

## Substituting new details for old? Effects of delaying postevent information on infant memory

CAROLYN ROVEE-COLLIER, SCOTT A. ADLER, and MARGARET A. BORZA  
*Rutgers University, New Brunswick, New Jersey*

How that which we remember is selectively distorted by new information was studied in 3-month-old infants who learned to move a particular crib mobile by operant foot kicking. Infants who were passively exposed to a novel mobile 1, 2, or 3 days later subsequently treated the novel mobile as if they had actually been trained with it. Also, after the longest exposure delay, they no longer recognized the original mobile. Likewise, when the novel mobile was exposed after the longest delay, it could prime the forgotten training memory in a reactivation paradigm, but the original mobile no longer could. These data reveal that what we remember about an event is selectively distorted by what we encounter later. Moreover, the later in the retention interval we encounter new postevent information, the greater is its impact on retention.

A significant question that confronts us all is, What do we really remember? Do we remember an event as it originally occurred? Or do we remember only the skeleton of an event and somehow fill in its details, perhaps by reconstructing what must have occurred or by recollecting information that we encounter later as part of the original event (Belli, Windschitl, McCarthy, & Winfrey, 1992; Lindsay, 1990, *in press*; Loftus, 1991; Nelson, 1986)? These are not new questions, but they have acquired new significance as a result of the current debate on the accuracy and completeness of what adults and children remember about events they have previously witnessed. Misleading questions and other forms of misleading postevent information, for example, often distort their subsequent recollections (for reviews, see Ceci, Toglia, & Ross, 1987; Doris, 1991; Loftus, 1979).

Considerable controversy has arisen in the literature concerning whether the original memory trace in adults is overwritten or displaced (e.g., Loftus, 1981; Loftus & Loftus, 1980), whether a new memory that consists of a blend of old and new attributes is formed (e.g., Loftus, Donders, Hoffman, & Schooler, 1989; Loftus & Hoffman, 1989), or whether the original memory coexists with a memory of the postevent information (e.g., Bekerian & Bowers, 1983; Chandler, 1989, 1991; Christiaansen & Ochalek, 1983; McCloskey & Zaragoza, 1985a, 1985b; Pirolli & Mitterer, 1984). These accounts

differ with regard to whether the effects of postevent information are attributed to changes in the original memory trace (a storage-based account) or to interference between a relatively more accessible memory and a prior one (a retrieval-based account).

The effect of postevent information on children's recollections has been even more controversial (e.g., Ceci, Ross, & Toglia, 1987a, 1987b; Ceci, Toglia, & Ross, 1988; Zaragoza, 1987, 1991). This problem is exacerbated by the major developmental changes that occur in children's expressive language skills, their inferential ability and logical reasoning, their general knowledge about events, their ability to distinguish between perceived and imagined events, and their desire to conform to social and task demands. Some investigators, for example, have reported that younger children may recall the details of some events as accurately as older children, but they remember less (Brainerd & Ornstein, 1991; Goodman & Clarke-Stewart, 1991), while others have obtained different conclusions (Dent, 1991; Peters, 1991; see Goodman, 1984, for review).

One source of the controversy in the adult and the children's literature may derive from the intervals between the original event and the introduction of misleading postevent information and between the postevent information and testing, both of which have varied unsystematically across studies. Loftus, Miller, and Burns (1978) originally explored the effect of increasing the interval between an original event and misleading postevent information about details in the event, while holding constant the interval between the postevent information and a forced-choice retention test. They found that adults were more likely to recognize the postevent information when they encountered it after a longer delay. Similarly, Ceci et al. (1987a) exposed children to misleading information 1 day after the original

---

This research was supported by Grant MH32307 and Research Scientist Award MH00902 from the National Institute of Mental Health to C.R.-C. Earlier portions of these data were presented at the meeting of the Eastern Psychological Association, New York, April 1992. We thank George Collier for critical comments on an earlier version of the manuscript. Address correspondence and requests for reprints to the first author at the Department of Psychology, Busch Campus, Rutgers University, New Brunswick, NJ 08903.

event (a story) and found that their recollections of the story were significantly impaired 2 days later—3 days after the original event. These data suggest that memories are easier to modify after longer delays. Zaragoza (1987), however, found no evidence of memory impairment in 4-year-olds when the original event, the misleading information, and testing occurred within a single 20-min session, or when the misleading information was presented after a 2-day delay and testing occurred immediately afterward. Her findings underscore the need for a more parametric approach to the study of the effects of postevent information delay.

We have previously argued that 3-month-olds are ideal subjects for the study of the effects of postevent information on the memory of a prior event, because their facility in learning and remembering a unique association has been well characterized, they are unaffected by social or task demands, and they lack the verbal facility and extensive network of associations of older children and adults (Rovee-Collier, Borza, Adler, & Boller, 1993). In the present experiments, we present evidence that what infants remember about an event is selectively distorted by new information that they encounter several days after the event occurred. Moreover, whether their memory for the original event is impaired or they subsequently recognize the new postevent information as having been part of the original event (a *source attribution error*; Belli, 1989) is determined by the timing of the new information within the retention interval. Initially, new postevent information supplements a prior memory, leading the new information to be treated as old. When novel postevent information is encountered late in the retention interval, however, memory for the original event is impaired.

In all of the succeeding experiments, we exploited the finding that adults (e.g., Hasher & Griffin, 1978) as well as infants (Bhatt & Rovee-Collier, 1994; Ohr, Fleckenstein, Fagen, Klein, & Pioli, 1990; Rovee-Collier & Sullivan, 1980) forget the specific details of an event more rapidly than its gist or general features. At 3 months, for example, infants' memories are initially highly specific. One day after learning to move a particular crib mobile by kicking, they respond robustly to it, but discriminate a novel test mobile, not attempting to move it by kicking. As infants progressively forget the details of the original training mobile over time, however, they increasingly respond to novel test mobiles until, 3 days after training, they attempt to move any mobile—novel or familiar—by kicking. After 5 days, their responding to both mobiles begins to decline equivalently, and after 6–7 days they forget the event altogether.

The initial specificity of infants' original memory is overridden, however, by briefly exposing them to a novel mobile shortly after training is over (Greco, Hayne, & Rovee-Collier, 1990; Rovee-Collier, Borza, et al., 1993; Rovee-Collier, Greco-Vigorito, & Hayne, 1993). Information about the novel mobile is apparently integrated with their prior training memory at this time

because the novel mobile, in addition to the original one, can subsequently cue retrieval of the training memory 24 h later. Given the specificity of their original memories, the rapidity with which they are affected by new postevent information is surprising. We do not know, however, whether the effects of postevent information on infants' subsequent retention shortly after training, before they have forgotten the details of the original event, are different from the effects of postevent information given later.

Given the relevance of this problem to the general controversy that has arisen over the veracity of eyewitness testimony following exposure to postevent information after different delays in children and adults, we thought it important to explore it systematically with infants. Before proceeding, however, it seemed prudent to ensure that the basic phenomena on which our manipulations were to be based could be obtained with the particular stimuli to be used in the succeeding studies. To this end, we initially sought to replicate the basic postevent information phenomenon with infants (Experiment 1A) and to document that they forget the details of the original training memory within 3 days (Experiment 1B).

### EXPERIMENT 1A Replication of the Postevent Information Phenomenon

This experiment was designed to replicate the original postevent information phenomenon with infants by using the particular stimuli to be used in the succeeding experiments. To this end, we trained infants with one mobile and tested them with either the same mobile or a different one. In addition, some of the infants were passively exposed to a different mobile immediately after the conclusion of training, 24 h prior to being tested with it. We expected the latter procedure to override the retention deficit otherwise seen when infants are tested with a novel mobile after a 24-h delay.

#### Method

**Subjects.** Eighteen infants (8 males, 10 females), recruited from published birth announcements and by word-of-mouth, served as subjects. Their mean age was 86.4 days ( $SD = 7.3$ ) on the first day of testing. Additional infants were excluded from the final sample for crying ( $n = 2$ ) or inattention to the mobile ( $n = 1$ ) for 2 consecutive minutes in any of the four sessions. The subjects were randomly assigned to one of three groups as they became available for testing.

**Apparatus.** Reinforcement was provided by one of three hand-painted wooden mobiles, identical in basic construction, size, complexity, and number of components, but differing in theme, component shape, and prominent colors (Nursery Plastics, Inc., Models 801, 805, and 809). Prior to participation, none of the infants had been exposed to any of these models, which are not commercially available. The models used during training and testing were counterbalanced within and across groups.

Inverted-L-shaped, metal mobile stands (BCS, South Plainfield, NJ) were clamped to opposite sides of the crib so that their overhead suspension bars protruded toward the center of the crib.

