paired-comparison task that used reaching as the dependent measure rather than looking, infants of 9 months showed robust recognition at all delays used (10 and 15 s, 1, 3, and 10 min; Diamond, 1995).

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Moreover, the developmental progression on the DNMS task itself suggests that the memory requirements of the task are not the reason children generally do not succeed until they are 21 months old. When children first succeed on the standard DNMS task with a 5-s delay, they perform comparably at delays of 30 and 60 s in the very same session (Diamond et al., 1994); the Delay × Age gradient is flat. If the developmental improvement on DNMS were charting a developmental improvement in memory, one would expect to find success first at shorter delays and then, at a later age, success at longer delays. Yet once children solve the task, they succeed at both long and short delays. In addition, if infants do not displace the stimuli to receive rewards, but the stimuli themselves are the reward, infants as young as 6 months succeed with delays as long as 180 s (Diamond, 1995).

Thus, the late emergence of success on the DNMS task does not appear to reflect the late development of recognition memory; that ability appears to be present quite early. The problem for infants is "acquisition"—that is, understanding what correct performance on the task entails, not retention at long delays. The late emergence of an ability other than recognition memory must account for the inability of infants and toddlers to succeed at DNMS. Infants' excellent performance when the rewards under the stimuli are removed and the stimuli themselves serve as the reward (Diamond, 1995) suggests that the presence of external rewards in the DNMS task appears to cause infants to perform worse. We report here an investigation of two hypotheses about why that might be. We hypothesized that the problem for infants on the DNMS task might be that infants (a) know they are being tested and so do not do what comes naturally (i.e., attend to novelty) or (b) do not understand the relation between the stimulus and reward in DNMS.

Hypothesis 1

One hypothesis was that the presence of feedback might change the way infants approach the task. The feedback (reward or no reward) that infants receive on each trial provides information that they are being tested and that there are right and wrong answers. Under those circumstances, perhaps infants try to figure out the rule rather than do what comes naturally. Certainly there are many activities that are performed better if one does not think about them. One is reminded of the Zen of archery (Herrigel, 1971) or of many activities such as dancing or bicycle riding that are performed much worse if one tries to think about what one should do next. There are also examples from the animal literature. For instance, rats will alternately enter one arm of a T maze and then the other if allowed free access to explore the maze ("spontaneous alternation"); however, if rats are put in a testing situation in which they are rewarded for alternating, it takes a great many trials to train a rat to alternately enter one arm of the T maze and then the other ("single alternation"; e.g., Greene, 1971; Means, Leander, & Isaacson, 1971). Although infants' spontaneous preference might lead them to choose the new object most of the time, perhaps trying to "think about" what they are doing, or what they are supposed to be doing, makes the task much harder than when they just respond automatically.

Young infants succeed at long delays on the version of the DNMS task in which the stimulus itself is the reward (DNMS [stimulus = reward]; Diamond, 1995) and on the closely related visual paired-comparison task. On each of those tasks infants receive no feedback about whether any response is correct or incorrect. If knowing that they are being tested causes infants to perform worse, we reasoned that using praise and applause from the experimenters as the reward, rather than using reward objects that sit in wells below the stimuli, should also cause infants to perform worse. Therefore infants should succeed on the task at the same age (approximately 21 months) as they do when reward objects are used. Thus, to test Hypothesis 1 we administered DNMS with no rewards under the stimuli, but with auditory and visual feedback from the experimenter, so that infants would know there were "right" and "wrong" answers. Infants acted on the stimuli to obtain the positive response from the experimenter; they were not allowed to spend much time with the stimulus objects themselves. We predicted that any feedback, any reward, or any indication that they were being tested and that there were right and wrong answers should delay success on the task if Hypothesis 1 were correct.

Hypothesis 2

Another hypothesis was that the problem for infants might be in grasping the relationship between the stimulus and the reward. When a physical reward is present, participants must relate two objects (the stimulus and the reward) to one another. In DNMS, the correct stimulus is a symbol or marker for the location of the reward. Perhaps young infants have difficulty understanding the relationship between the stimulus and the reward. In the visual paired-comparison task and the version of DNMS where the stimulus is the reward, participants look at, or reach for, something because it is intrinsically interesting, not because of its relationship to anything else. However, in the standard DNMS task, the stimulus one sees and initially acts upon is not the reward but only stands for the reward. This is more abstract than if the stimulus itself is the reward. Perhaps problems in understanding the relation between the stimulus and the reward are what make the standard DNMS task so difficult for infants. Maybe infants do not understand that in the DNMS task the stimulus objects are supposed to indicate where the rewards are located. We reasoned that if the rewards were physically connected to the stimuli, so that a given reward moved with its associated stimulus, infants might find the relationship between the stimuli and rewards easier to grasp and would therefore perform better. To test this, we attached the rewards to the bases of the stimuli by means of Velcro. The stimuli were still placed atop wells, as in the standard condition, and the rewards were still in the wells, but now, instead of the reward remaining in the well when a stimulus was displaced, the reward came with the stimulus. The reward was a separate object from the stimulus, but it was contiguous with, and physically attached to, the stimulus so that it moved with the stimulus. We predicted that this should make it easier to grasp the relation between stimuli and rewards: If Hypothesis 2 is correct, infants should succeed on this version of the task at a younger age than they succeed on the standard DNMS task.

