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Brief report

# Odor as a contextual cue in memory reactivation in young infants

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ABSTRACT

Three-month-old infants were trained to move a mobile in the presence of a coconut or cherry odor (context). Six days later, a reactivation session took place. Infants were randomly assigned to 4 groups (same odor during training and reactivation, different odor during training and reactivation, no odor present during reactivation, no reactivation). A retention test was conducted 24 h later in the presence of the training odor and mobile. Retention was seen only in the group of infants trained and reactivated with the same odor. This indicates that olfactory contextual cues function in a similar manner to visual and auditory contextual cues in that a novel context, or the absence of the context in which the memory was formed, are ineffective as reminders once the original memory has been forgotten.



One of the primary difficulties in assessing memory development in the earliest weeks and months of life is that infants are in the preverbal stages of development. As such, the process of acquisition and retention of information must be inferred from measurements calculated from basic behavioral observations (Rovee-Collier, 1996). One technique often used to conduct such behavior-based studies of learning and memory is the mobile conjugate reinforcement task. In this task, a ribbon is attached from the ankle of the infant to an overhead crib mobile. The infant is reinforced for kicking through the contingent movement of the mobile; movement that varies in direct proportion to the frequency and force of kicking (conjugate reinforcement). Once learning has occurred, retention may be assessed. For example, after two training sessions, 24 h apart, 3-month-old infants demonstrated retention at intervals of up to 8 days (Sullivan, Rovee-Collier, & Tynes, 1979). But, like adults, infants forget, which in this paradigm means that after a period, they no longer exhibit the high rate of kicking characteristic of learning but their kick rate returns to where it was before they learned the task. Their forgetting is not permanent, however. Research by Rovee-Collier et al. (e.g., Rovee-Collier, Sullivan, Lucas, Enright, & Fagen, 1980) has revealed that a brief, noncontingent re-exposure to the moving mobile (a reactivation treatment) can alleviate forgetting.

In addition to its usefulness for studying simple learning and forgetting, the mobile conjugate reinforcement task has furthered our knowledge of some of the variables that affect infants' memories. One of the factors that has been considered is the role context plays in the retention of information. Context refers to stimuli that are present during learning but are incidental to the target material (Baddley, 1982). Examples of contextual cues in the mobile task would be colors and shapes presented on bumpers that surround the inside of an infant's crib, or sounds or odors present in the infant's surroundings as the infant learns the task.

Research with 3-month-old infants by Rovee-Collier et al. (e.g., Rovee-Collier, Griesler, & Earley, 1985) using distinctive crib bumpers as the context, and by Fagen and colleagues (e.g., Fagen et al., 1997) using music as the context, has found that at short retention intervals such as 1 day after 2 days of training, a change in the visual or auditory context does not disrupt retention. At longer intervals such as 5 or 7 days, however, changing the crib bumpers or the music disrupts retention of the

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task. Three-month-old infants similarly trained but without any distinctive context present show retention at both of these intervals (Sullivan et al., 1979).

The findings with both visual and auditory context cues are consistent with what Butler and Rovee-Collier (1989) proposed in their hierarchical attention-gating hypothesis. According to this model of the retrieval process, context serves as an initial attention gate to retrieve the memory of the mobile task at long retention intervals when retrieval has become increasingly difficult due to the normal forgetting of the details of the mobile (e.g., Rovee-Collier & Sullivan, 1980). A perceptual match between the context present during the retrieval test and the stored attributes of that context opens the first gate, "allowing its memory representation to enter a short-term or active memory store, and the gate then closes" (Butler & Rovee-Collier, p. 545) Attention is then directed at the mobile (the focal cue) and if its cues (objects) match the stored memory attributes of the training mobile, its memory representation enters the short-term/active store. "Activation of the memory representation of the cue is prerequisite for accessing the subject's memory of the contingency (or response requirement) and enabling the response to be made. If the context is novel and the first gate does not open, the retrieval process is aborted at that point" (Butler & Rovee-Collier, p. 545). In other words, changes in either the context (crib bumpers, music) or the cue (the mobile) will lead to a failure to detect the appropriate retrieval cues, and the memory will not be retrieved.

The above research focused on visual and auditory context; the present research focused on olfactory context (see also Rubin, Fagen, & Carroll, 1998). Schroers, Prigot, and Fagen (2007) trained infants for 2 days in the presence of a coconut or cherry odor that had been infused into the infant's bedroom. Consistent with the research using visual and auditory contexts, they found that retention was observed at 1 and 5 days when the infants were exposed to the same odor during both training and the retention test. However, unlike the findings with visual or auditory contexts, the infants failed to exhibit retention at both intervals when either a novel odor (i.e., the one not exposed to during training) or no odor were present during the retention test. Although different from the results with visual and auditory contextual cues, overall these results indicate that odors can serve as necessary contextual cues for initiating memory retrieval (cf. Rubin et al., 1998).

In the present study, we focused on the 5-day forgetting observed by Schroers et al. (2007), but extended it to 7 days and asked if it could be alleviated with a reactivation treatment (Rovee-Collier, 1996; Rovee-Collier et al., 1980). To test this hypothesis, infants were exposed to the same odor, a novel odor, or no odor in a reactivation session 6 days following training in the mobile conjugate reinforcement task. This session lasted only 3 min and was accompanied by the moving mobile; however, the mobile was moved by the experimenter and not the infant so that its movement was noncontingent with the infant's kicking. The re-exposure to the training odor along with the moving mobile was designed to serve as a reactivation cue to enhance recollection of the learned contingency. Presentation of the moving mobile in the presence of either the novel odor or no odor during the reactivation session was not expected to lead to retention due to the absence of the training context.