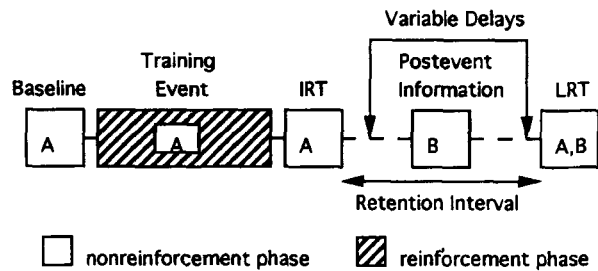
A mobile was suspended from the hook of either bar approximately 25–30 cm above the infant's chest. A white satin ribbon was looped around the infant's right ankle and was connected without slack to one of the overhead suspension bars; a mobile was hung from the suspension bar nearest the experimenter. During reinforcement phases, the ribbon was connected to the suspension bar that held the mobile, with the result that each kick activated the mobile at a rate and with an intensity proportional to the rate and intensity of kicking. During nonreinforcement phases, the ribbon was connected to the suspension bar most distant from the experimenter; in this arrangement, the mobile remained in view, but the infants' kicks could not activate it.

**Procedure.** The general procedure used with 3-month-olds is analogous to yes/no recognition tasks that have been used in studies of retention with adults (e.g., Belli, 1989; Tversky & Tuchen, 1989). However, because infants lack a verbal response and therefore cannot indicate whether or not they recognize a particular mobile, we taught them a motoric response—an operant foot kick—and then tested them in a go/no-go paradigm. In this paradigm, they produced the motoric response at a rate above baseline if they recognized the test mobile, and did not respond above baseline if they did not recognize it.

The infants were tested in a supine position in their home cribs at a time of day when their mothers thought they were likely to be playful and alert. This time differed from infant to infant, but remained relatively constant across sessions for a given infant. The infants received a 15-min training session on each of 2 successive days and a procedurally identical test session 24 h later. Each session began after the ankle ribbon was attached, when the stationary mobile was suspended over the infant for 3 min. In Session 1, this nonreinforcement period was a *baseline phase*, in which the infant's unlearned activity level, or operant level, was ascertained. In Session 3, the initial nonreinforcement period served as the *long-term retention test*, during which the infant's retention or transfer (depending upon whether the test mobile was the same or different, respectively) was recorded. Next followed a 9-min reinforcement phase (*acquisition*), during which the ankle ribbon was moved to the hook that held the mobile, and the infant's kicks were conjugately reinforced by mobile movement. Finally, each session ended as it had begun, with a 3-min nonreinforcement period, during which the ankle ribbon was returned to the inactive or "empty" stand. In Session 2, this served as the *immediate retention test*, during which the infant's final level of acquisition was assessed after zero delay.

The *postevent information procedure* was administered immediately after training. At this time, the ankle ribbon was detached and draped over the side of the crib, the training mobile was replaced by a novel one, and the other end of the ribbon was returned to the active stand (i.e., the stand from which the novel mobile hung). For 3 min, the experimenter drew and released the ribbon, moving the novel mobile noncontingently for 3 min at the same rate that the infant had kicked to move the original training mobile in the final 3 min of acquisition. During this period, the infant could passively observe the novel mobile. Figure 1 presents a general schematic of training and testing with an interpolated exposure to the postevent information.

Following the 3-min long-term retention/transfer test in Session 3, reinforcement was again introduced to ensure that the infants who had failed to respond during the initial long-term test were not unmotivated, ill, or otherwise incapable of responding on that particular day. We emphasize that all measures of retention were obtained only during periods when the stationary mobile and the ankle ribbon were attached to *different* stands. In this way, measures of retention reflected only what the infant brought into the session from his or her *prior* experience and not new learning or savings at the time of testing.



**Figure 1.** The postevent information paradigm. Infants' kicks were initially reinforced by the movement of Mobile A for a total of 18 min in two sessions, each of which was preceded and followed by a 3-min nonreinforcement phase. Prior to training in Session 1, this was the *baseline phase*; at the end of training in Session 2, it was the *immediate retention test (IRT)*. The *long-term retention test (LRT)*, with either original Mobile A or novel Mobile B, occurred during an identical 3-min nonreinforcement phase after a specified delay. The training-testing delay was the *retention interval*. In some experiments, infants were tested with completely novel Mobile C (not shown). In Experiment 1A, infants were passively exposed to novel *postevent information (Mobile B)* immediately following the IRT in Session 2; in the succeeding experiments, postevent information followed training by 1–3 days. The delay between infants' exposure to the postevent information and testing was 1 day in Experiment 1A; in succeeding experiments, this delay varied.

The infants were trained for two sessions with Mobile A and were tested 1 day later with either the same mobile (Group AA/24A) or a different one (Group AA/24B). A third group (Group AAb/24B), also tested with a different mobile, was exposed to novel postevent information (the novel test mobile was moved noncontingently by the experimenter for 3 min) immediately following the end of Session 2. (The uppercase letters preceding and following the slash in the group labels represent the mobiles used during the two training sessions and the test session, respectively; the lowercase letter denotes the infants' passive exposure to Mobile B at the end of Session 2.)

A kick was defined as any horizontal or vertical movement of the leg with the ribbon attachment that at least partially retraced its arc of excursion in a smooth, continuous motion (Rovee & Rovee, 1969). A trained observer, positioned out of the infant's direct line of sight, recorded the number of kicks per minute of the foot with the ribbon attached. A second observer, also stationed out of the infant's direct view, independently recorded kicks per minute for 180 min of 12 randomly selected sessions of 7 infants. A Pearson product-moment correlation computed over their joint response counts per minute yielded an interobserver reliability coefficient of .96.

## Results and Discussion

Retention was assessed with two individual measures of relative retention (baseline ratio, retention ratio) that we have used in all previous studies of infant memory (for review, see Rovee-Collier & Hayne, 1987). The primary index of retention is the *baseline ratio*. This expresses the extent to which an infant's response rate during the long-term retention test at the outset of Session 3 exceeds that same infant's pretraining response rate during the 3-min baseline phase at the outset of Session 1. A baseline ratio that significantly exceeds a theoretical population baseline ratio of 1.00 (i.e., performance at

the baseline level or “no retention”) indicates that a group exhibited significant retention during the long-term test. If a group’s baseline ratio does not significantly exceed 1.00, then it exhibited no retention, irrespective of its performance on the second measure. (Random responding is not expected to be less than the baseline rate, or operant level.)

The *retention ratio* indexes the degree of retention. It expresses an infant’s rate of responding during the long-term retention test at the outset of Session 3 as a fraction of the same infant’s response rate during the immediate retention test at the end of Session 2. A retention ratio of 1.00 or higher indicates that responding continued to be as high during the long-term retention test as it was after no delay. Retention ratios significantly less than a theoretical population retention ratio of 1.00 (i.e., no forgetting) indicate that retention was significantly impaired during the long-term test. (Note that performance during a long-term retention test is not expected to be higher than performance after no delay.) A group whose retention ratio is significantly less than 1.00 but whose baseline ratio significantly exceeds 1.00 has displayed partial retention.

A one-way analysis of variance (ANOVA) over the mean baseline and retention ratios of the three groups indicated that they differed significantly [baseline ratio,  $F(2,15) = 12.64, p < .001$ ; retention ratio,  $F(2,15) = 3.86, p < .05$ ]. Tukey’s honestly significant difference (HSD) test revealed that Groups AA/24A and AAb/24B

**Table 1**  
**Statistical Summary of Retention Ratio Analyses for Four No-Exposure Groups and One Immediate-Exposure Group Tested Either 24 h (Experiment 1A) or 72 h (Experiment 1B) After Training**

| Group         | Retention Ratio | Standard Error | <i>t</i> * | <i>p</i> |
|---------------|-----------------|----------------|------------|----------|
| Experiment 1A |                 |                |            |          |
| AA/24A        | 0.94            | 0.13           | 0.43       | n.s.     |
| AA/24B        | 0.53            | 0.17           | 2.70       | .04      |
| AAb/24B       | 0.92            | 0.12           | 0.69       | n.s.     |
| Experiment 1B |                 |                |            |          |
| AA/72A        | 0.94            | 0.13           | 0.44       | n.s.     |
| AA/72B        | 0.86            | 0.08           | 1.83       | n.s.     |

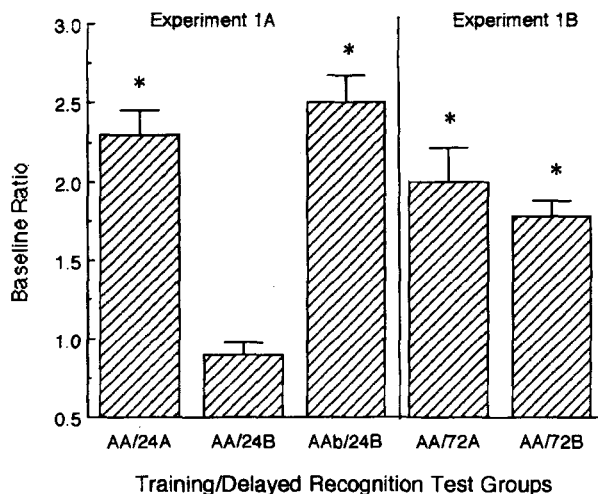
\*Comparison with a theoretical retention ratio of 1.00 (i.e., perfect retention).

did not differ on either measure, and both had values significantly higher than that of Group AA/24B (see Figure 2, left panel).