Method

Overview

We administered three conditions of the task (the standard DNMS procedure, a verbal-reward condition, and a Velcro condition) to infants 9 and 12 months of age. To test the first hypothesis, we administered the verbal-reward condition: When an infant reached correctly, the experimenter cheered and applauded, praising the infant. When an infant reached incorrectly, the experimenter sounded very disappointed. Thus, there was clear feedback after each reach about whether the infant had been correct or not. However, no rewards were hidden, no wells were used, and there was no reward object to relate to the stimulus object. If simply knowing that they are being tested causes infants to be unsuccessful at DNMS until an older age, then infants of 9 or 12 months should not succeed in the verbal-reward condition. However, if the problem is understanding the relation between the physical reward object and the physical stimulus objects, then because the verbal-reward condition does not include reward objects, infants of 9 or 12 months should succeed.

To test the second hypothesis, we administered the Velcro condition: Rewards were fastened by Velcro to the underside of the stimuli. When the stimulus objects were atop the wells, the rewards were concealed within the wells (just as in the standard condition). However, when an infant picked up the sample (during familiarization) or the novel stimulus (during the test phase), the reward came with the stimulus rather than remaining in the well. We reasoned that if failure to grasp the relation between stimuli and rewards is why younger infants cannot succeed on DNMS, then infants of 9 or 12 months might well be able to succeed in the Velcro condition.

Participants

A total of 98 infants provided usable sessions. Twenty infants (10 male, 10 female) were tested at each of two ages (9 and 12 months) on the verbal-reward condition and on the Velcro condition (for a total of 80 infants). Another 18 infants (6 male and 6 female at 12 months of age; 3 male and 3 female at 9 months of age) were tested on the standard DNMS procedure. Only 12 infants were tested at 12 months of age on the standard procedure, as previous research had established that infants at 12 months fail this task (Diamond, 1990; Diamond et al., 1994; Overman, 1990; Overman et al., 1992); it is thus a frustrating experience for 12-month-olds. At 9 months, infants were so frustrated by the task that the attrition rate was very high, and only 6 babies provided usable sessions.

The exact ages of the infants are given in Table 1. All infants were full term and healthy. Most were from upper-middle-class homes and of European Caucasian descent (see Table 1). Most parents were college graduates (mean years of education were 16.75 for mothers and 16.5 for fathers). The mean age of the fathers was 35 years, and the mean age of the mothers was 32 years. Just over half of the infants were only children; most of the others had only one sibling. The mean number of siblings was 0.6.

In addition to the 98 infants included in the data analyses, another 29 sessions were attempted but were not usable (in the standard condition, 12 sessions were not usable at 9 months and 5 sessions at 12 months; in the verbal-reward condition, 3 sessions were not usable at 9 months and 2 sessions at 12 months; in the Velcro condition 3 sessions were not usable at 9 months and 4 sessions at 12 months because the infant became too fussy or did not sustain interest in the task long enough to be able to complete testing). The two most common causes of fussiness were frustration at not succeeding and frustration at our removing the stimuli and rewards before the infant was ready to relinquish them. Four sessions could not be used because of procedural error or equipment failure. One session could not be used because the infant appeared to have a serious motor or neurological impairment.

Materials

The same 30 pairs of "junk" objects were used for all conditions. The stimuli were brightly colored and made of wood, plastic, and/or foam. (See Diamond et al., 1994, for photographs of some of the stimuli.) The stimuli were constructed to be unusual so that the participants would not have seen them before. Heights of the objects ranged from 3–15 cm, and the widths ranged from 3–7 cm. Objects paired together on a given trial had similar dimensions and were roughly equal in their attractiveness to infants, although they always differed in color and shape. All objects could stand on their own. Most were glued to individual wooden bases. Glued to the underside of each was a piece of Velcro.

Wooden blocks (7.5 × 7.5 × 4 cm) contained the "wells" used in the standard and Velcro conditions. (No wells were used in the verbal-reward condition.) Each block contained a well (2 cm in radius and 2.5 cm deep) in the center of its top surface. During the experiment, a reward was placed in the appropriate well and the stimulus objects were placed on top of the wells, completely covering the wells and the reward within.

A collection of small toys served as rewards in the standard and Velcro conditions. The size of these toys was constrained by the size of the wells, so all rewards were fairly small. They included brightly colored wooden and plastic animals, boats, planes, beads, and marbles. Occasionally Cheerios were used if the infant was not motivated by the toy rewards. In the Velcro condition, each reward had a piece of Velcro glued to it, which enabled it to be attached to the base of a stimulus.

An animal puppet, a toy truck, a plastic tube, a Velcro board, and a metal cup were used (a) to give the infant something to do with the reward during the delay period of each trial and during the intertrial intervals and (b) to retrieve the reward from the infant so that the paired presentation or the next trial could take place after the appropriate delay. Although some infants were distressed at having to give up their rewards, the assistant tried to keep the infants happy and engaged by rattling rewards in the cup, showing the infant how many rewards he or she was accumulating, or removing the reward with the puppet.

For infants tested at the 30-s delay, either a maze was used to let the infant enjoy the marble reward or a plastic toy ball was brought out to entertain the infant during the delay. Participants could play interactively with these toys and delighted in doing so. This allowed the experimenter to impose the long 30-s delay without upsetting or boring the infant.

