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The Effect of a Salient Odor Context on Memory Retrieval 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). 1 or 5 days later, the infants were tested for retrieval in the presence of either the same odor, the alternate odor, or no odor. Infants tested with the training odor displayed retention at both intervals; retention was not seen at either interval in the alternate odor or no odor conditions. These data suggest that the odor combines with the mobile to form a compound-stimulus representation of the learned task whose presence after both short (1 day) and long (5 days) intervals is a necessary retrieval cue.

Keywords

Memory; Context; Olfaction

The pioneering research of Rovee-Collier and her associates has revealed that young infants' memories are affected by several variables including the amount and distribution of training, serial position, and post-event information (for review, see Rovee-Collier, Hayne, & Colombo, 2001). This research has used the mobile conjugate reinforcement paradigm in which an infant learns to move an overhead crib mobile by kicking one of his or her feet and is returned to the experimental situation days or weeks later. Similar results have been reported with the deferred imitation paradigm in which the infant observes the experimenter demonstrate a novel action on an unfamiliar object and the infant's ability to reproduce the action is assessed after a delay (for review, see Hayne, 2004; Rovee-Collier et al., 2001). As noted by Rovee-Collier (1997; Rovee-Collier et al., 2001), the similarity in the findings from these two paradigms has important implications for theories of memory development that posit the existence of two distinct memory systems (declarative, procedural/nondeclarative) with different developmental trajectories: If there are two distinct memory systems, they are both present in early infancy and they develop in parallel.

One additional independent variable that has received attention by infant memory researchers is context. As defined by Baddeley (1982), context refers to the stimuli that are present when a memory is acquired but which are incidental to the material being learned (e.g., the stimuli present in the room in which you are reading this). In spite of their irrelevance, these stimuli can exert functional control over behavior such that their presence may be a necessary condition for retrieval of the target information. Context is an important variable to study in young infants because of the widespread belief that context cues are involved in declarative but not

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nondeclarative memory. With the mobile conjugate reinforcement paradigm, researchers have found that changes in the visual (Rovee-Collier, Griesler, & Earley, 1985), auditory (Fagen et al., 1997), and olfactory (Rubin, Fagen, & Carroll, 1998) contexts between learning and memory testing can disrupt retrieval. Changes in visual context have also been found to disrupt deferred imitation (Hayne, Boniface, & Barr, 2000)

Rovee-Collier et al. (1985) conducted the first study of the effects of context on 3-month-old infants' memories for the mobile conjugate reinforcement task. Context was manipulated by training the infants in the presence of a distinctive crib bumper and then testing the infants with either the same bumper or a novel bumper 1 week later. Infants trained and tested with the same bumper remembered the association between kicking and mobile movement as evidenced by the maintenance of the above-baseline rate of kicking exhibited at the end of training. Infants trained and tested with a different bumper, however, displayed a kick rate during the 1-week retention test that was no different from what it had been during their pretraining baseline (i.e., forgetting). In a follow-up study, Butler and Rovee-Collier manipulated both the crib bumper and mobile used during training and retention tests given 1, 3, or 5 days later. Infants showed retention of the contingency when the same crib bumper and mobile were used during retention as during training at 1-, 3-, and 5-day intervals, but no retention if a different crib bumper and the same mobile were used at 3, and 5 days. Retention was not disrupted using a different crib bumper and the same mobile at the 1-day retention interval only. Regardless of which crib bumper was used, if a different mobile was present during the retention test there was no evidence of retention at any of the intervals.

Questions arise from this study's findings as to why changes in the crib bumper impaired memory retrieval when there was no predictive association between the crib bumper and the mobile movement, and also as to why changing the crib bumper affected retrieval only at the longer retention intervals. Butler and Rovee-Collier (1989) proposed that the crib bumper context functions as an "attention gate" to retrieve the memory representation of the mobile at longer retention intervals. At shorter retention intervals, the infants have access to the specific details of the mobile (see Rovee-Collier & Sullivan, 1980) and detection of effective retrieval cues in the mobile triggers retrieval of the contingency. At longer retention intervals, the details of the mobile have been forgotten. A change in either the context (bumper) or the nominal cue (mobile) will result in a failure to detect the appropriate cues and memory retrieval will be disrupted (see also Rovee-Collier & Shyi, 1992).