Although an ANOVA indicates whether or not groups differ, it does not answer our question of primary interest; that is, did any group exhibit significant retention? Even though the groups differed, all or none may have exhibited retention. To answer this, we used directional *t* tests to compare the baseline and retention ratios of each group against their corresponding theoretical population ratios of 1.00 (no retention and no forgetting, respectively).

As expected, Group AA/24A exhibited excellent 24-h retention, but Group AA/24B exhibited none. The mean baseline ratio of Group AA/24A was significantly greater than a theoretical baseline ratio of 1.00 [ $t(5) = 4.99, p < .004$ ], and its mean retention ratio was not significantly less than a theoretical retention ratio of 1.00 [ $t(5) = .48, n.s.$ ]. In contrast, the mean baseline ratio of Group AA/24B was not significantly greater than 1.00 [ $t(5) = 1.26, n.s.$ ], and its mean retention ratio was significantly less than 1.00 [ $t(5) = 2.70, p < .04$ ], confirming a significant retrieval deficit. When novel Mobile B was passively exposed immediately after Session 2, however, it did cue retrieval of the training memory 24 h later. Like Group AA/24A, the mean baseline ratio of Group AAb/24B was significantly greater than 1.00 [ $t(5) = 8.77, p < .0005$ ], and its mean retention ratio was not significantly less than 1.00. The retention ratio analyses are summarized in Table 1.

These findings replicate our previous finding of a postevent information effect with infants (Rovee-Collier, Borza, et al., 1993): Passively exposing infants to a novel mobile after they had been trained for 2 days with another mobile apparently causes the novel mobile to be integrated with the prior training memory. As a result, infants treat the novel mobile as if they had actually been trained with it (source misattribution) and respond robustly to it during a delayed recognition test 24 h later (Group AAb/24B). In contrast, infants who were tested with the novel mobile, without having encountered it subsequent to training, treat it as unique



**Figure 2.** Left panel: Mean baseline ratios of three groups of 3-month-olds who were trained for two sessions with Mobile A and tested with either the same mobile (Group AA/24A) or a different one (Groups AA/24B and AAb/24B) 24 h later. Group AAb/24B was briefly exposed to a novel test mobile, in motion, immediately after the end of training (Experiment 1A). Right panel: Mean baseline ratios of two groups of 3-month-olds who were trained for two sessions with Mobile A and were tested with either the same mobile (Group AA/72A) or a different one (Group AA/72B) 72 h later (Experiment 1B). Asterisks indicate significant retention (i.e., baseline ratio significantly >1.00). Vertical bars indicate  $\pm 1$  standard error.

and do not respond to it during the 24-h test (Group AA/24B).

### EXPERIMENT 1B

#### Replication of Forgetting the Details of an Event

We previously reported that 3-month-olds forget the details of their original mobile within 3 days of training. Whereas they discriminate a novel mobile after a 24-h delay (e.g., Group AA/24B in Experiment 1A), they generalize to the novel mobile after a 72-h delay, treating it and the original training mobile equivalently (Rovee-Collier & Sullivan, 1980). In Experiment 1B, we sought to replicate the generalization phenomenon by testing two groups, as in Experiment 1A, with either their original training mobile or a novel one. This time, however, we tested the infants after 72 h instead of after 24 h.

#### Method

**Subjects.** The subjects were 20 infants (13 males, 7 females) with a mean age of 89.5 days ( $SD = 7.4$ ) on the first training day. Recruitment was the same as that in Experiment 1A, and they were assigned to one of two groups ( $n = 10$ ) as they became available for study. Testing was discontinued on 3 additional infants who cried continuously for 2 min in any of the three sessions ( $n = 2$ ), or because of a scheduling conflict ( $n = 1$ ).

**Apparatus and Procedure.** The apparatus and training and testing procedures were the same as those used with Groups AA/24A and AA/24B in Experiment 1A. Groups AA/72A and AA/72B were trained for two sessions with Mobile A and were tested 72 h later with either Mobile A or Mobile B (a novel mobile), respectively.

#### Results and Discussion

A Student's  $t$  test between the mean baseline and retention ratios of Groups AA/72A and AA/72B indicated that the groups did not differ on either measure [ $t(18) = .22$ , n.s., and  $t(18) = .37$ , n.s., respectively; see Figure 2, right panel]. As expected, both groups exhibited significant retention during the 72-h delayed recognition test. The mean baseline ratio of Group AA/72A was significantly greater than a theoretical baseline ratio of 1.00 [ $t(9) = 4.52$ ,  $p < .001$ ], and its mean retention ratio was not significantly less than a theoretical retention ratio of 1.00. Likewise, the mean baseline ratio of Group AA/72B was significantly greater than a theoretical ratio of 1.00 [ $t(9) = 7.97$ ,  $p < .0001$ ], indicating significant generalization, and its mean retention ratio was not significantly less than a theoretical ratio of 1.00, indicating that generalization was complete in this group. These retention ratio analyses are also summarized in Table 1.

The finding that both groups responded to the test mobile whether it was novel or familiar during the 3-day test confirms that the infants in Group AA/72B no longer behaved as if they had been trained with a *particular* mobile (as, for example, Group AA/24B had behaved in Experiment 1A) and behaved instead as if they had been trained only with *a* mobile.

### EXPERIMENT 2A

#### Effect of Delaying Postevent Information

In Experiment 1A, we confirmed that when infants are exposed to novel postevent information immediately after training, they subsequently treat the exposed mobile as if they had actually been trained with it and respond to the original mobile and the novel one equivalently. Infants who were not exposed to the novel mobile immediately after the end of training discriminated it 1 day later. In Experiment 1B, we demonstrated that infants forget the specific details of their original training mobile within 3 days. Infants who were tested with a completely novel mobile 72 h after the end of training generalized to it; they responded in the same way that they had responded to the original mobile after that delay. Thus, after 3 days, their retention was mediated by the general features of the mobile. (From prior research, we know that the general features of the mobile continue to be remembered for at least 5 days after training, after which time they are gradually forgotten [Butler & Rovee-Collier, 1989; Rovee-Collier & Sullivan, 1980; Sullivan, Rovee-Collier, & Tynes, 1979].)

In the present study, therefore, we exposed independent groups of infants to a novel mobile after delays ranging from 1 to 3 days and then tested them 1 day later with either the original mobile (Mobile A) or the novel one, to which they had more recently been exposed (Mobile B). In this way, we sought to trace the effect of novel postevent information on recognition of the original event over the period within which infants progress from discriminating that information as novel to no longer being able to do so.

#### Method

**Subjects.** Forty-two infants (23 males, 19 females), recruited from published birth announcements and by word-of-mouth, served as subjects. Their mean age was 88.7 days ( $SD = 6.0$ ) on the first day of testing. Additional infants were excluded from the final sample for crying ( $n = 13$ ) for 2 consecutive minutes in any of the four sessions, for failing to meet the learning criterion (a response rate equal to 1.5 times the baseline rate by the end of training;  $n = 1$ ), for failing to maintain a supine posture ( $n = 1$ ), or because of a scheduling conflict ( $n = 1$ ). The infants were randomly assigned to one of seven groups as they became available for testing.

**Apparatus and Procedure.** The apparatus and procedure were the same as those for Group AA/24B in Experiment 1A, except that Mobile B was passively exposed 24, 48, or 72 h after training. The infants in each delay condition were tested with either the original mobile (Groups AA24b/A, AA48b/A, AA72b/A) or the novel one (Groups AA24b/B, AA48b/B, AA72b/B). A final group (Group AA24b/C) was exposed to the novel mobile 24 h after training and tested with a completely novel mobile (Mobile C). As before, the interval between exposure to the postevent information and the delayed recognition test was constant (24 h).

#### Results and Discussion

One-way ANOVAs over the mean baseline and retention ratios of the groups indicated that their baseline ra-

tios did not differ [ $F(2,39) = 1.81, n.s.$ ], but their retention ratios did [ $F(2,39) = 5.62, p < .007$ ].

Directional  $t$  tests indicated that all the groups exhibited excellent retention, except the group that was exposed to Mobile B 24 h after training and was tested with a completely novel mobile the next day (Group AA24b/C) and the group that was exposed to Mobile B after 72 h and was tested with its original training mobile the next day (Group AA72b/A) (see Figure 3). These groups exhibited no retention whatsoever. Their mean baseline ratios were not significantly above a theoretical baseline ratio of 1.00 [Group AA24b/C,  $t(5) = 1.65, n.s.$ ; Group AA72b/A,  $t(5) = .78, n.s.$ ], and their mean retention ratios were significantly less than a theoretical retention ratio of 1.00 [Group AA24b/C,  $t(5) = 10.63, p < .0005$ ; Group AA72b/A,  $t(5) = 10.28, p < .0005$ ]. The baseline ratios of all the other groups were significantly greater than 1.00 [Group AA24b/A,  $t(5) = 2.52, p < .05$ ; Group AA48b/A,  $t(5) = 4.08, p < .005$ ; Group AA24b/B,  $t(5) = 3.82, p < .01$ ; Group AA48b/B,  $t(5) = 2.86, p < .025$ ; Group AA72b/B,  $t(5) = 5.29, p < .005$ ], and their retention ratios were not significantly less than 1.00 (see Table 2).