Procedures Common to All Conditions

Different, novel objects were used on every trial. The stimuli were presented to the infants on the testing table. An infant sat on his or her parent's lap on one side of the table, and the experimenter sat opposite them. An assistant sat next to the parent and infant.

Regardless of the condition, each infant participated in approximately 25 trials. Infants who did not perform well until near the end of the session

Table 1
Ages of Infants Tested

Experimental condition	Age category	Age range (in weeks + days)	Mean age (in weeks + days)
Reward attached to stimulus	9 months	38 + 0 − 42 + 4	40 + 0
	12 months	50 + 1 − 55 + 4	52 + 6
Verbal reward	9 months	38 + 0 − 42 + 0	40 + 3
	12 months	50 + 0 − 54 + 4	52 + 3
Standard condition	9 months	38 + 4 − 40 + 2	39 + 2
	12 months	51 + 6 − 52 + 6	52 + 1

were allowed up to 3 additional trials if they were close to reaching criterion at the 5-s delay by Trial 25. This happened three times. Testing began with a 5-s delay; the delay was increased to 30 s if the infant passed criterion at the 5-s delay by Trial 15. The criterion for passing the 5-s delay was five correct responses in a row.

Each trial consisted of a familiarization (or sample presentation) phase and a test (or paired presentation) phase, separated by a delay. During familiarization a stimulus object (the sample) was presented on its own at the infant's midline. During the test phase, the previously presented sample object was paired with a new object. On the first trial, the sample object was on the left during the paired presentation and the novel object was on the right. On subsequent trials the positions of the sample and novel objects during the test phase varied according to a Gellerman series (sample stimulus on right, left, left, right, right, left, etc.).

Sample presentation (familiarization phase). At the beginning of each trial, the experimenter presented a stimulus object ("the sample") at the rear of the testing table, about 60 cm from the infant, and slid the stimulus forward (atop its well in the two conditions in which wells were used) along the tabletop at a constant rate until it was within reaching distance of the infant. The infant was encouraged to reach for the stimulus and, in the standard and Velcro conditions, to retrieve the reward. The infant was allowed to examine the stimulus for only a brief period. We took great care to ensure that infants were only given a brief time with the stimuli because previous work had shown that if the stimulus itself is allowed to serve as the reward, infants as young as 6 months succeed at long delays (Diamond, 1995). We wanted to try to prevent the stimulus objects themselves from serving as the reward in the present experiment so that we could investigate the effect of extrinsic rewards that were being used. From the time the stimulus was first presented until it was removed from view was never more than 5 s. The infant was rewarded for displacing the sample stimulus.

Delay period. Immediately after the sample presentation phase, a delay was imposed. Each testing session began with delays of 5 s. Once an infant was correct on five consecutive trials, the delay between the sample and test phases was increased to 30 s. During the delay, the assistant held a white foamboard barrier between the infant and the experimenter so that the infants' view of the testing surface was obscured.

Test phase (paired presentation). At the end of the delay period, any objects on the table or in the infant's hands were removed. The experimenter instructed the parent to close his or her eyes so that the parent would not know where either stimulus was and thus could not influence the infant's behavior. The assistant then removed the foamboard barrier and the experimenter presented a pair of stimulus objects (the same object presented during the familiarization phase and an object new to the infant). The stimuli were introduced at the rear of the table, side by side at the midline, out of the infant's reach. To ensure that the infant saw both objects, the experimenter drew the infant's attention to them by moving the objects independently at the rear of the table, or by tapping the objects, drawing the infant's attention first to one object and then to the other. The experimenter always tapped or moved the stimulus on the right first and then the left. Because the right–left presentation of the familiar stimulus and novel stimulus was counterbalanced and randomized over trials, on half the trials the novel stimulus was tapped first and on half the trials the familiar stimulus was tapped first.

Once the infant had clearly seen both stimulus objects, the objects were moved diagonally forward at a constant rate until they were just within the infant's reach, one on either side of the midline. The stimuli were placed so that they were barely within reach to make it difficult for the infant to reach for both objects at the same time. A choice was scored as the first object the infant touched. Once the infant touched a stimulus, the other stimulus was immediately removed.

A correct response was defined as choosing the new stimulus object, the one that did not match the sample presented during familiarization. Rewards were always associated with the new, nonmatching stimulus. Trials in which infants made an incorrect response were not rewarded, and the experimenter explained in a sad and disappointed voice that the infant was incorrect and showed the infant that the other stimulus had been the correct choice. Trials in which infants made no attempt to choose either stimulus object or managed to reach for both objects at the same time were not counted. When an infant reached for both stimulus objects, the experimenter placed the objects farther away from the infant on subsequent trials. No infant reached for both objects on more than two trials. All sessions were videotaped, which allowed for detailed analysis, including verification of the length of each sample–presentation and delay period.

Procedures Specific to the Verbal-Reward Condition

In the verbal-reward condition, the infant was rewarded by cheering and applause from the experimenter and assistant when the infant reached correctly. We were concerned that infants in this condition might see the object itself as the reward (instead of the cheering and applause) if they were allowed to play with or explore the object. Therefore, we did not allow the infant to hold the stimulus any longer here than in the other two conditions (3–5 s). If the infant chose incorrectly, the experimenter removed the incorrect stimulus, and, pointing to the new stimulus, said in a sad tone, "No, you were supposed to choose *this* one." No wells were used in this condition.