The retention test session was conducted 24 h after reactivation (i.e., 7 days after training). It was procedurally identical to the first training session; that is, it contained a 3-min phase when the mobile was in view but could not be moved by the infant, 9 min when the infant could move the mobile by kicking, and a final 3-min period when the mobile was again unresponsive to the infant's kicks. The training odor was also present.

Forty-nine 3-month-old infants (23 males, 26 females) were recruited for participation in this study (mean age = 101 days; mean birth weight = 3218.52 g). Infants were randomly assigned to one of four groups. One group was presented with the same odor during both training and reactivation (cherry/cherry or coconut/coconut), one group was presented with a different odor during training and reactivation (cherry/coconut or coconut/cherry), one group received no odor during the reactivation session, despite having been presented with the odor during training (cherry/no odor or coconut/no odor), and a final group, trained with either the cherry or coconut odor, did not receive the reactivation session. This final group served as a control condition to determine whether reactivation, regardless of odor as a contextual cue, is necessary for the retention of the learned contingency. All infants were trained and tested in the presence of one of two mobiles, each consisting of five wooden objects that were brightly painted as either clowns or zoo animals. Assignment to these mobile conditions was random.

The odors used in this study were circulated throughout the infant's room using an aromatic diffuser (AromaSys, Inc., Minneapolis, MN). The diffuser was placed in or near the crib or bassinet, outside of the infant's line of vision. Two cartridges were prepared, containing a solution of 70% liquid fragrance of either cherry or coconut and 30% 190-proof grain alcohol. Ten minutes prior to the start of each session, one of the two cartridges was inserted into the diffuser and allowed to diffuse throughout the infant's room. At the completion of each session, all parents were asked to wait approximately 60 min before returning the infant to the nursery in order to minimize the infant's exposure to the olfactory context independent of the mobile task.

The standard measure of retention/forgetting in the mobile conjugate reinforcement task is the Baseline Ratio which is calculated by dividing an infant's number of kicks during the first 3 min of the retention test session, when the infant cannot move the mobile, by that infant's pretraining baseline response rate (the first 3 min of the first training session). Retention is inferred when a group has an average baseline ratio greater than 1.00 which indicates that performance has remained above baseline following the retention interval (Rovee-Collier, 1996). When a group's baseline ratio is significantly greater than 1.00, a second measure, the Retention Ratio, is calculated. The retention ratio indicates whether a group's retention was complete or partial. Complete retention is evidence when the response rate at the outset of the retention session is not different from the rate at the end of training. In partial retention, the response rate has declined between the end of training and the outset of the retention test session while still remaining above baseline (Rovee-Collier, 1996). The retention

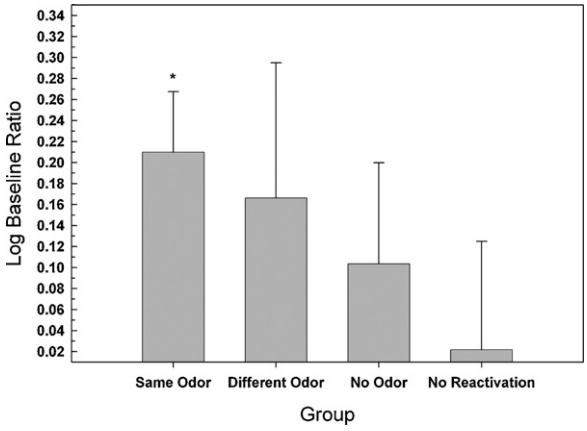


**Fig. 1.** Mean log baseline ratios for infants exposed to the same odor during training and reactivation, a different odor, or no odor. The group labeled no reactivation did not receive the reactivation treatment. Only the group reactivated with the same odor had a mean log baseline ratio significantly above 0, indicated by the asterisk, which reflects retention. Vertical bars represent one standard error.

ratio is calculated by dividing each infant's response rate during the first 3 min of the retention test session by that infant's number of kicks during the last 3 min of the second training session. Complete retention is inferred when a group's baseline ratio is significantly greater than 1.00 and its retention ratio is not significantly less than 1.00 (i.e., a response rate above baseline and not below the end of training). Partial retention is defined by a baseline ratio significantly greater than 1.00 with a retention ratio significantly less than 1.00 (Rovee-Collier, Adler, & Borza, 1994).

The baseline ratios were positively skewed. To correct for this, they were logarithmically transformed prior to analysis. Studies of retention that use the mobile conjugate reinforcement paradigm use a series of directional *t*-tests to compare each group's baseline ratio to a value of 1.00 (resulting from a response rate that has returned to baseline). Because a log transformation was used, the value to which the baseline ratio was compared was 0.00 ($\log 1 = 0$). As hypothesized, a log baseline ratio significantly above 0.00 was obtained only for the same odor condition, $t(11) = 3.64$, $p = .004$ (see Fig. 1). The mean retention ratio for the same-odor group was 1.06, a value not different from 1.00, indicating complete retention of the learned contingency.

One of the key assumptions of the effectiveness of the reactivation procedure is its similarity to the original contextual cues present during acquisition. Consistent with the attention-gating hypothesis, the presence of a novel cue or context is considered to be completely ineffective as a reminder once the original memory has been forgotten, preventing the reactivation of the memory and resulting in a failure to retrieve the memory for the learned contingency (Rovee-Collier et al., 1994). The results of this study clearly support this assumption.

Rovee-Collier and Hayne (1987) argued that the locus of the encoding-specificity effect (Thomson & Tulving, 1973) is the reminder (reactivation). The presence of a similar but more generalized contextual cue (e.g., an odor, but of a different scent; crib bumpers with different colors and patterns; classical vs. jazz music) is not sufficient for reactivating the encoded memory. Instead, the effectiveness of a reminder is very specific to what was encoded during the initial acquisition process.

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