The effect of context changes on memory retrieval in young infants has also been studied using auditory context cues and the results have been similar to those reported with visual context cues. In two experiments, Fagen et al. (1997) found that infants trained in the mobile conjugate reinforcement paradigm with either classical or jazz music playing in the background failed to exhibit retention 7 days later if the music was changed. Changing the music after 1 day, however, had no effect. Taken together, it appears that as the infant's memory fades, the visual or auditory context of training is a necessary but not sufficient cue for retrieval of the memory of the contingency.

A change in the olfactory context between training and testing disrupts memory in 3-month-old infants in a manner different from visual and auditory context cues. Rubin et al. (1998) trained infants to move the mobile in the presence of either a floral (Lily-of-the-Valley) or woodsy (Douglas fir) odor. These odors were selected because they were judged to be pleasant, distinct from each other, and of similar intensity. The infants were tested 1, 3 or 5 days later in the presence of the training odor, a different odor, or no odor. The infants tested in the presence of the training odor exhibited retention at the 1-day interval whereas those tested with the novel odor did not. Partial retention was seen in the 1-day no odor group. Recall that changing the visual or auditory context after 1 day does not disrupt retrieval. At 3 and 5 days,

all groups, even the one exposed to the familiar training odor, displayed forgetting. Rubin et al. proposed that visual and auditory context cues may function as occasion setters (Holland, 1983), setting the stage for the occurrence of the contingency. The odor, however, may function differently by becoming associated with the nominal cue (the mobile) to form a compound stimulus (a “smelly mobile”). Rubin et al. presumed that the odor was rapidly forgotten such that even 1 day later the infant did not recognize the mobile as familiar when the odor was changed, just as exposing an infant to a novel mobile disrupts 1-day retention (Rovee & Fagen, 1976). Fagen, Carroll, Brennan, Bromberg, and Prigot (2000) found nearly identical 1-day results with 2-month-old infants who exhibited retention only when tested with the training odor and showed no retention when tested with a novel odor or no odor.

Before explanations that suggest that olfactory context functions differently from other sensory contexts in infancy can be adopted, a more parsimonious hypothesis needs to be explored. In the studies by Rubin et al. (1998), and Fagen et al. (2000), the odors of Lily-of-the-Valley (floral) and Douglas fir (woody) were used in testing olfactory context in relation to memory. There is a possibility that the findings using olfactory context with 2 and 3-month-olds are specific to the olfactory stimuli used, namely the floral or woody odors. As Rubin et al. (1998) pointed out, infants encounter a variety of odors during their daily lives, and it may be that retaining an association for every inconsequential odor would disorganize rather than organize their environment. Research has demonstrated that infants are especially sensitive to particular types of odors such as those associated with foods (Porter, Balogh, & Makin, 1988) and food-related odors have been used in memory experiments with young infants. For example, Davis and Porter (1991) found that female neonates exposed to cherry and ginger odors exhibited a preference for the familiar but not the novel odor when tested 1 hr after the exposure period, and they retained a memory of these odors for up to 2 weeks. Fernandez and Bahrack (1994) found that 4-month-old female infants but not males increased their looking to a target object that had previously been paired with a cherry odor when the object was presented with the cherry odor but not when it was presented in the absence of the odor. These studies suggest good memory for certain odors, and that prior experience with odors influences later infant behavioral responses.