Procedures Specific to the Standard and Velcro (Reward-Attached-to-Stimulus) Conditions

Here, the reward consisted of the infant's retrieving and playing with the small object hidden under the stimulus as well as cheering and applause from the experimenter and assistant. The reward object was hidden under the sample during familiarization and under the novel object during the test phase. The stimuli and wells looked identical in both conditions. However, in the Velcro condition, once a stimulus was removed from its well, its reward went with it, instead of remaining in the well (see Figure 1). If an infant chose incorrectly in either the standard or Velcro condition, the experimenter removed the incorrect object and displaced the correct stimulus object, thereby showing the infant that the reward had been in the well under the correct object or attached to the underside of that object.

In the standard condition, the reward object sat in the shallow well below the correct stimulus. The wells were only 2.5 cm deep, so any reward was only a tiny fraction of an inch from the stimulus object above it. The infant lifted the stimulus and looked in the well to see if the reward was there. The infant was allowed to retrieve the reward and play with it. Praise and applause began after the infant began to reach for the reward.

In the Velcro condition, the reward object was attached to the base of the correct stimulus. When the stimuli were placed atop the wells, a stimulus with an attached Velcro reward looked identical to a stimulus that covered an empty well, or to stimuli in the standard condition in which rewards sat in the wells, unattached to the stimuli. In both the standard and Velcro conditions, rewards were completely hidden inside the wells beneath the stimuli when stimuli were presented. When the infant chose a stimulus in the Velcro condition, the infant lifted the stimulus and turned it over to see if a reward was attached to its underside (see Figure 2). The infant then pulled the reward from the stimulus and was allowed to play with the reward. Praise and applause began after the infant began to retrieve the reward. Some of the youngest infants had difficulty removing the reward from the stimulus on the first few trials and were helped by the experimenter or the assistant. For many infants, removing the reward from the base was as rewarding as having the reward object itself.

Results

No significant effects of sex were found; therefore, all results are reported collapsed across gender. There was also no significant effect of tester. Although all analyses reported here are based on

Figure 1. Example of a stimulus and reward in the Velcro condition. *Left frame:* When a stimulus is presented to an infant in the Velcro condition, everything looks as it does in the standard condition. The same stimuli and wells are used in both conditions, and the stimulus is placed atop the well the same way in both conditions. *Middle frame:* However, when an infant picks up the stimulus object in the Velcro condition, the reward comes with the stimulus (attached to its underside) instead of remaining in the shallow well as it does in the standard condition. *Right frame:* The reward is not permanently attached to the stimulus in the Velcro condition. It is easily detached by pulling on it. On each trial the infant sees that the stimulus and the reward are separate objects.

the results of standard analyses of variance (ANOVAs) and chi-square tests, we also ran all of our analyses using StatXact (1999) versions of these procedures (Mehta, 1990; Mehta & Patel, 1998) because the number of participants per group was not large and there were fewer participants in the standard condition than in the other conditions.[1] StatXact and standard analyses yielded similar results for all analyses; the results of the standard analyses are reported here because those procedures are more familiar to most readers.

Most infants at 9 and at 12 months succeeded in the verbal-reward and Velcro conditions (see Table 2). They performed significantly better on both of those conditions than on the standard condition. Infants performed similarly in the verbal-reward and Velcro conditions. There were no significant differences on any dependent measure at either age or across both ages between performance in the verbal-reward and Velcro conditions. Most infants failed to pass criterion in the standard condition, a finding that confirms the results of previous studies (see Table 2; Diamond, 1990; Diamond et al., 1994; Overman, 1990; Overman et al., 1992). On the other hand, at least three quarters of the infants tested in the other two conditions succeeded, that is, passed criterion (85% in the verbal-reward condition and 75% in the Velcro condition; see Table 2 and Figure 3). Significantly fewer infants passed criterion in the standard condition than in the verbal-reward and Velcro conditions, $\chi^2(1, N = 98) = 13.4, p < .001$. This was true both at 9 months, $\chi^2(1, N = 46) = 8.5, p < .01$, and at 12 months, $\chi^2(1, N = 58) = 6.9, p < .03$. It was also true when the percentage of infants passing criterion in the standard condition was compared with the percentage of infants passing criterion in the verbal-reward condition, $\chi^2(1, N = 58) = 12.7, p < .001$, or in the Velcro condition, $\chi^2(1, N = 58) = 7.0, p < .01$. Across the verbal-reward and Velcro conditions, 85% of 12-month-old infants succeeded and 75% of 9-month-old infants succeeded (compared with only 50% and 17% of 9- and 12-month-olds succeeding in the standard condition).

We conducted a 2 (age: 9 and 12 months) × 3 (condition: verbal, Velcro, and standard) ANOVA. There was a main effect of condition for the number of trials needed to pass criterion at the 5-s delay, $F(2, 92) = 4.07, p < .02$. More trials were needed to pass criterion in the standard condition than in either the verbal-reward condition, $F(1, 56) = 5.15, p < .01$, or the Velcro condition, $F(1, 56) = 3.43, p < .04$. Within individual ages, these differences continued to be significant for infants of 9 months: standard vs. verbal reward, $F(1, 24) = 8.98, p < .003$; standard vs. Velcro: $F(1, 24) = 4.58, p < .02$. However, they failed to reach significance for infants of 12 months. Infants of 9 months required an average of 14 trials to pass criterion on the verbal-reward and Velcro conditions, but they required an average of 25 trials in the standard condition. There was no Age × Condition interaction.