These results were unexpected. Typically, infants respond robustly to all test mobiles, both novel and familiar, within 3 days of training (Bhatt & Rovee-Collier, 1994; Ohr et al., 1990; Rovee-Collier & Sullivan, 1980), and in Experiment 1B the infants had also responded to their training mobile and a novel one after a 3-day delay

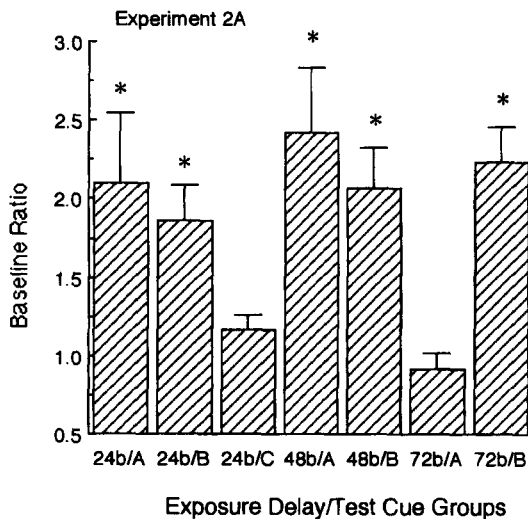


Figure 3. Mean baseline ratios of seven groups of 3-month-olds who were trained for two sessions with Mobile A and were exposed for 3 min to a novel mobile (Mobile B) 24, 48, or 72 h later. These infants were tested 1 day after the exposure (2, 3, or 4 days after training, respectively) with either the original mobile (Mobile A) or the novel exposure one (Mobile B). A final group was exposed to the novel mobile 24 h after training and was tested with a completely novel mobile (Mobile C) 1 day later. Asterisks indicate significant retention (i.e., baseline ratio significantly >1.00). Vertical bars indicate  $\pm 1$  standard error (Experiment 2A).

Table 2  
Statistical Summary of Retention Ratio Analyses for 11 Groups Passively Exposed to a Novel Mobile 24, 48, or 72 h After Training and Tested Either 1 Day After the Exposure (Experiment 2A) or 4 Days After Training (Experiment 2B)

| Group         | Retention Ratio | Standard Error | $t^*$ | $p$   |
|---------------|-----------------|----------------|-------|-------|
| Experiment 2A |                 |                |       |       |
| 24b/A         | 0.81            | 0.13           | 1.46  | n.s.  |
| 24b/B         | 0.83            | 0.12           | 1.42  | n.s.  |
| 24b/C         | 0.54            | 0.04           | 10.63 | .0005 |
| 48b/A         | 1.20            | 0.26           | 0.77  | n.s.  |
| 48b/B         | 0.91            | 0.12           | 0.77  | n.s.  |
| 72b/A         | 0.41            | 0.06           | 10.28 | .0005 |
| 72b/B         | 0.81            | 0.15           | 1.26  | n.s.  |
| Experiment 2B |                 |                |       |       |
| 24b/A         | 1.03            | 0.22           | 0.12  | n.s.  |
| 24b/C         | 0.70            | 0.09           | 3.46  | .018  |
| 72b/A         | 0.41            | 0.06           | 10.28 | .0005 |
| 72b/C         | 0.38            | 0.03           | 17.58 | .0005 |

\*Comparison with a theoretical retention ratio of 1.00 (i.e., perfect retention).

(see Figure 2, right panel). Yet when tested after 4 days in the present experiment, the infants who had been passively exposed to a novel mobile 24 h earlier (3 days after the end of training) responded *only* to that novel exposure mobile and *not* to the original one. This result was particularly surprising in that the infants who had been passively exposed to the novel mobile after shorter delays had continued to recognize the original mobile 24 h later. One account for this result is that when the novel mobile was exposed 3 days after training, its specific details were substituted for the details of the original mobile, which had been forgotten after that delay. In summary, postevent information about the novel mobile not only led infants to treat that novel mobile as part of the original event (i.e., source misattribution), but it impaired their recognition of the original mobile when the novel postevent information was encountered after a longer delay.

The failure of Group AA24b/C to respond to a completely novel test mobile confirmed that the interpolated exposure to Mobile B 1 day after training did not lead the infants to respond indiscriminately to any novel test mobile 24 h later. Rather, the infants' recognition of the novel exposure mobile was *specific* to the fact that they had previously been exposed to it.

### EXPERIMENT 2B

#### Confirming Evidence for Memory Impairment

According to the account suggested previously, because the details of the novel exposure mobile had been substituted in the memory representation for the details of the original mobile, the infants treated the original training mobile as novel 1 day later during the 4-day delayed recognition test, just as the infants in Experiment 1A had discriminated a novel mobile from the

original mobile during testing 1 day after the end of training.

This account predicts that infants who are exposed to a novel mobile 3 days after training should also discriminate a *completely novel* mobile from the novel exposure mobile 1 day later, despite the fact that infants who have encountered no interpolated postevent information typically do not discriminate novel from familiar mobiles 4 days after training (e.g., Group AA/72B in Experiment 1B). In addition, if the details of the novel exposure mobile (Mobile B) were substituted for the details of the original mobile (Mobile A) only *after* the details of the original mobile had been forgotten, then exposure to the novel mobile earlier in time, before the details were forgotten, should *not* impair the infants' recognition of the original mobile during the 4-day test. These possibilities were tested in Experiment 2B.

Finally, although the infants who had been exposed to a novel mobile 1 day after training in Experiment 2A had discriminated a completely novel mobile (Mobile C) 24 h later, it seemed reasonable to expect that the details of the novel exposure mobile, which had been viewed for only 3 min 1 day after training, would be forgotten 3 days later, just as the details of the original mobile are usually forgotten within 3 days. Were this the case, the infants should generalize to a completely novel mobile during the 4-day test. On the other hand, because the infants had discriminated the completely novel mobile after having been exposed to a novel mobile 1 day after training (Group AA24b/C, Experiment 2A), they might continue to do so after an even longer delay. These alternatives were also explored in Experiment 2B.

## Method

**Subjects.** The subjects were 18 infants (8 males, 10 females) with a mean age of 92.4 days ( $SD = 10.1$ ) on the first training day. Recruitment was the same as that for the previous experiments, and the infants were assigned to one of the three groups as they became available for study. Testing was discontinued on 4 additional infants for failing to meet the original learning criterion, for crying continuously for 2 min in any of the four sessions, for failing to remain supine, and because of a scheduling conflict.

**Procedure.** The training, postevent information, and testing procedures were the same as those in Experiments 1A and 2A, except that *all groups were tested 4 days after the end of training*. Group AA72b/C was passively exposed to Mobile B 72 h after the end of training and was tested with a completely novel mobile (Mobile C) 1 day later; Group AA24b/A was passively exposed to Mobile B 24 h after the end of training and was tested with Mobile A 3 days later; and Group AA24b/C was passively exposed to Mobile B 24 h after the end of training and was tested with Mobile C 3 days later.

Group AA24b/A was included to determine whether infants' recognition of the original mobile 4 days after training differed as a function of when Mobile B was interpolated between training and testing. Recall that in Experiment 2A, when infants had been exposed to Mobile B 24 h after training and tested 1 day later, they had responded to Mobile A; when they had been exposed to Mobile B 72 h after training and tested 1 day later, they had not. Although the difference in their recognition of Mobile A in these two instances may have reflected differences in when Mobile B was exposed in relation to the end of training (e.g., differences in

whether the details of Mobile A were forgotten or not at the time of the exposure), it also may have reflected differences in when Mobile B was exposed in relation to testing. For this analysis, the data of Group AA24b/A were compared with those of Group AA72b/A from Experiment 2A; both groups were tested after a 4-day retention interval, but they were exposed to Mobile B at different points within that interval.

## Results and Discussion

An ANOVA over the mean baseline ratios of Groups AA24b/C, AA72b/C, AA24b/A, and AA72b/A indicated that they differed significantly [ $F(3,20) = 5.32, p < .007$ ]. Post hoc comparisons between the two groups tested with Mobile A and the two groups tested with Mobile C revealed that the infants' recognition of the original mobile was affected by when Mobile B was exposed within the 4-day retention interval, but recognition of the completely novel mobile was not (see Figure 4). The mean baseline ratio of Group AA24b/A was significantly higher than that of Group AA72b/A [ $F(1,10) = 9.93, p < .01$ ], but the mean baseline ratios of Groups AA24b/C and AA72b/C did not differ [ $F(1,10) = 3.99, n.s.$ ].

A one-way ANOVA indicated that the mean retention ratios of the four groups differed significantly [ $F(3,20) = 6.22, p < .004$ ]. The mean retention ratio of Group AA24b/A was significantly higher than that of Group AA72b/A [ $F(1,10) = 7.69, p < .02$ ], and the mean retention ratio of Group AA24b/C was significantly higher than that of Group AA72b/C [ $F(1,10) = 11.44, p < .007$ ]. The meaning of these differences is unclear, however, without knowing whether these groups exhibited significant retention in the first place.