The purpose of the present study was to determine if the use of sweet, food-related odors (cherry and coconut) as context cues would replicate the 1- and 5-day findings of Rubin et al. (1998, Experiment 1) in which non-nutritive plant fragrances were used, or if these odors would affect memory in a manner similar to the way visual and auditory context cues do. Forty-eight 3-month-old infants (24 males, 24 females) were randomly assigned to one of six groups ($n=8$ /group). These groups were defined by the relation between the odor present during the training sessions and the odor present during the testing session (same odor, different odor, or no odor), and the retention interval (1 or 5 days). Random assignment was constrained only by the requirement that an equal number of males and females be placed in each group. The data on an additional 19 infants were excluded due to continuous crying for 2 min during training ($n=6$), failing to exhibit an average operant baseline level between 2 and 32 kicks per min ($n=2$), falling asleep ($n=2$), failure to look at the mobile for at least 50% of the available time ($n=1$), or not meeting the standard learning criterion of 1.5 times that average baseline kick rate for 2 of 3 consecutive min ($n=8$). The infants were tested at home in their own cribs or bassinets.

The mobile conjugate reinforcement task uses two inverted L-shaped bars attached to opposite sides of the crib. The infant is placed supine in his or her crib or bassinet and a white ribbon is connected to one of these stands and one of the infant's ankles. During reinforcement periods, the mobile is suspended from the stand to which the ankle ribbon is attached (active stand), and the infant's kicking activates movement of the mobile by causing the bar to draw and

release. During periods of nonreinforcement, the ribbon is attached to the other stand (inactive stand) so that the infant's kicks do not move the mobile.

The odor was circulated throughout the infant's room using an aromatic diffuser (AromaSys Model EPA 1000B, Minneapolis, MN). The diffuser was placed in or very near the crib or bassinet, but outside the infant's line of vision. The control knob of the unit was set at 7 (moderate) during the task. Two cartridges were prepared containing a solution of 70% liquid fragrance of coconut or cherry and 30% 190 proof grain alcohol. The odors were allowed to diffuse throughout the infant's room beginning 10 min prior to the start of each session and continuously throughout the session. Parents were asked to turn off any air-conditioners, fans, or portable heating units in the room during the testing period. Following each session, the parent was asked to wait at least 60 min before returning the infant to the nursery to minimize exposure to the olfactory context independent of the mobile task.

There were two training sessions, 24 hr apart. During training, the infants were exposed to either the cherry odor or the coconut odor. Half the infants were exposed to the coconut odor and half were exposed to the cherry odor during sessions 1 and 2. The infant was also randomly assigned to one of two mobiles, with either an animal or a clown theme. Each training session began with a 3-min nonreinforcement period during which the mobile was suspended from the inactive stand; in Session 1 this served as a measure of each infant's kick-rate baseline. Next, the mobile was switched to the active stand for 9 min so that when the infant kicked, the mobile moved. Finally, each training session ended with a 3-min nonreinforcement period. At the end of the second day of training, this nonreinforced period served as an immediate retention test of the infant's performance. The 1- or 5-day retention test session was identical in procedure to a training session. The infants were randomly tested in one of three conditions for each retention interval: (a) infants trained and tested with the same odor, (b) infants trained with one odor and tested with a different odor, and (c) infants trained with one odor and tested with no odor. A trained observer recorded the number of times per minute the infant moved the foot to which the ribbon was attached.

Retention of the contingency was assessed by calculating two standard measures (see Rovee-Collier, 1996). The Baseline Ratio, which is the primary measure of retention, was calculated by dividing the number of kicks during the 3-min nonreinforced period at the start of the 1- or 5-day retention test session by the number of kicks during baseline (initial nonreinforced period at the start of the first training session). This reflects the extent to which the infant's response rate following a retention interval continued to exceed his or her baseline rate. Retention is operationally defined as a baseline ratio > 1.00 . The Retention Ratio, which indicates the degree of retention, was calculated by dividing the number of kicks during nonreinforced 3-min period at the outset of the retention test session by the number of kicks during the final nonreinforced 3-min. period at the end of training. Retention ratios ≥ 1.00 indicate that no forgetting has occurred during the retention interval; ratios < 1.00 indicate impaired retention. A group with a baseline ratio significantly greater than 1.00 but a retention ratio significantly less than 1.00 is said to have demonstrated partial retention (retention is present but impaired). Retention ratios are interpretable only if significant retention is demonstrated by the primary measure of retention, the baseline ratio (Rovee-Collier, 1996).