There were no significant differences in percentage of correct responses at the 5- and 30-s delays in any condition of the task. There were significant age differences collapsed across all three DNMS conditions for number of trials to reach criterion at the 5-s delay, $F(1, 92) = 5.68, p < .02$ (at 9 months, $M = 15.2$; at 12 months, $M = 12.3$), and for the percentage of correct responses at the 30-s delay, $F(1, 41) = 7.0, p < .01$ (at 9 months, $M = 58.1\%$; at 12 months, $M = 71.2\%$). There were no significant differences between the performance of infants of 9 and 12 months, however, on any individual DNMS condition.

Discussion

Most children cannot succeed (i.e., cannot pass criterion) on the standard DNMS task (5-s delay) until they are 21 months old. In the standard task, rewards are located in shallow wells directly beneath the stimuli. By rewarding our participants either by praise and applause alone or by reward objects that were attached by Velcro to the base of the stimuli, we found that 90% (verbal-reward condition) and 80% (Velcro condition) of infants succeeded on the DNMS task at 12 months of age. That is, most succeeded at an age almost half that at which infants succeed on the standard task (21 months). Indeed, most younger infants of 9 months succeeded in the verbal-reward (80%) and Velcro (70%) conditions. By comparison, only 17% of 9-month-olds and only 50% of 12-month-olds succeeded in the standard DNMS condition.

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[1] StatXact is especially designed for small samples. Traditional methods, such as ANOVA, use asymptotic distributions rather than exact distributions and make assumptions that may not always fit one's data. StatXact relies on no such assumptions and provides exact statistical inference rather than approximations.

Figure 2. Example of a trial in the Velcro condition. *Top sequence:* The stimulus presentation (or familiarization) phase. An infant reaches for the sample stimulus; picks it up and, turning it over, sees the reward attached to the underside; detaches the reward from the stimulus; shifts her attention from the stimulus to the reward. *Bottom sequence:* The paired presentation (or test phase). The mother's eyes are closed until the infant chooses so as not to influence the infant's choice. The infant reaches for the novel stimulus; picks it up and, turning it over, sees the reward attached to the underside; detaches the reward from the stimulus; shifts her attention from the stimulus to the reward. Note: The stimuli portrayed here were roughly equal in infant's spontaneous preferences for one or the other, but they were not roughly equal in size. That is the exception. On almost every trial the stimuli were closely matched in both attractiveness to infants and size (see, e.g., Figure 1 in Diamond et al., 1994). The same stimuli used by Diamond et al. (1994) in the standard delayed nonmatching to sample task were used here, and, as shown in that figure, the stimulus objects in each pair are roughly comparable in size.

There was no significant difference between performance at any age on any dependent measure in the verbal-reward and Velcro conditions. There was, however, a nonsignificant trend for performance to be better in the verbal-reward condition. We think that reflects our inability to find reward objects that were as thoroughly enjoyable as the exuberant praise of the verbal-reward condition, especially when the reward objects had to be relinquished after only a few moments. The slightly better performance in the verbal-reward condition probably reflects the more effective reward that was used there. The verbal-reward and Velcro conditions differed little in the temporal proximity of stimulus and reward. Infants saw the reward object attached to the base of the stimulus and heard the verbal reward almost immediately in their respective conditions.

In the verbal-reward condition, infants received positive or negative feedback after each choice. The experimenter and assistant cheered and clapped when the infant chose the correct object and sounded disappointed when the infant chose incorrectly. If infants' difficulty with DNMS lies in the knowledge that they are being tested and can be wrong, then infants should have performed poorly in the verbal-reward condition. Yet they performed splendidly. Therefore, the presence of a reward cannot account for why success in the standard DNMS procedure is not usually seen until 21 months of age.

In the verbal-reward condition there were no reward objects to relate to the stimulus objects. Infants did not need to understand the association between two objects. However, in the Velcro condition there were reward objects, and infants still performed well.

Why should the Velcro condition have proved within the grasp of most infants when the standard DNMS procedure did not? After all, in the Velcro condition, just as in the standard condition, the stimuli are placed atop wells, the rewards are in the wells below, and the reward is a separate object from the stimulus. In the Velcro condition, however, the reward is physically closer to the stimulus than in the standard procedure and, instead of remaining in the well when a stimulus is displaced, the reward moves with the stimulus: Each reward is connected to (though detachable from) its stimulus. Attaching the rewards to the stimuli with Velcro, a seemingly minor variation in the procedure, appeared to dramatically alter infants' understanding of the task. When the reward and stimulus were physically connected—when the reward moved with the

Table 2
Performance in the Three Versions of the Delayed Nonmatching to Sample Task