To determine this, we used directional *t* tests to compare the mean baseline and retention ratios of all groups

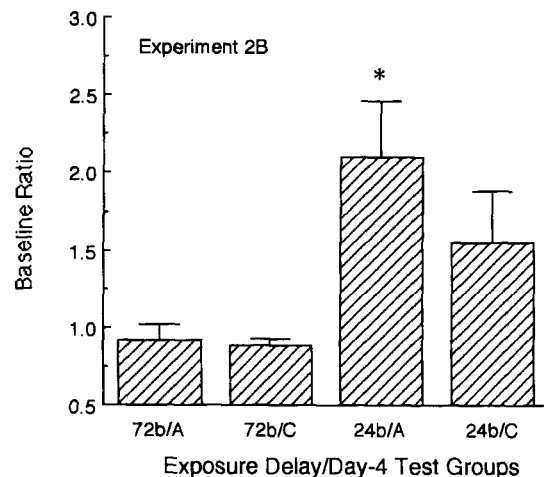


Figure 4. Mean baseline ratios of four groups of infants who were exposed to Mobile B either 24 h (Groups AA24b/A and AA24b/C) or 72 h (Groups AA72b/A and AA72b/C) after training. All were tested 4 days after training with either the original mobile (Mobile A) or a completely novel mobile (Mobile C). An asterisk indicates significant retention (i.e., baseline ratio significantly  $>1.00$ ). Vertical bars indicate  $\pm 1$  standard error (Experiment 2B).

against the corresponding theoretical population baseline and retention ratios of 1.00. These analyses indicated that only Group AA24b/A exhibited significant retention. Its mean baseline ratio was significantly greater than a theoretical baseline ratio of 1.00 [ $t(5) = 3.06, p < .025$ ], and its mean retention ratio was not significantly less than a theoretical retention ratio of 1.00. Neither of the mean baseline ratios of Groups AA24b/C or AA72b/C was significantly greater than a theoretical baseline ratio of 1.00 [ $t(5) = 1.65, n.s.$ , and  $t(5) = -2.28, n.s.$ , respectively], and both mean retention ratios were significantly less than a theoretical ratio of 1.00 [ $t(5) = 3.46, p < .018$ , and  $t(5) = 17.58, p < .0005$ , respectively]. The retention ratio analyses are summarized in Table 2.

Thus, when novel Mobile B was exposed during the 4-day retention interval it had no impact on subsequent retention if the infants were tested with a completely novel mobile. Despite the fact that retention ratios improved as the delay between exposure and testing increased, neither group recognized Mobile C during the 4-day test. In contrast, the infants who were tested with their original mobile failed to recognize it *only* if they had been exposed to novel Mobile B after a 3-day delay (Group AA72b/A). When these infants were exposed to Mobile B only 1 day after training, before the details of the original mobile were forgotten, they exhibited excellent retention when tested with the original mobile 3 days later (Group AA24b/A). These data confirm that (1) the timing of infants' exposure to a novel mobile during the retention interval determines whether or not their recognition of the original mobile will be impaired, and (2) the source-attribution error that results from exposing a novel mobile during the retention interval is specific to that particular mobile.

To summarize the findings to this point, the typical behavior of infants without an interpolated exposure to novel postevent information is to "recognize" all test mobiles—novel and familiar—after delays of 3–4 days. This is a simple generalization effect that results because the specific details of the original training mobile have been forgotten (Experiment 1B). In Experiment 2A, however, the infants did not recognize any test mobile after 4 days *except* the novel exposure one. Their recognition of the novel exposure mobile could not have resulted from simple generalization because they did *not* recognize a completely novel mobile after 4 days. Because the infants had also recognized the novel exposure mobile after shorter retention intervals (Experiments 1A and 2A), when they otherwise would have discriminated a novel mobile from the original training mobile, we conclude that their recognition resulted from source misattribution, as occurs in studies with adults.

But what about memory impairment? Although the infants had recognized the original training mobile after shorter retention intervals *despite* an interpolated exposure to the novel mobile, they failed to recognize it when the novel exposure had occurred later in the retention interval (Experiments 2A and 2B). These infants should have recognized the original mobile after a 4-day reten-

tion interval simply on the basis of its general features, as in Experiment 1B, but they did not. We conclude, therefore, that Group AA72b/A in Experiment 2A exhibited a memory impairment that resulted from their interpolated exposure to novel Mobile B the day before. This analysis was confirmed in Experiment 2B: The infants who were exposed to a novel mobile 1 day after training recognized their original mobile whether they were tested 1 day later (Experiment 2A) or 3 days later (Experiment 2B). Thus, neither the 4-day retention interval between training and testing nor the 3-day delay between exposure to the novel mobile and testing predicted the recognition failure of Group AA72b/A in Experiment 2A.

### EXPERIMENT 3 Memory Reactivation

Memory reactivation was originally observed in rat pups (Campbell & Jaynes, 1966; Spear & Parsons, 1976), but has since been obtained with human infants (Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980; Sullivan, 1982; for review, see Rovee-Collier & Hayne, 1987) and children (Hoving & Choi, 1972; Hoving, Coates, Bertucci, & Riccio, 1972; Howe, Courage, & Bryant-Brown, 1993). In the reactivation procedure, subjects are briefly exposed to a retrieval cue (a "reactivation treatment") that is known to have been encoded in the original memory. The retrieval cue, or *reminder*, presumably primes the inactive or latent memory, thereby increasing its accessibility. As a result, retention during the subsequent delayed recognition test is excellent once more. The reactivation treatment must occur significantly in advance of the long-term retention test, hence it is referred to as a *prior-cuing procedure* (Spear, 1973). At 3 months, evidence that the forgotten memory was reactivated does not surface for at least 8 h after the reminder procedure (Fagen & Rovee-Collier, 1983); at 6 months, recovery is more rapid, taking place within 1–2 h (Boller, Rovee-Collier, Borovsky, O'Connor, & Shyi, 1990).

Although the mobile reactivation procedure is physically identical to a postevent information procedure, it is not administered until the memory is no longer accessible to retrieval cues presented at the time of testing; the postevent information procedure, in contrast, is administered when all or part of the memory can still be accessed by contemporaneous retrieval cues. Although newly acquired memories, as evidenced in the present experiments, are readily modified by novel postevent information, reactivated memories are not. In fact, we have been unable to modify a reactivated memory by the same passive exposure procedures that affect newly acquired memories, irrespective of the delay between the reactivation treatment and the novel postevent information (Boller & Rovee-Collier, 1994).

In addition, the mere presence of a novel cue (e.g., a novel mobile) at the time of the reactivation procedure completely precludes memory reactivation. And though



infants generalize responding to novel mobiles within 3 days of training, novel mobiles are completely ineffective as reminders once the original memory has been forgotten (Butler & Rovee-Collier, 1989; Rovee-Collier & Hayne, 1987). In fact, *only a mobile that is virtually identical to the mobile that was present at the time of original encoding can prime the forgotten training memory* and restore it to an active state. If the original training mobile contains more than a single novel object, for example, it is not an effective reminder (Rovee-Collier, Patterson, & Hayne, 1985). Thus, despite the commonalities between the postevent information and reactivation procedures, presentation of the novel exposure mobile as a reminder could not modify the original memory, nor could it reactivate the training memory, *unless it were represented in that memory*.

We previously found that when infants were passively exposed to a novel mobile 24 h after training, both that novel exposure mobile (Mobile B) and the original one (Mobile A) could cue responding during a delayed recognition test 1 day later, and both could reactivate the forgotten memory 2 weeks later (Rovee-Collier, Borza, et al., 1993). Similarly, in Experiment 2A, the novel exposure mobile as well as the original mobile had cued retrieval of the training memory 1 day later, when the exposure occurred either 24 h or 48 h after training. But when the infants were passively exposed to the novel mobile 72 h after training, *only* the novel exposure mobile could cue retrieval 1 day later—the original mobile could not. This result suggested that if the novel mobile were exposed 3 days after training, it might be an effective reminder for the forgotten memory, while the original mobile might not. Experiment 3 was designed to test these hypotheses.

## Method

**Subjects.** The subjects were 10 males and 8 females with a mean age of 88.5 days ( $SD = 5.3$ ) on their first day of training. Recruitment was the same as that for the previous experiments, and infants were randomly assigned to one of three reactivation groups as they became available for study. Additional infants were excluded from the final sample for crying ( $n = 2$ ) or inattention to the mobile ( $n = 1$ ) for 2 consecutive minutes in any of the five sessions.

**Apparatus and Procedure.** The apparatus and the training, the postevent information, and the testing procedures were identical to those used with Groups AA72b/B and AA72b/A in the preceding experiment, except that the interval between training and testing was 14 days—an interval after which infants of this age exhibit no evidence of retention (Fagen & Rovee-Collier, 1983; Hayne, 1990; Sullivan, 1982). All groups received a reactivation treatment 13 days after training.

Group AA72b-A/A was reminded and tested with the original training mobile, and Group AA72b-B/B was reminded and tested with the novel exposure mobile. A third group, Group AA24b-C/D, was included as a control for the specificity of the reminder. Recall that in Experiments 2A and 2B, infants who were exposed to Mobile B 1 day after training had failed to respond to Mobile C whether they had been tested 1 day or 3 days later, respectively. Because Mobile C was not an effective retrieval cue for infants who had been passively exposed to Mobile B, it was not expected to be an effective reminder either. (In the group labels, the first two

letters indicate the training mobile, the lowercase letter indicates the novel exposure mobile, the letter before the slash indicates the reminder mobile, and the letter after the slash indicates the test mobile.)

