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# A Dissociation in Infants' Memory for Stimulus Size: Evidence for the Early Development of Multiple Memory Systems

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**ABSTRACT:** Adults' memory performance on recognition (explicit memory) tests is sensitive to stimulus size, but their performance on priming (implicit memory) tests is not. This memory dissociation is taken as evidence for two, functionally distinct memory systems. Young infants, however, are thought to possess only a single representational system that supports implicit memory; the system that supports explicit memory is thought not to mature before 8–9 months of age. In two experiments with 54 infants, we asked if 3-month-olds exhibit a memory dissociation for stimulus size on recognition and priming tests. All infants learned to move a mobile displaying +s of a given size. In Experiment 1, infants recognized +s in the original size but not 33% smaller or larger. In Experiment 2, +s were effective memory primes in a reactivation task, irrespective of size. The finding that young infants exhibit a memory dissociation for stimulus size adds to growing evidence that two memory systems are functional from early in development. © 2000 John Wiley & Sons, Inc. *Dev Psychobiol* 36: 123–135, 2000

**Keywords:** infant size perception; reactivation; memory development; visual perception

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Objects in the physical world cannot be perceived independent of their size, and information about object size is apparently encoded as a separable attribute in the memory representation. Whether that information is retrieved and used on a subsequent occasion, however, depends on the task at hand (Biederman & E. Cooper, 1992; L. Cooper, Schacter, Ballesteros, & Moore, 1992; Ungerleider & Mishkin, 1982). Biederman and E. Cooper (1992), for example, presented adults with a set of line drawings of common objects

and asked them to identify the objects. Adults who performed a same/different recognition task following their first exposure were slower to recognize previously viewed objects that were larger or smaller than previously viewed objects whose size was unchanged. On a repetition priming task, however, adults' naming latencies were faster whether the size of the previously viewed objects was the same or different. Biederman and E. Cooper interpreted these findings as evidence that separate memory systems—one size-sensitive and one size-insensitive—were tapped by the two different tasks.

L. Cooper et al. (1992) obtained similar results us-

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ing line drawings of unfamiliar objects, some of which could actually exist in three-dimensional space (“possible objects”) and some of which could not (“impossible objects”). Adults judged the direction that each object faced on its first exposure and, following a delay, received either a recognition test (old/new judgment) or a priming (possible/impossible object decision) test. The size of the objects was manipulated between the first and second exposures. They found that adults’ latency to recognize old objects at a new size was substantially slower than their latency to recognize old objects at their original size. Adults’ performance on the object decision task, however, was not sensitive to a change in size. They exhibited equal priming whether the size of the possible objects was changed or not, although impossible objects showed no priming effect. Like Biederman and E. Cooper, L. Cooper et al. attributed this dissociation in adults’ memory performance on the recognition and object decision (priming) tasks to two, functionally distinct memory systems, one that supports explicit memory (the size-sensitive system) and one that supports implicit memory (the size-insensitive system).

A number of researchers have examined infants’ ability to perceive size (Bower, 1966; Day & McKenzie, 1981; Fantz & Fagan, 1975; Granrud, Haake, & Yonas, 1985; McKenzie, Tootell, & Day, 1980; Skouteris, McKenzie, & Day, 1992). Using a habituation/discrimination task, for example, McKenzie and colleagues (Day & McKenzie, 1981; McKenzie et al., 1980) found that infants could perceive an object’s true size by 4½ months of age. Using a reaching task, Granrud et al. (1985) subsequently found that 7-month-olds were sensitive to familiar size, but 5-month-olds were not. They concluded that the representation of object size in infancy was not present prior to the appearance of binocular vision.

Subsequently, however, Slater, Mattock, and Brown (1990) reported that newborns who were familiarized with a cube of a single size at different distances looked longer at a test cube of a different (distal) size. This result was obtained despite the fact that the two test cubes were equated for (proximal) retinal image size. Slater et al. concluded that newborns possess the ability to compute size constancy. To demonstrate size constancy, however, newborns must have encoded the actual (distal) size of the object, meaning that a size-sensitive representational system must be functional early in life. Data consistent with this interpretation were obtained by Adler and Rovee-Collier (1994), who found that 3-month-olds failed to recognize a test mobile 24 hr after training in an operant task if it displayed Ls that were 25% smaller than the Ls that had been displayed on the training mobile. Be-

cause this result was part of a control manipulation in the service of another experimental question, however, the control groups necessary to confirm this conclusion were not tested, nor were the groups necessary to resolve whether 3-month-olds also possess a functional, size-insensitive representational system.

In the present study, we asked whether 3-month-olds, like adults, possess two memory systems—one that is size-sensitive and one that is not. Following the experimental approach previously used with adults, we assessed infants’ sensitivity to a size change using the same stimuli in a delayed recognition task (Experiment 1) and in a priming task (Experiment 2). If both memory systems are functional by 3 months of age, then infants should exhibit a task-specific dissociation, detecting a size change in the recognition task but not in the priming task.