	5-s delay									30-s delay[a]		
	Mean no. of trials to criterion[b]											
	All participants[c]			Only those who passed criterion			% passing criterion	% correct		% correct		
	M	*SD*	*n*	*M*	*SD*	*n*		*M*	*SD*	*M*	*SD*	*n*
	Verbal: Cheering and applause as reward											
9-month-olds												
Male	13.4	7.5	10	12.1	6.7	9	90	67.6	11.7	73.3	20.3	3
Female	12.1	9.7	10	6.6	4.7	7	70	61.8	13.8	56.8	18.6	6
All	12.8	8.5	20	9.7	6.4	16	80	64.7	12.8	62.3	19.7	9
12-month-olds												
Male	10.7	7.8	10	9.1	6.3	9	90	67.8	16.1	76.0	24.8	7
Female	13.7	5.8	10	12.4	4.5	9	90	67.1	6.2	79.0	15.2	6
All	12.2	6.9	20	10.8	5.6	18	90	67.5	11.9	77.4	20.2	13
	Velcro: Reward attached to base of stimulus											
9-month-olds												
Male	18.7	8.8	10	12.4	8.7	5	50	58.6	12.1	55.7	6.7	3
Female	11.7	8.5	10	10.2	7.5	9	90	63.6	16.5	64.6	15.5	5
All	15.2	9.2	20	11.0	7.7	14	70	61.1	14.3	61.2	13.1	8
12-month-olds												
Male	10.3	8.5	10	6.6	4.0	8	80	65.3	11.2	69.2	7.2	4
Female	11.5	8.0	10	8.1	4.1	8	80	62.2	6.7	70.5	6.8	6
All	10.9	8.1	20	7.4	4.0	16	80	63.8	9.2	70.0	6.6	10
	Standard: Reward in well below stimulus											
9-month-olds												
Male	25.0	0	3				0	48.0	1.7	0		
Female	22.0	5.2	3	16.0	0	1	33	57.7	11.5	0		
All	24.5	3.7	6	16.0	0	1	17	51.8	8.5	0		
12-month-olds												
Male	15.3	11.0	6	5.7	4.7	3	50	60.7	18.0	52.7	15.6	3
Female	14.7	11.5	6	4.3	2.9	3	50	57.0	17.3	67.0	17.4	3
All	15.0	10.7	12	5.0	3.6	6	50	58.8	16.9	59.8	16.8	6

[a] Only participants who passed criterion at the 5-s delay were tested at 30 s. In addition, participants who received fewer than eight trials at 30 s because they grew too bored or fidgety were not included here either. [b] Number of trials to criterion = the number of trials up to (but not including) the string of five consecutively correct trials that satisfied the criterion for correct performance. [c] Those who failed criterion were assigned a score of 25 here (the maximum number of trials administered at the 5-s delay).

stimulus as the subject displaced the stimulus—the task was easy. Why?

Attaching the rewards to the stimuli may make obvious to infants that there is a critical relation between the stimulus and the reward. In the standard version of the task, infants may not realize that the stimuli provide information about the location of the rewards. The physical connection between rewards and stimuli may help infants grasp the relation between the stimuli and rewards because of (a) the increased spatial proximity of the stimuli and rewards, (b) the increased temporal proximity of the stimuli and rewards, (c) a possible tendency of infants to treat the reward-attached-to-stimulus as a single unit rather than as two separate things, or (d) fewer relationships for the infant to keep track of (reward-attached-to-stimulus vs. stimulus-on-top-of-well plus reward-inside-well).

Increased Spatial Proximity

Certainly, there is considerable evidence that spatial separations between response and reward or between stimulus and response can make a task much more difficult (e.g., for research on infants, see DeLoache & Brown, 1983; Millar & Schaffer, 1972, 1973; for research on monkeys, see Bates & Ettlinger, 1960; French, 1978; Passingham, 1985a, 1985b). Perhaps even a tiny spatial separation between stimulus and reward (as is present in the standard DNMS task) makes a task significantly more difficult than when there is no spatial separation at all. Perhaps even a tiny spatial separation is enough to change the relation into the more complex one of marker and referent. Indeed, there is evidence that spatial separations make learning more difficult even for older children. Rudel (1955), for example, found that when a reward was placed inside the stimulus (boxes served as her stimuli), children 1½–3½-years-