The reactivation treatment began when the mother placed the infant in a sling seat inside its crib, and the designated mobile was suspended overhead. One end of the ribbon was attached to the hook that also held the mobile, and the other end was draped over the side of the crib. Here it was drawn and released for 3 min by the experimenter, crouched out of the infant's direct line of sight, at the same rate that the infant had kicked to move the original mobile in each of the last 3 min of acquisition in Session 2. After 3 min, the mother removed her infant from the sling seat, and the reactivation treatment was over.

Recall that during each infant's passive exposure to the novel mobile, it was also moved noncontingently at the same rate as that when the infant had kicked to move the original training mobile during the final 3 min of acquisition in Session 2. During the reactivation treatment, therefore, each infant was exposed to a reminder that was phenomenologically equivalent to what he or she had previously witnessed both at the end of acquisition and during the postevent information procedure.

## Results and Discussion

One-way ANOVAs indicated that the baseline ratios of the groups differed significantly [ $F(2,15) = 3.68, p < .05$ ], but their retention ratios did not [ $F(2,15) = .83, n.s.$ ]. Post hoc tests revealed that the baseline ratio of Group AA72b-B/B was significantly higher than those of the other two groups [Group AA72b-A/A,  $t(10) = 2.45, p < .03$ ; Group AA24b-C/D,  $t(10) = 2.22, p < .05$ ], which did not differ [ $t(10) = .23, n.s.$ ; see Figure 5].

Directional  $t$  tests revealed that Mobile B was an effective reminder, but Mobile A was not. The mean baseline ratio of Group AA72b-B/B was significantly greater than a theoretical baseline ratio of 1.00 [ $t(5) = 2.73, p < .04$ ], indicating that the novel exposure mobile was an effective reminder for the original training memory. Its mean retention ratio, however, was significantly less than a theoretical ratio of 1.00 [ $t(5) = 3.52, p < .017$ ], indicating that the recovery was not complete (see Table 3). In contrast, the mean baseline ratio of Group AA72b-A/A was not significantly greater than a theoretical baseline ratio of 1.00 [ $t(5) = .73, n.s.$ ], and its mean retention ratio [ $t(5) = 3.67, p < .014$ ] was significantly less than a theoretical ratio of 1.00. These data reveal that the original mobile, which usually is an effective reminder—even when Mobile B is exposed after a delay of 1 day (Rovee-Collier, Borza, et al., 1993)—was unable to recover the training memory when the novel mobile was exposed late in the retention interval.

As expected, when a completely novel mobile was used as the reminder, it too was unable to recover the prior training memory. The mean baseline ratio of Group AA24b-C/D was not significantly greater than a theoretical baseline ratio of 1.00 [ $t(5) = .41, n.s.$ ], and its mean retention ratio was significantly less than a theoretical retention ratio of 1.00 [ $t(5) = 4.26, p < .008$ ]. This result confirms that a generalized reminder is ineffective in priming the forgotten memory. To be effective, a reminder must be represented in the forgotten memory.

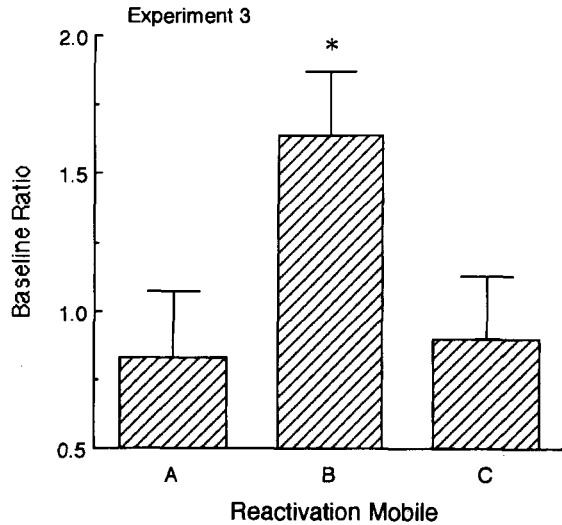


Figure 5. Mean baseline ratios of three groups of 3-month-olds who were reminded with their original mobile (Mobile A), the novel exposure mobile (Mobile B), or a completely novel mobile (Mobile C) in a reactivation paradigm. All groups received a standard delayed recognition test 24 h later to confirm whether or not the memory had been reactivated. Infants reminded with Mobile A or B were exposed to Mobile B 72 h after training; infants reminded with Mobile C were exposed to Mobile B 24 h after training. An asterisk indicates significant retention (i.e., baseline ratio significantly >1.00). Vertical bars indicate  $\pm 1$  standard error (Experiment 3).

As a result of its brief exposure following training, Mobile B apparently was, but the completely novel mobile (Mobile C) was not—and it could not reactivate the training memory. Because Mobile A also could not reactivate the forgotten memory of infants who had been exposed to novel Mobile B after a 3-day delay, we conclude that Mobile A was also not represented in the memory that was reactivated. The fact that Mobile A was an effective reminder when Mobile B was exposed only 1 day after training (Rovee-Collier, Borza, et al., 1993), but not when Mobile B was exposed 3 days afterwards, suggests that the details of Mobile B were substituted for the details of Mobile A when Mobile B was exposed after the 3-day delay.

In summary, in order for a memory to be primed or reactivated, the details of the cue that is presented as a reminder must strike a veridical perceptual match with the representation that was originally encoded. Even though

infants generalize to novel mobiles after long delays, novel mobiles are not effective reminders for the forgotten training memory—only the original mobile can prime the original memory (Rovee-Collier et al., 1985; for review, see Rovee-Collier & Hayne, 1987). In Experiment 3, however, only the novel exposure mobile could prime the memory! The original mobile and a completely novel mobile could not—even though the original mobile was able to do so when the novel mobile had been exposed early in the retention interval (Rovee-Collier, Borza, et al., 1993).

We were surprised that when infants viewed a novel mobile later in the retention interval, their ability to recognize their original mobile was so completely impaired. After all, their recognition failure occurred after a delay at which they typically respond robustly to *all* test mobiles—novel and familiar. It appeared, therefore, that the details of the novel mobile had been substituted for the details of the original mobile, which had been forgotten. This conclusion seemed justified by three lines of evidence. First, infants who had been exposed to novel Mobile B 3 days after training had discriminated a completely novel mobile during the 4-day test instead of generalizing to it. Second, when postevent information was exposed only 1 day after training, it did not impair recognition of the original mobile either 1 day later or during the 4-day test, but when the same postevent information was exposed 3 days after training (a point when the details of the original mobile are forgotten), it did impair recognition of the original mobile 1 day later, during the 4-day test. And, third, following exposure to the novel mobile 3 days after training, the novel mobile was an effective reminder for the training memory, but the original mobile no longer was.

Although we were concerned that the latter result might be adventitious, similar findings have recently been reported with 6-month-olds by Muzzio (1994). In this work, exposure to a novel mobile immediately after training did not impair recognition of the original mobile, but subjects later behaved as if they had been trained with it (source misattribution), just as had the 3-month-olds in the present Experiment 1A. However, after all novel exposure delays between 1 and 13 days (the period over which 6-month-olds remember the task), infants failed to recognize the original mobile 1 day later (memory impairment). After exposure delays of 1–6 days, they also displayed a source-attribution error, but after exposure delays of 7–13 days, they failed to recognize the novel exposure mobile as well.

Even though Muzzio's subjects did not recognize the original mobile, they still could be reminded by it if the novel exposure had occurred early in the retention interval—1 day after training—indicating that the original memory had not been displaced. However, when the novel exposure had occurred late in the retention interval—13 days after training—the original mobile was no longer an effective reminder, but the novel exposure mobile still was. We conclude, therefore, that the results

Table 3  
Statistical Summary of Retention Ratio Analyses for the Three Reactivation Groups in Experiment 3

| Reactivation Mobile | Retention Ratio | Standard Error | <i>t</i> * | <i>p</i> |
|---------------------|-----------------|----------------|------------|----------|
| A                   | 0.43            | 0.16           | 3.67       | .014     |
| B                   | 0.63            | 0.11           | 3.52       | .017     |
| C                   | 0.50            | 0.12           | 4.26       | .008     |

\*Comparison with a theoretical retention ratio of 1.00 (i.e., perfect retention).

presently obtained in Experiment 3 were genuine. Moreover, whether a mobile is recognized or not shortly after a postevent information procedure does not predict its efficacy as a reminder, which depends on the integrity of the underlying perceptual representation of the memory.

Finally, because 6-month-olds usually remember the details of their original mobile for 13 days, Muzzio's (1994) finding that the original mobile was not an effective reminder when the novel exposure occurred after 13 days suggests that the original details need not be forgotten in order for new details to be substituted for old ones, as we had hypothesized. Rather, it may only be necessary that access to the original memory for details be diminished at the time the novel postevent information is encountered. This revised hypothesis, like the original one, is consistent with the suggestion that weaker memories are more susceptible to modification (Brainerd & Reyna, 1988; Loftus et al., 1978).