Consistent with previous studies (e.g. Rubin et al., 1998), the baseline and retention ratios were positively skewed necessitating a logarithmic transformation prior to analysis. Six directional t -tests were then conducted which compared the mean log baseline ratio of each group to 0, which would indicate a return to the pretraining operant level ($\log 1=0$). The t -test results demonstrate if a group has remembered the learned contingency (see Figure 1). At the 1-day retention interval, a log baseline ratio significantly greater than 0 was obtained for the same odor group, $t(7) = 2.84$, $p = .025$, but not for the different odor or no odor groups. At the 5-

day retention interval, a log baseline ratio significantly greater than 0 was also obtained for the same odor group, $t(7) = 2.57$, $p = .037$, but not for the different odor or no odor groups. This indicates that for infants tested with either a different odor or no odor, regardless if tested 1-day or 5-days later, responding returned to its pretraining level. The finding of retention in the 5-day, same odor group differs from that obtained by Rubin et al. (1998) who found that responding for all odor groups tested after a 5-day retention interval returned to their pretraining levels. Finally, the analyses of the log-transformed retention ratios of the 1- and 5-day same odor groups indicated that their mean log retention ratios of $-.07$ and $-.13$, respectively, did not differ significantly from 0, indicating that their retention was complete (i.e., there was no change in responding from the end of training to the retention test) and not partial.

The hypothesis that repeating the Rubin et al. (1998, Experiment 1) procedure with cherry or coconut odors, which are sweet, food-related fragrances, would yield results parallel to those obtained when visual or auditory context cues are used was not supported by these results: a change in the odor disrupted retention even at the 1-day retention interval. Furthermore, contrary to the findings of Rubin et al., infants in the 1-day no odor group demonstrated forgetting rather than partial retention, and infants in the 5-day same odor group displayed retention rather than forgetting. Taken together, we believe that these results support the second hypothesis of the present study that the infants would find the food-related odors more salient than the non-food related odors used by Rubin et al., and they extend the Rubin et al. conclusion that unlike visual or auditory background stimuli, odor does not function as a contextual cue or an occasion setter for the young infant. Rather, it becomes an integral part of the infant's memory for the mobile itself (i.e., the mobile and the odor form a compound stimulus). Thus, at both 1 and 5 days, when the infant was presented with the familiar mobile without the familiar odor, retrieval failed (cf. Rovee-Collier & Sullivan, 1980 who found that in a neutral context, 3-month-old infants responded to a novel test mobile 4 days after training but not 1 day after training). To explain their 5-day finding of no retention in any group, Rubin et al. hypothesized that odor memories are rapidly forgotten by young infants such that at 5 days their infant's failed to recognize the mobile as something they could move by kicking because they had forgotten the odor part of the compound stimulus, a necessary retrieval cue. That forgetting did not happen in the present study because the odors were more salient and therefore not forgotten at 5 days.

Finally, why does odor becomes a more integral part of the infant's experience than a colorful crib bumper or a selection of jazz or classical music? It is well established that "olfactory sensory neurons are the only true neurons in direct contact with the environment" (Zelano & Sobel, 2005, p. 435). Furthermore, "the neuroanatomical projections to and from the olfactory cortex and the intrinsic links with circuits known to mediate episodic memory" (Chu & Downes, 2002, p. 517) are different from those in other sensory modalities (see also Herz, Eliassen, Beland, & Souza, 2004). Chu and Downes (2002) proposed "*the differential cue affordance hypothesis*" (p. 512, italics original) and found support for the hypothesis that olfactory cues have higher affordance values compared with other types of cues. These neuroanatomical and psychological differences may explain the modality differences observed when olfactory stimuli are used in the mobile conjugate reinforcement paradigm as compared to auditory and visual stimuli.

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Figure 1.

Mean log baseline ratios for infants tested in the presence of the same/different/no odor after a retention interval of 1 or 5 days. Ratios significantly above the theoretical log baseline value of 0, indicated by an asterisk, reflect retention. Vertical lines indicate 1 standard error.