Before proceeding, we should explain the rationale underlying the mobile procedure. Because prelinguistic infants lack a verbal response to tell us what they do and do not recognize, we provide them with a motoric one. To this end, we initially train infants to kick to move a crib mobile that displays the target stimuli. Later, we test infants with a mobile that displays stimuli which are either the same as or different from those on the training mobile. Infants “tell” us if they perceive the stimuli on the test mobile as the same or different by their kicking behavior. If they kick significantly above baseline, then they are saying “yes” or “same;” if they do not kick above baseline, then they are saying “no” or “different.” We have repeatedly found that 3-month-olds whose test mobile is the same as the training mobile exhibit near-perfect retention for several days after training but discriminate if a test mobile differs from the training mobile over this same period.

## EXPERIMENT 1: DELAYED RECOGNITION TASK

Infants’ ability to recognize stimulus size was assessed by training them with a mobile displaying +s in a particular size and giving them a delayed recognition test 24 hr later with a mobile displaying +s that were either 33% larger or smaller. Because 3-month-olds continue to recognize a + mobile for at least 1 week after training (Adler & Rovee-Collier, 1994), testing them with a mobile that displayed +s in either the same or a different size only 1 day after training was tantamount to asking “Is this mobile the same as your training mobile or is it different?” Were infants to recognize the test stimuli in their original size but not when their size was different, then we would conclude that they had encoded the size of the original stimuli

and discriminated a change in size during the delayed recognition test. This result, in turn, would be taken as evidence that 3-month-olds possess a functional size-sensitive memory system.

## Method

**Participants.** Infants were twenty-four 3-month-olds (8 males, 16 females) with a mean age of 95.0 days ( $SD = 10.1$ ) on their first day of training. They were recruited from birth announcements published in local newspapers and by word-of-mouth and were randomly assigned to test groups as they became available for study. Infants were Asian ( $n = 1$ ), Hispanic ( $n = 2$ ), Caucasian ( $n = 20$ ), and Other ( $n = 1$ ). Their parents' mean socioeconomic index (Nakao & Treas, 1992) was 63.9 ( $SD = 19.9$ ), and their mean educational attainment was 14.9 years ( $SD = 1.8$ ). Additional infants were dropped from the final sample for either crying longer than 2 consecutive min ( $n = 9$ ) or falling asleep ( $n = 1$ ) in any of the three sessions, or failing to meet the learning criterion (responding 1.5 times above operant level in 2 of any 3 consecutive min of

an acquisition phase;  $n = 1$ ). This level of attrition is typical of multisession studies in which each infant has several opportunities to be lost from the sample (e.g., Greco, Hayne, & Rovee-Collier, 1990).

**Apparatus and Stimuli.** Mobiles were composed of seven pink disks, each of which displayed a pair of computer-generated black bars arranged as a + on both sides (see Figures 1a and 1b). All disks on a given mobile were either 3 in. or 4 in. (diameter), and the dimensions of the crossed bars were either  $1.00 \times 0.25$  in. (small +s) or  $1.33 \times 0.33$  in. (large +s). When the mobile was suspended 9 in. above the infant's upper abdomen, the disks and +s subtended a visual angle of approximately 18.5 degrees (3-in. disk), 24 degrees (4-in. disk), 6.3 degrees (small +), and 8.4 degrees (large +). These stimuli were slightly larger than the stimuli used by Biederman and E. Cooper (1992) in order to compensate for any maturational deficiency in visual acuity.

The mobile was hung from one of two L-shaped metal stands (BCS, South Plainfield, NJ) that were clamped to opposite rails of the infant's home crib.



**FIGURE 1** (a) The experimental arrangement during a delayed recognition test with a 3-month-old (Experiment 1). Note that the ribbon is connected to the empty stand, preventing the infant from activating the mobile during the test. (b) The experimental arrangement during priming (reactivation) with a 3-month-old (Experiment 2). Here, the ribbon is not connected to the infant's ankle, preventing the infant from moving the mobile by kicking.

During reinforcement periods, a white ribbon connected one of the infant's ankles to the same hook as the mobile. This arrangement allowed the infant's kicks to move the mobile in a manner commensurate with the rate and vigor of kicking ("conjugate reinforcement"). During nonreinforcement periods, the ankle ribbon was connected to the empty mobile hook. In this arrangement, the infant could see the mobile but kicks could not move it.

**Procedure.** Infants were trained and tested in their homes during a typical play period. This time varied among infants but remained relatively constant across sessions for a given infant. All infants received a 15-min training session on each of 2 consecutive days and a 3-min delayed recognition test 24 hr later.

Each training session began with a 3-min nonreinforcement period. In Session 1, this was the *baseline phase*, when the mean kicks per min defined the infant's base rate of unlearned activity (operant level). Next followed a 9-min reinforcement period (*acquisition*), when kicks moved the mobile. Finally, each session ended with another 3-min nonreinforcement period. In Session 2, this was the *immediate retention test*, when the infant's final level of learning and retention after zero delay was measured. Twenty-four hours later, infants received a *long-term retention test* during another 3-min nonreinforcement period (see Figure 1a), when the infant's rate of responding to the test mobile was measured. Following the long-term test, reinforcement was reintroduced as a control procedure to insure that any infants who had responded poorly during the test were not ill, fatigued, or unmotivated on that particular day. None were.