### GENERAL DISCUSSION

The present experiments underscore the critical distinction between *source misattribution* (treating an interpolated stimulus as if it had actually been present during an original event) and *memory impairment* (failing to recognize a stimulus that had been present during the original event) and provide a potential explanation for discrepancies in the findings of prior studies with adults and children on the effect (or lack thereof) of misleading postevent information on a prior memory. In short, whether one obtains evidence for source misattribution, memory impairment, or both depends on the interval between the original event and exposure to the interpolated information. Postevent information encountered early in the retention interval leads to source misattribution, which may persist throughout the interval; the same postevent information encountered later in the retention interval leads to memory impairment. What constitutes "early" or "late," however, depends on a number of factors that include the rate at which the original information is forgotten, the subject's age, the salience of the original and interpolated events, and the similarity of the postevent information to the original event. Failure to consider these factors seriously compromises cross-study comparisons. These findings have practical implications for legal cases in which adults or children are asked to recount the details of events that transpired at some earlier time. They reveal that what is remembered about a prior event may be selectively distorted in a time-dependent fashion.

Whether memory impairment occurred or not was determined by the interval between the original event and the postevent information (exposure to the novel mobile) and not by the interval between the postevent information and testing. In Experiment 2A, for example, when the delay between the original event and the postevent information varied while the delay between the novel postevent information and testing remained constant,

recognition of the original event differed as a function of the delay between that event and the postevent information. This result is consistent with prior findings obtained with adults (Belli et al., 1992) and children (Ceci et al., 1987a). When the timing of the postevent information was constant relative to the original event (e.g., 24 h after training), the subjects' recognition of the original event was not impaired, whether the interval between the postevent information and testing was 1 day (Experiment 2A) or 3 days (Experiment 2B). This general result likewise is consistent with findings from studies of adults (McCloskey & Zaragoza, 1985a) and children (Zaragoza, 1987, 1991).

What are the implications of the present data for storage-based and retrieval-based accounts of the effects of misleading postevent information? Certainly, when the postevent information is presented early in the retention interval, traces of the postevent information and the original event must coexist. Not only do subjects subsequently recognize the details of both the original event and the postevent information, but both events can prime the memory in a reactivation paradigm if the postevent information was exposed after only 1 day (Experiment 2A; Rovee-Collier, Borza, et al., 1993; Rovee-Collier, Greco-Vigorito, et al., 1993). When the postevent information is presented later in the retention interval, however, it impairs recognition of the original event, and the original cue is no longer an effective memory prime.

The latter result raises the familiar question—*What is the fate of the original memory?* First, the novel details of the exposure mobile could have *overwritten* the original details in the original training memory. This account requires, however, that there be a single original memory—an account challenged by prior data (Rovee-Collier, Borza, et al., 1993) suggesting that each encounter with either the original cue or the novel one is encoded as a separate *memory token*. Second, separate memories for the gist and the verbatim details of the original event may have been encoded in parallel (Brainerd & Reyna, 1993; Reyna, in press). Because verbatim memory fades more rapidly (in the present study, within 3 days of training), memory impairment may occur only after this has happened, when the gist memory is still strong. Muzzio's (1994) finding that older infants exhibit memory impairment after delays when verbatim memory is still intact, however, is inconsistent with this account. Her data could be accommodated by assuming a preference for processing gist. Such a hypothesis has been advanced by Reyna and Brainerd (1991).

Our preferred account is based on the proposal that each time an individual experiences a perceptually different event or episode, it is encoded as a different memory token (for discussion, see Rovee-Collier, Borza, et al., 1993, pp. 277–278). By this account, the memory token(s) representing the original event competes with the memory token representing the novel postevent information at the time of retrieval. This competition may result in the more recent token being retrieved, in either

token being retrieved (depending on the retrieval cue), or in neither token being retrieved. After relatively long delays, the probability that the original memory token(s) will be retrieved fades relative to the probability that the more recent memory token representing the novel postevent information will be retrieved. That the original memory still exists in storage even though it cannot be retrieved (i.e., the original mobile is no longer recognized) is evidenced by the fact that the original mobile can still prime the original memory in a reactivation paradigm when exposure to the novel mobile occurred early in the retention interval.

But how can this account explain the failure of the original mobile to prime the memory when the novel mobile still could? These results seem to show that the details of the novel exposure mobile were substituted for the details of the original mobile in the original training memory. Recall that memory can be reactivated only if the details of a reminder veridically match the details that were *originally encoded* in the forgotten memory. Only two alternatives can reconcile the data with this fact: Either the novel details replaced or overwrote the original details in the original memory representation (an account we have already dismissed), or *the novel mobile reminder did not access the original memory token(s), but instead accessed the memory token that had been formed most recently, during the novel exposure procedure. That is, the novel mobile reactivated the only memory token in which it was represented.* Apparently, the original mobile could not access the original memory, nor could it reactivate the more recently formed memory token containing the novel postevent information, because the details of the original mobile were not represented in that memory. Note that this result was obtained *only* when the novel mobile was exposed late in the retention interval and *only* after delays so long that all memory tokens had been completely forgotten.

Thus, although the details of the novel exposure mobile *appeared* to substitute for or replace the details of the original mobile in the original training memory, we argue that *access* to the original memory token(s) was replaced by *access* to the more recently formed one. It is possible that the original memory continued to be available in storage even after it could no longer be primed. Because a storage-based account cannot be unequivocally tested without also requiring retrieval (Spear, 1971), however, this possibility is unlikely to be resolved unless the original memory token(s) could somehow be accessed again.

The facility with which young infants readily integrate new information with information already in memory suggests that memory modification is a primary means by which their accumulating knowledge base is updated to reflect their changing circumstances. In retrospect, the fact that the form of updating changes as a function of the retention interval should not be surprising. This facility is particularly adaptive for young infants, who are undergoing very rapid physical and social

change and for whom many prior memories may also rapidly become inappropriate or lose their utility. What is advantageous for the young, however, can become disadvantageous when individuals are older, and more recent postevent information interferes with their attempts to accurately remember the details of significant events in their past.

## REFERENCES

- BEKERIAN, D. A., & BOWERS, J. M. (1983). Eyewitness testimony: Were we misled? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *9*, 139-145.
- BELLI, R. F. (1989). Influences of misleading postevent information: Misinformation interference and acceptance. *Journal of Experimental Psychology: General*, *118*, 72-85.
- BELLI, R. F., WINDSCHITL, P. D., MCCARTHY, T. T., & WINFREY, S. E. (1992). Detecting memory impairment with a modified test procedure: Manipulating retention interval with centrally presented event items. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *18*, 356-367.
- BHATT, R. S., & ROVEE-COLLIER, C. (1994). Perception and 24-hour retention of feature relations in infant memory. *Developmental Psychology*, *30*, 142-150.
- BOLLER, K., & ROVEE-COLLIER, C. (1994). Contextual updating of reactivated memories. *Developmental Psychobiology*, *27*, 241-256.
- BOLLER, K., ROVEE-COLLIER, C., BOROVSKY, D., O'CONNOR, J., & SHYL, G. (1990). Developmental changes in the time-dependent nature of memory retrieval. *Developmental Psychology*, *26*, 770-779.
- BRAINERD, C. J., & ORNSTEIN, P. A. (1991). Children's memory for witnessed events: The developmental backdrop. In J. Doris (Ed.), *The suggestibility of children's recollections: Implications for eyewitness testimony* (pp. 10-20). Washington, DC: American Psychological Association.
- BRAINERD, C. J., & REYNA, V. F. (1988). Memory loci of suggestibility development: Comment on Ceci, Ross, and Toglia (1987). *Journal of Experimental Psychology: General*, *117*, 208-211.
- BRAINERD, C. J., & REYNA, V. F. (1993). Memory independence and memory interference in cognitive development. *Psychological Review*, *100*, 42-67.
- BUTLER, J., & ROVEE-COLLIER, C. (1989). Contextual gating of memory retrieval. *Developmental Psychobiology*, *22*, 533-552.
- CAMPBELL, B. A., & JAYNES, J. (1966). Reinstatement. *Psychological Review*, *73*, 478-480.
- CECI, S. J., ROSS, D. F., & TOGLIA, M. P. (1987a). Age differences in susceptibility: Narrowing the uncertainties. In S. J. Ceci, M. P. Toglia, & D. F. Ross (Eds.), *Children's eyewitness testimony* (pp. 79-91). New York: Springer-Verlag.
- CECI, S. J., ROSS, D. F., & TOGLIA, M. P. (1987b). Suggestibility of children's memory: Psycholegal implications. *Journal of Experimental Psychology: General*, *116*, 38-49.
- CECI, S. J., TOGLIA, M. P., & ROSS, D. F. (Eds.) (1987). *Children's eyewitness testimony*. New York: Springer-Verlag.
- CECI, S. J., TOGLIA, M. P., & ROSS, D. F. (1988). On remembering . . . more or less: A trace strength interpretation of developmental differences in suggestibility. *Journal of Experimental Psychology: General*, *117*, 201-203.
- CHANDLER, C. C. (1989). Specific retroactive interference in modified recognition tests: Evidence for an unknown cause of interference. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *15*, 256-265.
- CHANDLER, C. C. (1991). How memory for an event is influenced by related events: Interference in modified recognition tests. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *17*, 115-125.
- CHRISTIAANSEN, R. E., & OCHALEK, K. (1983). Editing misleading information from memory: Evidence for the coexistence of original and postevent information. *Memory & Cognition*, *11*, 467-475.
- DENT, H. R. (1991). Experimental studies of interviewing child witnesses. In J. Doris (Ed.), *The suggestibility of children's recollections*.