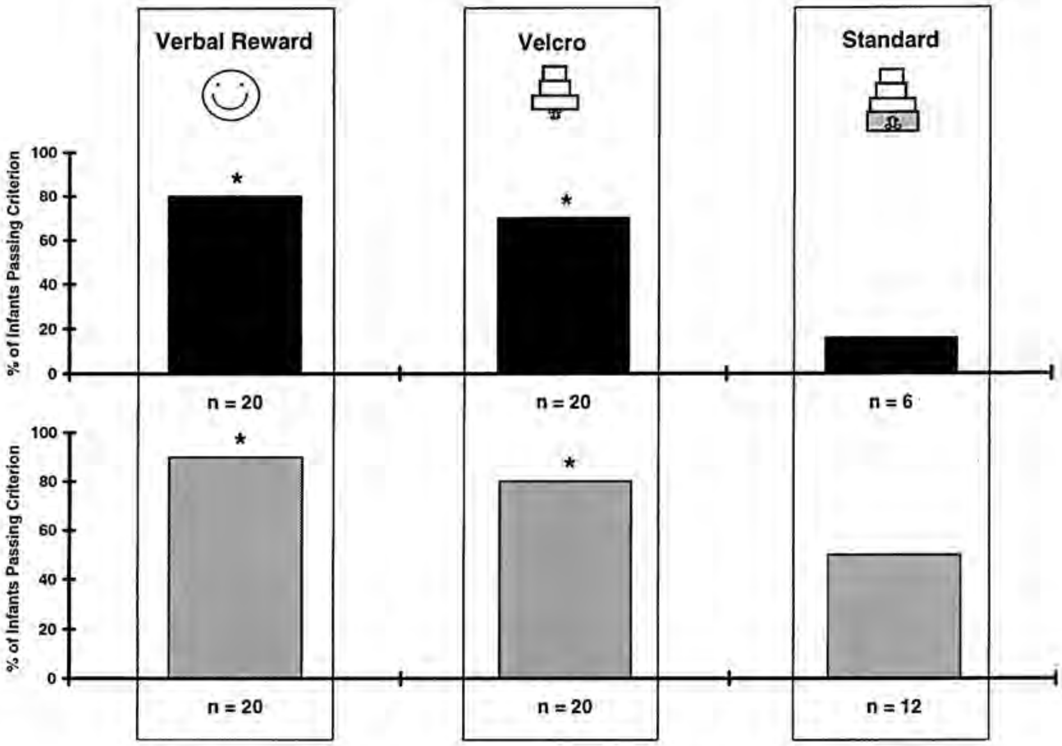

Figure 3. Infants' performance at the 5-s delay in the three versions of the delayed nonmatching to sample task. An asterisk indicates a significant difference compared with the standard condition.

old could learn to choose on the basis of relative size in far fewer trials than do even older children tested with the reward underneath the stimulus (Alberts & Ehrenfreund, 1951; Kuene, 1946). DeLoache (1986) found that 21-month-olds succeeded significantly more often in finding hidden rewards when a reward was hidden in a piece of furniture (rather than near it) or in a distinctive container itself (rather than when the distinctive container marked where the reward was hidden).

Increased Temporal Proximity

When the rewards are in the wells, as in the standard DNMS procedure, infants pick up the stimulus, and then look in the well for the reward. There is thus a temporal gap between choosing a stimulus and seeing its attendant reward. When the rewards are attached to the base of stimuli, as in the Velcro procedure, infants see the reward as soon as they lift and turn the stimulus. The time between choosing the correct stimulus and the receipt of the reward is very short in the verbal-reward condition. As soon as an infant touched the correct stimulus, the experimenter started cheering and applauding. There is much evidence from developmental psychology (e.g., Millar & Watson, 1979) and from animal research (e.g., work demonstrating that trace eyeblink conditioning, which introduces a trace interval of 0.5 s, is far more difficult to acquire than delay eyeblink conditioning, in which the conditioned and unconditioned stimuli overlap in time; Thompson, Moyer, & Disterhoft, 1996; Woodruf-Pak, Logan, & Thompson, 1990) that even a small temporal separation can make a task much more difficult. There is considerable evidence from neuroscience that when neurons fire at the same time, the connections between them are strengthened (e.g., Ahissar, Abeles, Ahissar, Haidarliu, & Vaadia, 1998; Milner, 1996; Shatz, 1992; van Heijst & Vos, 1997). This could provide the neural basis for why it is easier to learn the association between a reward and a stimulus if they are temporally synchronous. The recent work of Saffran, Aslin, and Newport (1996; Aslin, Saffran, & Newport, 1998) suggests that infants are exquisitely sensitive to temporal synchrony.

Single Unit Versus Two Separate Objects

Attaching the reward to the stimulus may help because it may lead infants to consider the reward and stimulus as parts of a single whole, as, for example, a box and its lid might be considered as parts of one entity even though they can be separated from each other. DeLoache's (1989, 1991, 1995) work with models provides a stark example of how well children can perform when they think they are dealing with one entity rather than two related ones, even though to the adult observer the cognitive problem posed by the two conditions seems the same.

In DeLoache's paradigm, children see a small-scale model of a room as well as the room itself, and a small version of a toy, as well as the full-size toy. They watch as the experimenter hides the full-size toy in the full-size room or the tiny toy in the three-dimensional model of the room. If, for example, they watch as the full-size toy is hidden, they are told that the tiny toy is in the analogous place in the model. Children of 2–2½ years can find the full-size (or tiny) toy in the space where they watched it being hidden (so they remember where it was placed), but they fail to find its counterpart in the other space (e.g., DeLoache, 1989). They appear not to understand the relationship between the models and their full-size equivalents. However, if children are told that there is only one room and only one toy and that the experimenter has a special machine that can shrink or enlarge things, then children of 2–2½ years can find both the tiny and full-size toys in both the "shrunken" room and the "enlarged" room (DeLoache, Miller, & Rosengren, 1997). Note that whether children are told there is only one room or a room and a scale model, the task is to find the full-size toy in the full-size room and the tiny toy in the smaller version of the room. For children, however, it makes a big difference whether they believe they are dealing with two things that they must relate to one another, or only one.

Relational Complexity

In earlier work, DeLoache and Brown (1983) did something reminiscent of Rudel's (1955) work. They varied hiding locations in a way that is perhaps comparable to our Velcro and standard conditions. Toys were hidden in a piece of furniture (corresponding, perhaps, to our Velcro condition, in which the reward is attached to the stimulus) or in a plain box on or near the piece of furniture (corresponding, perhaps, to the standard DNMS condition with the reward in a well under the stimulus). In a related set of experiments, DeLoache (1986) varied whether rewards were hidden in distinctive containers, in identical boxes on top of which the distinctive containers were attached, or in identical boxes with pictures of the distinctive containers affixed to the box tops. In all of these experiments, 21-month-olds performed significantly better when the connection between stimulus and reward was more direct.