During all sessions, an experimenter stood out of the infant's direct line of sight and recorded the number of kicks per min of the foot with the attached ribbon. Kicks were defined as any upwards or sideways excursion of the foot that at least partially retraced its original path in a smooth and continuous motion (Rovee & Rovee, 1969). A naive observer, blind with respect to the experimental design and hypotheses, independently recorded kicks for 171 min during 12 randomly selected sessions of 7 infants in Experiments 1 and 2. A Pearson product-moment correlation, computed over the joint response counts per min, yielded an interobserver reliability coefficient of 0.93.

**Design.** Infants were randomly assigned to four groups ( $n = 6$ ). Infants in the *no size-change* group were trained and tested with exactly the same disks (3-in) and +s (half small, half large). Within each of the remaining groups, the training and test combinations were counterbalanced. The *symbol size-change* group

was trained with small +s on 3-in. disks and was tested with large +s on 3-in. disks (and vice versa). The *disk size-change* group was trained with small +s on 3-in. disks and was tested with small +s on 4-in. disks (and vice versa). This group was included to qualify the basis for the expected size discrimination by the symbol size-change group, that is, whether the proportion of figure to ground contributed to the perceived size difference from training to testing. The *both size-change* control group was trained with small +s on 3-in. disks and was tested with large +s on 4-in. disks (and vice versa). This group was included to insure that infants' expected size discrimination was not based on a perceived differences in the overall brightness of the training and test disks.

## Retention Measures

Retention was assessed in terms of two measures that we have used in all previous studies of infant memory (Rovee-Collier, 1996; Rovee-Collier & Gerhardstein, 1997). The primary measure, the *baseline ratio* (LRT/B), reflects the extent to which an infant's rate of learned responding during the long-term test (LRT) exceeded that same infant's rate of unlearned responding, or operant level, during the baseline phase (B). Therefore, a mean baseline ratio significantly greater than the theoretical population baseline ratio of 1.00 indicates that a group continued to respond significantly above its pretraining rate after a substantial retention interval (i.e., the group exhibited significant retention). A mean baseline ratio not significantly greater than 1.00, however, indicates that a group's rate of learned responding during the long-term test could not be distinguished from its pretraining rate of unlearned responding (i.e., the group exhibited no retention).

The second measure, the *retention ratio* (LRT/IRT), expresses each infant's kick rate during the LRT as a fraction of that same infant's kick rate at the very end of training, during the immediate retention test (IRT). This measure provides information about the degree of forgetting by groups that exhibited retention in the first place. It assumes that forgetting takes place gradually over the retention interval, such that the level of learned performance will progressively decline as the time between the end of training and testing increases—an assumption that we have repeatedly validated (Adler, Gerhardstein, & Rovee-Collier, 1998; Hayne, 1990; Sullivan, Rovee-Collier, & Tynes, 1979). A mean retention ratio significantly less than a theoretical population retention ratio of 1.00 indicates significant discrimination or forgetting, depending on whether the delay is short or long, respectively. Con-

versely, a mean retention ratio not significantly less than 1.00 indicates that the group's memory performance after a delay was as strong as it was after no delay. Because baseline ratios not significantly greater than 1.00 typically are accompanied by retention ratios significantly less than 1.00 (i.e., both ratios indicate no retention), conclusions regarding long-term retention are always based on the *joint* analysis of these two ratios. This practice safeguards against accepting conclusions based on the null hypothesis.

## Results and Discussion

Separate one-way analyses of variance (ANOVAs) over infants' absolute kick rates during the baseline and immediate retention test phases indicated that the four groups did not differ either before training,  $F(3, 20) < 1$ , or afterward,  $F(3, 20) = 1.14$ , n.s. (see Table 1). Thus, any subsequent differences in their retention could not be attributed to differences in unlearned activity or final level of learning, respectively.

An outlier data correction procedure was applied prior to analyses of all baseline and retention ratios. Scores falling above or below the 90th percentile for a given group were replaced with the upper or lower

fence value, respectively, and the *df* for that group was adjusted accordingly (Tukey, 1977). As it turned out, there were no low-end outliers in the baseline ratios of any group in either experiment, and corrections did not alter the outcome of any significance test in either experiment.