- tions: Implications for eyewitness testimony (pp. 138-146). Washington, DC: American Psychological Association.
- DORIS, J. (Ed.) (1991). *The suggestibility of children's recollections: Implications for eyewitness testimony*. Washington, DC: American Psychological Association.
- FAGEN, J. W., & ROVEE-COLLIER, C. (1983). Memory retrieval: A time-locked process in infancy. *Science*, **222**, 1349-1351.
- GOODMAN, G. S. (1984). Children's testimony in historical perspective. *Journal of Social Issues*, **40**, 9-32.
- GOODMAN, G. S., & CLARKE-STEWART, A. (1991). Suggestibility in children's testimony: Implications for sexual abuse investigations. In J. Doris (Ed.), *The suggestibility of children's recollections: Implications for eyewitness testimony* (pp. 92-105). Washington, DC: American Psychological Association.
- GRECO, C., HAYNE, H., & ROVEE-COLLIER, C. (1990). Roles of function, reminding, and variability in categorization by 3-month-old infants. *Journal of Experimental Psychology: Human Learning & Memory*, **16**, 617-633.
- HASHER, L., & GRIFFIN, M. J. (1978). Reconstructive and reproductive processes in memory. *Journal of Experimental Psychology: Human Learning & Memory*, **4**, 318-330.
- HAYNE, H. (1990). The effect of multiple reminders on long-term retention in human infants. *Developmental Psychobiology*, **23**, 453-477.
- HOVING, K. L., & CHOI, K. (1972). Some necessary conditions for producing reinstatement effects in children. *Developmental Psychology*, **6**, 214-217.
- HOVING, K. L., COATES, L., BERTUCCI, M., & RICCIO, D. C. (1972). Reinstatement effects in children. *Developmental Psychology*, **6**, 426-429.
- HOWE, M. L., COURAGE, M. L., & BRYANT-BROWN, L. (1993). Reinstating preschoolers' memories. *Developmental Psychology*, **29**, 854-869.
- LINDSAY, D. S. (1990). Misleading suggestions can impair eyewitnesses' ability to remember event details. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **16**, 1077-1083.
- LINDSAY, D. S. (in press). Memory source monitoring and eyewitness testimony. In D. F. Ross, J. D. Read, & M. P. Toglia (Eds.), *Adult eyewitness testimony: Current trends and developments*. New York: Cambridge University Press.
- LOFTUS, E. F. (1979). *Eyewitness testimony*. Cambridge, MA: Harvard University Press.
- LOFTUS, E. F. (1981). Mental morphosis: Alterations in memory produced by the mental bonding of new information to old. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 417-434). Hillsdale, NJ: Erlbaum.
- LOFTUS, E. F. (1991). Made in memory: Distortions in recollection after misleading information. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 27, pp. 187-215). Orlando, FL: Academic Press.
- LOFTUS, E. F., DONDERS, K., HOFFMAN, H. G., & SCHOOLER, J. W. (1989). Creating new memories that are quickly accessed and confidently held. *Memory & Cognition*, **17**, 607-616.
- LOFTUS, E. F., & HOFFMAN, H. G. (1989). Misinformation and memory: The creation of new memories. *Journal of Experimental Psychology: General*, **118**, 100-104.
- LOFTUS, E. F., & LOFTUS, G. R. (1980). On the permanence of stored information in the human brain. *American Psychologist*, **35**, 409-420.
- LOFTUS, E. F., MILLER, D. G., & BURNS, H. J. (1978). Semantic integration of verbal information into visual memory. *Journal of Experimental Psychology: Human Learning & Memory*, **4**, 19-31.
- MCCLOSKEY, M., & ZARAGOZA, M. (1985a). Misleading postevent information and memory for events: Arguments and evidence against memory impairment hypotheses. *Journal of Experimental Psychology: General*, **114**, 1-16.
- MCCLOSKEY, M., & ZARAGOZA, M. (1985b). Postevent information and memory: Reply to Loftus, Schooler, and Wagenaar. *Journal of Experimental Psychology: General*, **114**, 381-387.
- MUZZIO, I. A. (1994). *Integrating information with a prior memory: Timing effects*. Unpublished master's thesis, Rutgers University, New Brunswick, NJ.
- NELSON, K. (1986). Event knowledge and cognitive development. In K. Nelson (Ed.), *Event knowledge: Structure and function in development* (pp. 1-19). Hillsdale, NJ: Erlbaum.
- OHR, P. S., FLECKENSTEIN, L. K., FAGEN, J. W., KLEIN, S. J., & PIOLI, L. M. (1990). Crying-produced forgetting in infants: A contextual analysis. *Infant Behavior & Development*, **13**, 305-320.
- PETERS, D. P. (1991). The influence of stress and arousal on the child witness. In J. Doris (Ed.), *The suggestibility of children's recollections: Implications for eyewitness testimony* (pp. 60-76). Washington, DC: American Psychological Association.
- PIROLI, P. L., & MITTERER, J. O. (1984). The effect of leading questions on prior memory: Evidence for the coexistence of inconsistent memory traces. *Canadian Journal of Psychology*, **38**, 135-141.
- REYNA, V. F. (in press). Interference effects in memory and reasoning: A fuzzy-trace theory analysis. In F. N. Dempster & C. J. Brainerd (Eds.), *New perspectives on interference and inhibition processes in cognition*. San Diego, CA: Academic Press.
- REYNA, V. F., & BRAINERD, C. J. (1991). Fuzzy-trace theory and children's acquisition of mathematical and scientific concepts. *Learning & Individual Differences*, **3**, 27-59.
- ROVEE, C. K., & ROVEE, D. T. (1969). Conjugate reinforcement of infant exploratory behavior. *Journal of Experimental Child Psychology*, **8**, 33-39.
- ROVEE-COLLIER, C., BORZA, M. A., ADLER, S. A., & BOLLER, K. (1993). Infants' eyewitness testimony: Effects of postevent information on a prior memory representation. *Memory & Cognition*, **21**, 267-279.
- ROVEE-COLLIER, C., GRECO-VIGORITO, C., & HAYNE, H. (1993). The time window hypothesis: Implications for categorization and memory modification. *Infant Behavior & Development*, **16**, 149-176.
- ROVEE-COLLIER, C., & HAYNE, H. (1987). Reactivation of infant memory: Implications for cognitive development. In H. W. Reese (Ed.), *Advances in child development and behavior* (Vol. 20, pp. 185-238). New York: Academic Press.
- ROVEE-COLLIER, C., PATTERSON, J., & HAYNE, H. (1985). Specificity in the reactivation of infant memory. *Developmental Psychobiology*, **18**, 559-574.
- ROVEE-COLLIER, C., & SULLIVAN, M. W. (1980). Organization of infant memory. *Journal of Experimental Psychology: Human Learning & Memory*, **6**, 798-807.
- ROVEE-COLLIER, C., SULLIVAN, M. W., ENRIGHT, M., LUCAS, D., & FAGEN, J. W. (1980). Reactivation of infant memory. *Science*, **208**, 1159-1161.
- SPEAR, N. E. (1971). Forgetting as a retrieval failure. In W. K. Honig & P. H. R. James (Eds.), *Animal memory* (pp. 45-109). New York: Academic Press.
- SPEAR, N. E. (1973). Retrieval of memory in animals. *Psychological Review*, **80**, 163-194.
- SPEAR, N. E., & PARSONS, P. J. (1976). Analysis of a reactivation treatment: Ontogenetic determinants of alleviated forgetting. In D. L. Medin, W. A. Roberts, & R. T. Davis (Eds.), *Processes of animal memory* (pp. 135-165). Hillsdale, NJ: Erlbaum.
- SULLIVAN, M. W. (1982). Reactivation: Priming forgotten memories in human infants. *Child Development*, **53**, 516-523.
- SULLIVAN, M. W., ROVEE-COLLIER, C., & TYNES, D. (1979). A conditioning analysis of infant memory. *Child Development*, **50**, 152-162.
- TVERSKY, B., & TUCHEN, M. (1989). A reconciliation of the evidence on eyewitness testimony: Comments on McCloskey and Zaragoza (1985). *Journal of Experimental Psychology: General*, **118**, 86-91.
- ZARAGOZA, M. A. (1987). Memory, suggestibility, and eyewitness testimony in children and adults. In S. J. Ceci, M. P. Toglia, & D. F. Ross (Eds.), *Children's eyewitness testimony* (pp. 53-78). New York: Springer-Verlag.
- ZARAGOZA, M. A. (1991). Preschool children's susceptibility to memory impairment. In J. Doris (Ed.), *The suggestibility of children's recollections: Implications for eyewitness testimony* (pp. 27-39). Washington, DC: American Psychological Association.