Our laboratory has found similar results using the A-not-B task. In Piaget's Stage IV version of the A-not-B task, the infant watches as the toy is hidden in a well in the tabletop, a brief delay is imposed, and then the infant can look for the toy in either of two identical wells, one on the left and one on the right. By the age of 10–12 months, most infants succeed on the task at delays of 5 s (e.g., Diamond, 1985; Fox et al., 1979). In Piaget's invisible displacement version of the A-not-B task, the child watches as the toy is placed in a container and as that container is moved to the left or right side of the table. A brief delay is imposed. Then the child can look for the toy in either of two identical containers, one on the left and one on the right. Children of 2 and 3 years of age err on the A-not-B task with invisible displacements at delays of only 5 s (Diamond, Prevor, Callender, & Druin, 1997). The only difference between these two versions of the A-not-B task is that in the Stage IV version, participants watch the toy being moved to the left or right, whereas in the invisible displacement version, they watch as the box containing the toy is moved to the left or right (a direct relation vs. a two-step relation). The relations to hold in mind are more complex in the invisible displacement version.

During the time of the vocabulary explosion and Piaget's Stage VI (18–24 months)—that is, the period when most children first begin to succeed on the standard DNMS task—the capacity to comprehend that one thing (e.g., a word) can stand for, or symbolically represent, another (e.g., a class of objects) emerges. The ability to use the relation between distal/external landmarks to orient oneself in space emerges at around 21 months of age (Newcombe, Huttenlocher, Drummey, & Wiley, 1998), which is precisely the age when success on the standard DNMS task emerges.

It probably complicates things that our stimuli (just as are all stimuli in traditional versions of the DNMS task) are objects in their own right (as are DeLoache's models) as well as being markers for how to obtain the reward. To see the stimuli both as objects themselves and in their role as reward indicators requires "dual representation," to use DeLoache's (1989) terminology. It is well documented that even preschoolers have great difficulty seeing the same thing from two different perspectives: for example, appearance–reality (Flavell, 1986; Gopnik & Astington, 1988), card sort (Zelazo, Frye, & Rapus, 1996; Zelazo, Reznick, & Piñon, 1995), egocentrism (Piaget, 1954), concrete operations (Piaget & Inhelder, 1969), and ambiguous figures (Elkind, 1978). Note that this problem is avoided in the verbal-reward condition, in which the reward is not an object but rather consists of verbal and auditory feedback. In the verbal-reward condition there is a direct connection between stimulus and reward in that the act of choosing the correct stimulus causes the praise and applause to commence from the experimenter.

It may be that putting the rewards in shallow wells directly below the stimuli not only makes it difficult for infants to grasp the relation between the stimuli and rewards, but it makes it difficult for animals as well. If so, that would have important implications for much of the research on animal learning. Studies of learning and memory typically present participants with stimuli to which they make a response, and either do or do not get rewarded. Participants are supposed to learn, and remember, which stimuli or responses are associated with rewards. In most experiments with nonhuman primates in the Wisconsin General Testing Apparatus, for example, the rewards are placed in shallow wells below the stimuli, just as is done in the standard DNMS procedure. All such paradigms are predicated on the participants' understanding the relation between stimuli and rewards. Jarvik (1956) asked why it takes a smart creature like a chimpanzee 100–200 trials to learn a simple color discrimination (e.g., always choose red or always choose blue). Color discrimination is normally tested in primates by placing, for example, a red plaque over one well and a blue plaque over another. The left–right placement of the two plaques is varied randomly over trials, but the reward is always under the plaque of a given color. Jarvik varied whether the reward was placed in the well under the plaque or taped to the underside of the plaque. When the reward was attached to the plaque, Jarvik found that the mean number of trials to criterion was 1.

It is possible that the ability to understand the relationship between the stimulus and reward when the reward is in the well beneath the stimulus is beyond the grasp of most children until they are 21 months old. Certainly, symbolic representation—understanding that one thing (e.g., a stimulus) can stand for another (e.g., the location of a reward)—is one of the crowning achievements of early cognitive development. It is possible that the various developments in performance on the DNMS task chart the progression of infants' and young children's ability to grasp the abstract, arbitrary relationship between stimuli and rewards.

From the results presented here one cannot determine whether spatial proximity or temporal proximity is key. However, Diamond and Lee (1999) tested a condition of DNMS in which the act of displacing the stimulus caused a jack-in-the-box to pop up directly behind the stimulus. The reward (the jack-in-the-box) was placed farther from the stimulus than was the reward in the standard DNMS condition, but it was temporally closer because it popped up immediately upon the slightest movement of the stimulus. Infants of 9 and 12 months perform every bit as well in the jack-in-the-box condition as they do in the verbal-reward and Velcro conditions reported here. The tight temporal coupling of stimulus-moves/jack-pops-up almost makes it appear as if the stimulus is a lever that causes the jack-in-the-box to pop up. This temporal proximity may enable infants to conceptualize the stimulus and the jack-in-the-box reward as connected, as two parts of a single unit. In all three conditions (verbal reward, Velcro, and jack-in-the-box), the reward was temporally close to the stimulus. In the jack-in-the-box condition, however, the reward was spatially even farther removed from the stimulus than in the standard condition, leading us to conclude that it is close *temporal* proximity between stimulus and reward that enables infants in the first year of life to begin to grasp the relation between stimulus and reward.

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