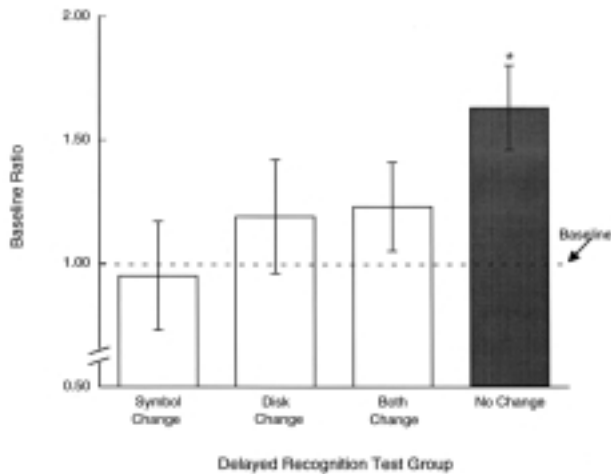
To determine whether any group recognized its test mobile, we used directional *t* tests to compare each group's mean baseline ratio and retention ratio (see Table 1) against the corresponding theoretical population values of 1.00. The no size-change group had a mean baseline ratio significantly above 1.00,  $t(5) = 3.68$ ,  $p < .007$ , indicating that infants in this group recognized the original training mobile during the long-term test. The three size-change groups, in contrast, failed to kick above their original baseline rates, indicating that they discriminated a change in the size of the +,  $t(4) < 1$ , a change in the size of the disk,  $t(5) < 1$ , and a change in the size of both the + and the disk,  $t(4) = 1.10$ , n.s. (see Figure 2). Identical tests of the corresponding retention ratios confirmed that these groups discriminated the three altered test mobiles from the original training mobile. All size-change groups had mean retention ratios significantly less than 1.00 whether the size of the +,  $t(5) = 5.19$ ,  $p < .002$ , the size of the disk,  $t(5) = 3.22$ ,  $p < .02$ , or the size

**Table 1. Mean Kick Rates During the Baseline (BASE), Immediate Retention Test (IRT), and Long-Term Retention Test (LRT) Phases, Mean Baseline Ratios (BR) and Retention Ratios (RR) for Delayed Recognition Test Groups (Experiment 1) and Priming (Reactivation) Test Groups (Experiment 2)**

Group	BASE	IRT	LRT	BR	RR
Experiment 1: Delayed Recognition					
No change	6.44 (0.97)	12.38 (1.00)	10.16 (1.12)	1.63* (1.17)	0.82** (0.05)
Symbol change	7.60 (1.78)	18.99 (4.87)	6.05 (0.56)	0.95 <sup>a</sup> (0.22)	0.42** (0.11)
Disk change	9.88 (2.52)	21.22 (4.57)	11.27 (3.13)	1.19 (0.23)	0.57** (0.13)
Both change control	8.00 (0.83)	16.38 (2.19)	11.16 (2.15)	1.23 <sup>a</sup> (0.18)	0.64*** (0.10)
Experiment 2: Priming (Reactivation)					
Size change react	4.58 (2.24)	10.67 (3.76)	8.33 (2.8)	2.02* (0.27)	0.87 (0.14)
No change control	8.04 (3.40)	20.04 (10.59)	15.08 (4.13)	2.24* (0.47)	0.96 (0.14)
Forgetting control	6.21 (2.42)	15.17 (9.20)	6.00 (2.75)	1.09 (0.25)	0.41** (0.06)
Reactivation control	8.30 (2.77)	— —	6.22 (3.32)	0.69 (0.14)	— —

*Note.* Parentheses contain  $\pm 1$  SE

\*Significant recognition (i.e., BR significantly  $> 1.00$ ). \*\*Significant discrimination (Experiment 1) or forgetting (Experiment 2) (i.e., RR significantly  $< 1$ ). <sup>a</sup>An outlier correction (Tukey, 1977) was applied prior to calculation of this statistic. Adjusting the value did not affect the outcome of the significance test.



**FIGURE 2** The delayed recognition performance of three size-change groups (symbol, disk, both) and a no size-change group tested 24 hr after training in Experiment 1. The asterisk indicates that only the no size-change group recognized the test mobile ( $M$  baseline ratio  $> 1.00$ ). Vertical bars indicate  $\pm 1 SE$ .

of both,  $t(3) = 3.47, p < .02$ , was different during the 24-hr test.

Of the four groups, the no size-change group had the lowest mean baseline rate prior to training. Although group baseline rates had not differed, we

thought it prudent to insure that the no size-change group did not show retention simply because the infants in that group were required to kick at a lower absolute rate during the long-term test in order to exhibit significant retention. As a check against this possibility, therefore, we conducted a tie-breaking analysis (Biederman & Tsao, 1979; Campbell, 1969) in which the no size-change group was successively compared with each of the remaining three groups. For this analysis, we iteratively removed the infant with the lowest baseline from the no size-change group and the infant with the highest baseline from the group with which it was being compared until the mean baseline of the remaining infants in the no size-change group was higher than that of the remaining infants in the comparison group, and then we again performed directional  $t$  tests on the baseline ratios of the adjusted groups.

These analyses reiterated the original findings: In each case, the no size-change group still showed significant recognition ( $M$  baseline ratio significantly  $> 1.00$ ) whereas the remaining three groups still showed none ( $M$  baseline ratios not significantly  $> 1.00$ ). Table 2 presents the mean baseline and baseline ratio of each group following the correction as well as the number of infants removed for each pairing of the no size-change group and the other three groups. Also presented are the  $t$  and  $p$  values that were obtained following each adjustment.

**Table 2. Mean Kick Rates During the Baseline and Comparison of Mean Baseline Ratios After Removal of Infants Following a Tie-Breaking Analysis for Delayed Recognition Test Groups (Experiment 1) and Priming (Reactivation) Test Groups (Experiment 2)**

	Prior $M$ Baseline	After $M$ Baseline	After $M$ BR	$p$	Infants Removed
Experiment 1 (Delayed Recognition)					
No-Change	6.44 (0.97)	6.86 (1.07)	1.56 (0.19)	$< .03$	1
versus					
Symbol-Change	7.60 (1.78)	6.13 (1.23)	1.09 (0.21)	n.s.	1
No-Change	6.44 (0.97)	7.41 (1.19)	1.39 (0.10)	$< .02$	2
versus					
DiskChange	9.88 (2.52)	6.08 (0.96)	1.26 (0.35)	n.s.	2
No-Change	6.44 (0.97)	7.41 (1.19)	1.39 (0.10)	$< .02$	2
versus					
Both-Change	8.00 (0.83)	7.00 (0.82)	1.16 (0.29)	n.s.	2
Experiment 2 (Reactivation)					
Size-Change	4.58 (0.79)	5.39 (0.32)	1.81 (0.32)	.05	2
versus					
Forget-Control	6.20 (0.85)	5.00 (0.32)	1.22 (0.32)	n.s.	2
Size Change	4.58 (0.79)	5.87 (0.75)	1.92 (0.77)	.05	2
versus					
React-Control	8.30 (2.77)	4.79 (0.84)	0.74 (0.12)	n.s.	2

Note. The No-Change group baseline was the highest of all four groups and was therefore not included. Parentheses contain  $\pm 1 SE$ .

As a final analysis, we performed a planned comparison between the mean baseline and retention ratios of the no size-change group, which was the only group that recognized its test mobile, and the critical symbol size-change group. This analysis revealed that the two groups differed significantly on both baseline ratio measure,  $F(1, 20) = 5.63, p < .03$ , and retention ratio measure,  $F(1, 20) = 7.25, p < .02$ , confirming that infants' size sensitivity on the delayed recognition test was a real phenomenon.

The results of Experiment 1 reveal that 3-month-old infants encode a memory representation that includes precise information about stimulus size and can retrieve that memory representation after a delay of at least 24 hr. The failure of the disk size-change group to exhibit delayed recognition suggests that a change in the relative proportion of figure to ground on the disks of the test mobile contributed to the size discrimination that was exhibited by the symbol size-change group. Because the size of the symbols was the same on the training mobile and the test mobile, the disk size-change group would otherwise have recognized its test mobile instead of discriminating it. Finally, the failure of the both size-change control group to exhibit delayed recognition confirms that the discrimination exhibited by the symbol and the disk size-change groups was not based on a perceived difference in overall brightness. Had these groups responded on the basis of a change in brightness rather than a change in size, then the both-change group would have recognized the test mobile instead of discriminating it because the training and test mobiles contained the same proportion of light/dark.

These results replicate the prior observation of Adler and Rovee-Collier (1994) and provide compelling evidence that 3-month-old infants possess a functional memory system that is sensitive to stimulus size.

## EXPERIMENT 2: PRIMING (REACTIVATION) TASK

Experiment 1 revealed that 3-month-olds, like adults, are sensitive to a change in stimulus size when tested in a delayed recognition task. In Experiment 2, we asked if infants would also exhibit an insensitivity to size in a priming task. If so, then this would be taken as evidence that they also possess a functional memory system that is insensitive to stimulus size. Repetition priming is described as a perceptual phenomenon in which the initial perceptual processing of a stimulus makes future processing of the same or a highly similar stimulus more rapid (Cave, 1997). Adults who are presented with a memory prime exhibit facilitated re-

tention on a subsequent test, presumably through reactivating or increasing the accessibility of a prior memory representation (Tulving & Schacter, 1990). Infants who are presented with a memory prime during a reactivation treatment at a time when they no longer can recognize the priming stimulus also show facilitated retention on a subsequent retention test, and such facilitation is also thought to result from reactivating or increasing the accessibility of a prior memory representation (Spear, 1973). In fact, without prior exposure to a memory prime infants display no retention on the ensuing test, but following exposure to a prime they exhibit near-perfect retention on the ensuing test (Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980).

Amnesics also exhibit excellent memory performance for previously exposed words on priming test even though they cannot recognize the same items (Warrington & Weiskrantz, 1970). Their memory dissociation on recognition and priming tests has been taken as evidence that priming involves a memory system different from the memory system that mediates explicit memory. Priming in adults is also very long-lasting. Although adults' recognition declines gradually over delay, they still respond successfully in a repetition priming task after a 48-week delay (Cave, 1997). Similarly, infants also exhibit long-lasting priming. Although 3-month-olds gradually forget most stimuli within 1 week, their retention following exposure to a prime after a 4-week delay is near-perfect (Rovee-Collier et al., 1980; Spear, 1973).

Biederman and E. Cooper (1992) and L. Cooper et al. (1992) demonstrated that adults' memory performance on a repetition priming task is not affected by size changes whereas their memory performance on a recognition task is. They attributed adults' lack of size sensitivity on the repetition priming task to the operation of a different representational system. Recently, evidence has begun to appear that a number of other fundamental perceptual changes, including changes in position, reflection, and some changes in viewpoint, do not affect repetition priming in adults as well (Biederman & E. Cooper, 1991a, 1991b; Biederman & Gerhardstein, 1993; E. Cooper, Biederman, & Hummel, 1992; L. Cooper et al., 1992). This evidence seems to contradict our previous findings from studies with infants that only a prime which strikes a fairly veridical match with the stimulus attributes in the original memory representation can reactivate it—a generalized memory prime cannot (Rovee-Collier & Hayne, 1987). In fact, we have never previously encountered an instance in which a stimulus that infants discriminated during a 24-hr recognition test was an effective memory prime. For example, 3-month-olds discrimi-

nate a test mobile that contains more than a single object that was not on the training mobile during a 24-hr recognition test (Hayne, Greco, Earley, Griesler, & Rovee-Collier, 1986), and that same altered mobile is not an effective memory prime 2 weeks later (Rovee-Collier, Hankins, & Bhatt, 1992). Likewise, when 3-month-olds are trained with a mobile displaying Ls, they discriminate a mobile displaying Ts during a 1-hr recognition test (Adler & Rovee-Collier, 1994); that same T mobile is not an effective memory prime 2 weeks later (Rovee-Collier et al., 1992). In studies with adults, changing aspects of the physical appearance of an item other than its size, reflectance, and so forth (e.g., from handwritten to typed words) between study and test similarly reduces the amount of priming (for review, see Richardson-Klavehn & Bjork, 1988). This fact has lent support to suggestions that the involuntary, automatic processing that characterizes visual repetition priming is related to brain mechanisms that analyze perceptual information (Grossberg, Mingolla, & Ross, 1997; Jacoby & Dallas, 1981; Musen & Treisman, 1990; Richardson-Klavehn, Gardiner, & Java, 1994; Tulving & Schacter, 1990).

Because infants had discriminated a change in the size of the test symbol in the 24-hr delayed recognition test in Experiment 1, therefore, we thought it unlikely that a stimulus altered in size would be an effective memory prime. The results of priming studies with adults (Biederman & E. Cooper, 1992; L. Cooper et al., 1992), however, predicted that infants would show a size-insensitivity in the priming (reactivation) task if both implicit and explicit memory systems were functional. Experiment 2 was designed to resolve this issue. To this end, we primed infants with a mobile containing +s that were 33% larger or smaller than the +s on the training mobile—the same stimuli that infants in the symbol size-change group had discriminated in Experiment 1. If the different-sized prime were to successfully reactivate the training memory, then infants would exhibit excellent retention during the ensuing memory test. This result, in turn, would be taken as evidence that 3-month-olds possess a functional size-insensitive representational system.

## Method

**Participants.** Infants in this experiment were thirty 3-month-olds (15 males, 15 females) with a mean age of 93.3 days ( $SD = 8.9$ ) on the first day of training. They were recruited as before and assigned to three groups as they became available for study. Infants were African American ( $n = 1$ ), Hispanic ( $n = 2$ ), Caucasian ( $n = 25$ ), and Not Reported ( $n = 2$ ). Their

parents' mean socioeconomic index (Nakao & Treas, 1992) was 60.3 ( $SD = 19.0$ ) and their mean educational attainment was 14.7 years ( $SD = 1.6$ ). Additional infants were dropped from the final sample for crying longer than 2 consecutive min in any of the four sessions ( $n = 5$ ), failing to meet the learning criterion ( $n = 3$ ), and failing to maintain a supine position in any session ( $n = 1$ ).

**Apparatus and Stimuli.** The apparatus and stimuli were the same as in Experiment 1. To minimize leg movement during priming, infants were strapped into a sling-type infant seat that was placed inside their crib. Also during priming, the ribbon was not attached to the infant's ankle but was held by the experimenter, who drew and released it to move the mobile.

**Procedure.** The training and testing procedures were the same as in Experiment 1 except that the long-term retention test with the original mobile was administered 2 weeks after the end of training, 1 day after the 3-min priming (reactivation) procedure. During priming, infants were exposed to a mobile (the prime) that was being moved noncontingently by the experimenter at the same rate that each infant had kicked to move it during the final 3 min of acquisition (see Figure 1b). Whether the memory prime was effective was assessed 1 day later in terms of whether infants exhibited renewed retention when tested with the original training mobile.

**Design.** Four independent groups of infants were trained for 2 days with either small or large +s on 3-in. disks; the size of the +s used during training was counterbalanced within groups. Infants in the *symbol size-change* group ( $n = 8$ ) were primed with a mobile that displayed +s of the other (nonstudied) size 24 hr before the 2-week retention test with the original training mobile. The *forgetting control* group ( $n = 8$ ) was not exposed to a memory prime prior to testing 2 weeks later with the original training mobile, and the *reactivation control* group ( $n = 6$ ) was primed and tested 1 day later but was not originally trained. The baseline rates of infants in the reactivation control group were measured in Session 1, and the rate at which the experimenter moved the mobile prime for each infant was yoked to the rate that the prime was moved for a corresponding infant in the experimental group. These are the standard control groups that are used in all reactivation studies to insure that subjects who are not primed display no retention and that priming, per se, does not induce new learning, respectively (Campbell & Jaynes, 1966). Finally, a *no-change con-*



control group ( $n = 8$ ) in which infants were trained, primed, and tested with the same mobile was included to provide a baseline for assessing the degree of priming in the symbol size-change group.

## Results and Discussion

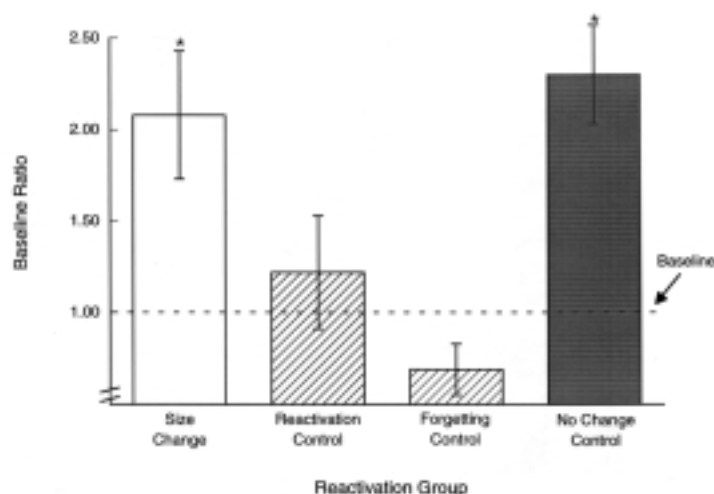
As before, separate one-way ANOVAs over the absolute number of kicks yielded no significant differences among the four groups during the baseline phase,  $F(3, 26) = 1.50$ , n.s., or among the three trained groups during the immediate retention test,  $F(2, 21) = 2.50$ , n.s., indicating that groups did not differ either before or after training, respectively (see Table 1). Thus, any subsequent differences in retention could not be attributed to differences in unlearned activity or the final level of learning, respectively.

Directional  $t$  tests were again used to compare the mean baseline and retention ratios against the corresponding theoretical ratios of 1.00 (see Table 1). As in Experiment 1, the results were straightforward (see Figure 3). As expected, the no-change control group exhibited excellent retention, with a mean baseline ratio significantly above 1.00,  $t(7) = 2.65$ ,  $p < .02$ , and a mean retention ratio not significantly less than 1.00,  $t(7) < 1$ . Surprisingly, however, the symbol size-change reactivation group also displayed excellent retention 1 day after being exposed to the memory prime. Its mean baseline ratio was significantly above 1.00,  $t(7) = 3.73$ ,  $p < .004$ , and its mean retention ratio was not significantly less than 1.00,  $t(7) < 1$ .

Thus, even though the memory prime displayed +s in a size different from the size of the +s on the training mobile, it successfully reactivated the original memory.

In contrast, the forgetting control group and the reactivation control group exhibited no retention whatsoever. Neither group had a mean baseline ratio significantly greater than 1.00, both  $t$ s  $< 1$ , and the forgetting control group had a mean retention ratio significantly less than 1.00,  $t(7) = 9.36$ ,  $p < .0001$ . (Because the reactivation control group was not originally trained, it had no retention ratio.) Campbell and Jaynes (1966) and Spear and Parsons (1976) established that both prior training and priming are necessary control conditions in order for the consequence of priming to be interpreted in terms of memory retrieval. Here, the absence of retention in the two control groups was evidence that these preconditions were satisfied.

Recall that retention ratios are sensitive to the degree of retention whereas baseline ratios are not. Because the relative priming performance of the different groups in Experiment 2 was of interest so that the present results could be directly compared with those of Biederman and E. Cooper (1992), we also conducted a one-way ANOVA over the retention ratios of the size change reactivation group, the no-change reactivation group, and the forgetting control group. This analysis yielded a significant effect of group,  $F(2, 21) = 6.34$ ,  $p < .007$ . Comparisons between individual groups indicated that the effect was due to the per-



**FIGURE 3** Memory performance of the symbol size-change reactivation group 24 hr after priming and three control groups in Experiment 2. Asterisks indicate that the symbol size-change and the no-change groups exhibited significant retention 1 day after priming ( $M$  baseline ratio  $> 1.00$ ). Vertical bars indicate  $\pm 1 SE$ .

formance of the forgetting control group, whose retention ratio was significantly less than those of the size change reactivation group,  $t(14) = 3.05, p < .008$ , and the no-change reactivation group,  $t(14) = 3.26, p < .005$ , which did not differ,  $t(14) < 1$ . Thus, a stimulus displaying size-altered stimuli was as effective a memory prime as one displaying stimuli whose size was not altered. The same pattern emerged when the Tukey WSD post hoc test was used. Finally, we again conducted a tie-breaking analysis in which we successively compared the baseline ratio of the experimental group with that of the other groups (Biederman & Tsao, 1979; Campbell, 1969). As before, these analyses reiterated the original findings (see Table 2).

We were surprised by the results of Experiment 2 given our previous studies of priming with infants. The present results revealed for the first time that 3-month-olds' memory for stimuli of a particular size could be primed by a stimulus that infants had discriminated in the delayed recognition test in Experiment 1. The finding that infants' memory was effectively primed by a stimulus differing in size from the size of the training stimulus demonstrated that 3-month-olds, like adults (Biederman & E. Cooper, 1992; Ungerleider & Mishkin, 1982), possess a size-insensitive memory system in addition to a size-sensitive memory system.

## GENERAL DISCUSSION

The combined results of Experiments 1 and 2 document a task-specific dissociation in 3-month-olds' memory for stimulus size. In Experiment 1, infants' memory performance in a delayed recognition task was size-sensitive whereas in Experiment 2 infants' memory performance in a priming task was size-insensitive. This dissociation is identical to the dissociation that researchers have recently found in adults' memory for size in recognition and priming tasks. If memory dissociations are to be taken as the diagnostic for two separate and functionally distinct memory systems (Biederman & E. Cooper, 1992; Schacter, 1987; Shimamura, 1986; Squire, 1986; Tulving & Schacter, 1990), then we conclude that two memory systems are functional by 3 months of age—one that is size-sensitive and supports explicit memory and one that is size-insensitive and supports implicit memory.

The suggestion that size-sensitive and size-insensitive memory performance on recognition and priming tests are mediated by different underlying memory systems has been supported by evidence that both normal adults and amnesics display preserved priming across size transformations (Schacter, L. Cooper, & Treadwell, 1993), but only normal adults detect size

transformations on recognition (L. Cooper et al., 1992; Schacter et al., 1993). In amnesia, implicit memory is spared but explicit memory is not (Graf & Schacter, 1985; Graf, Squire, & Mandler, 1984; Warrington & Weiskrantz, 1970, 1982). For almost a decade and a half, however, researchers have generally assumed that infants possess only the capacity for implicit memory until late in the first postnatal year, when the system that supports explicit memory was thought to become functionally mature (Bachevalier & Mishkin, 1984; Kagan & Hamburg, 1981; Nadel, 1992, 1994; Nadel, Willner, & Kurz, 1985; Naito, 1990; Naito & Komatsu, 1993; Nelson, 1995; Parkin, 1989; Schacter & Moscovitch, 1984; Tulving & Schacter, 1990). Recently, however, operant studies using mobiles (Adler et al., 1998; Bhatt & Rovee-Collier, 1997; Gulya, Rovee-Collier, Galluccio, & Wilk, 1998; Hartshorn et al., 1998; Hildreth & Rovee-Collier, in press) and studies of deferred imitation (Barr, Dowden, & Hayne, 1996; Hayne & Campbell, 1997; Meltzoff & Moore, 1994) with infants aged 6 months and younger have found evidence that both memory systems are functional early in infancy (for review, see Rovee-Collier, 1997). The present finding that 3-month-olds, like adults, encode both size-sensitive and size-insensitive memory representations and exhibit a memory dissociation in response to a change in stimulus size on priming and recognition tasks adds to the growing evidence that the two memory systems develop in parallel rather than hierarchically during the first year of life.

Despite evidence that young infants exhibit memory dissociations on priming and recognition tasks that are functionally identical to the memory dissociations that are exhibited by adults—and do so in response to manipulations of the same independent variables (Rovee-Collier, 1997), developmental and cognitive psychologists have resisted conclusions that infants possess two functionally distinct memory systems. Ironically, those who hold that very young infants possess *only* the system that supports implicit memory have not challenged whether the recognition task used with infants as a measure of explicit memory is analogous to the recognition task that is used with adults but, rather, whether the priming task (reactivation) that has been used with infants as a measure of *implicit memory* is equivalent to priming tasks that have been used with adults. The basis for this challenge has been the fact that the time required by very young infants to respond to a memory prime in a reactivation task is much longer than the time required by adults to respond to a memory prime in, for example, a word-stem completion task. Recently, however, Hildreth and Rovee-Collier (in press) have reported that the la-

tency of infants' response to a memory prime in a reactivation task decreases linearly over the first year of life until, by 1 year of age, they respond to a memory prime instantaneously, as do adults. This finding has provided additional evidence that priming in reactivation tasks with infants is the same automatic, perceptual identification phenomenon as repetition priming in studies with adults.

Apart from its implications for the early development of explicit memory, the finding that 3-month-olds can represent an object at a specific size and can discriminate that particular size from other sizes 24 hr later is interesting in its own right. The present finding confirms that the reported appearance of relative size judgments at 7 months (Granrud et al., 1985) does not reflect the sudden "switching on" of a size-sensitive representational system but the task used to assess it. When infants are tested in a task that does not require reaching, even newborns demonstrate the ability to perceive and encode precise information about object size (Slater et al., 1990).

## NOTES

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