Empirical support for object constancy in 3-month-old infants using a memory reactivation task

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Abstract

Reminder cues can impact remembering in infancy in multiple ways. Infants typically show highly specific remembering following a reminder, or reactivation procedure, but in some instances, (such as size perception) have demonstrated an ability to remember when given a cue or prime that differs in certain specific characteristics, relative to the training experience. The capacity of infants to use a novel view of an object as a prime to retrieve a training view was tested in this investigation, using simple (single part) 3D objects, and an operant training procedure. Infants trained with a simple object, shown in a limited range of views, demonstrated remembering of this event following a delay sufficient to produce forgetting in a control group. Remembering was demonstrated both when the primed view of the object was from within the limited training range and when the primed view was substantially novel (that is, outside the training range). This finding holds implications for the capacity of young infants to establish an abstract representation of 3D shape.space

Keywords: development, memory reactivation, viewpoint invariance, object priming, visual development.

Object recognition refers to the ability to have stable object representations despite ongoing changes in view, angle, size, retinal images, etc as the observer moves throughout the environment (Gibson, 1979). The development of object recognition in infants is a topic of strong interest to perceptual researchers as well as clinically oriented researchers and clinical practitioners because it demonstrates the presence of functional lower-level perceptual capabilities as well as higher-level memory constructs.

Most of what is known about infant remembering and perception has been learned through the use of behavioral techniques (Gerhardstein, Kraebel, & Tse, 2006; Rovee-Collier, & Cuevas, 2006). In studying the presence of functions underlying object recognition, researchers used such techniques, for example, to show that infants can discriminate between items as simple as a horizontal as compared to an oblique line at approximately 6-8 weeks of age (Atkinson & Braddick, 1992; Atkinson, Hood, Wattam-Bell, Anker, & Tickleback, 1988; Bornstein, Krinsky, & Benasich, 1986), and have shown that infants possess a rudimentary capacity for depth perception from motion cues at about the same age (Yonas et al., 1977). Slightly older infants have been found to be capable of discriminating between two different projections of a shape around three months of age (Caron, Caron, & Carlson, 1979; Slater & Morison, 1985).

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Caron, Caron, and Carlson (1979), for example, found that three-month-old infants, following familiarization with a simple shape (a rectangle, shown in 3D as, essentially, a piece of paper) demonstrated an ability to generalize to a novel projection of the shape, generated by rotating the rectangle in depth about the x-axis, so as to tilt the top of the rectangle backward and the bottom forward at a novel angle. Infants also discriminated the familiar shape from a novel shape (a trapezoid), which was (in its retinal projection) matched to a view used during familiarization of the original object.

The findings of Caron et al. (1979) demonstrated the presence of shape constancy, an important component of stable object recognition. That is, infants at this age demonstrated an ability to discriminate between two flat shapes based on their distal, or "objective" properties, as Caron et al. labeled them, and not on the basis of their retinal projections, which overlapped (in some cases completely). Note that the 2D projection of a rectangle face tilted in depth is effectively a trapezoid, thus creating ambiguity at the retinal level. Yet, the three-month-olds were still able to discriminate the tilted rectangle from a veridical trapezoid. The ability to base perception on distal object properties is likely to be crucial to the operation of a successful visual system; if each new retinal projection elicits a novel reaction, then a single simple object, as it rotates in any dimension, will result in a large number of novel views. The ability to base perception on the distal object shape, and not its (proximal) retinal projection (i.e., shape constancy), eliminates this potential need to deal with the many projections that the same shape can produce.

A second and related perceptual process is object constancy (or viewpoint invariance), which is the ability to recognize two different views of an object as the same 3D distal object. Object constancy is distinct from shape constancy in that view differences in object constancy are explicitly perceptible, while changes in view resulting in shape constancy are not explicitly perceived. To illustrate this point, imagine a coffee cup is rotated forward from the upright such that the top circular opening becomes more widely visible to an observer. As this happens, the retinal projection of the top opening changes from one ellipse to a differently shaped ellipse. Casual observation, however, reveals that perception is immediately of a circular opening in both cases, not a changing ellipse. The perceptual equivalence of the changing ellipse is an example of shape constancy. When the same upright cup is then rotated about the vertical axis so as to self-occlude most of the handle, these view changes at the scale of the entire object are clearly apparent. This generalization across clearly perceptually different views is object constancy.

Can young infants demonstrate object constancy? Kellman (1984; Kellman & Short, 1987) showed four-month-olds generalized to novel views following familiarization experience with a video of a moving object presented in a full 360° sweep. Kraebel, West, and Gerhardstein (in press) showed infants at this age generalize to new views of a simple 3D object (e.g., a brick), different from the views received during operant training. Kraebel and Gerhardstein (2006) found infants are capable of this type of perceptual performance with more complex (multi-part) objects. Kraebel and Gerhardstein found if the range of motion provided during training is small (±5°), then infants would not generalize to a novel view of an object. The view change that these researchers used would clearly pose no challenge whatsoever for adult observers, even if no motion were presented during training at all. The extent which motion is needed for infants to form abstract representations of 3D objects will be examined further in the Discussion section of this paper, but all three findings point to the basic conclusion, first detailed by Kellman (1984): Object motion facilitates the encoding of the 3D structure of distal objects in infants.

These findings more generally indicate, while some level of capacity for abstract object perception is present at three months, infants at this age do not possess a mature system for the perception of distal object shape, given their need for a minimum level of experience with varying viewpoints or motion-sourced information prior to showing object constancy[2]. Might there be other indicators of a lack of a mature object perception process at this age? In the adult literature, different aspects of object constancy have been assessed using explicit and implicit memory tasks. For example, changes in object size appear to impair explicit memory performance (Schacter, 1992; Schacter & Moscovitch, 1984), but not implicit memory performance (Nissen, Knopman, & Schacter, 1987; Sherry & Schacter, 1988). A test of three-month-olds revealed the same dichotomy (Gerhardstein, Adler, & Rovee-Collier, 2000), and other tests have revealed that this dichotomy is not specific to size in infants (see Rovee-Collier, Hayne, & Colombo, 2001 for review).

This dissociation of performance has been tested in adults using changes in viewpoint (Biederman & Cooper, 1991; Cooper, Schacter, Ballesteros, & Moore, 1992; Stankiewicz & Hummel, 2002): Adults show viewpoint-specific recognition performance when tested with a recognition task, but not with a priming task. The dichotomy between implicit and explicit memory systems using changes in viewpoint, however, has not yet been investigated in infants. An assessment of whether infants can show viewpoint-independent performance in a priming task will help reveal which aspects of infant object constancy are similar to adults. If infants are able to abstract away from the particular characteristics (the features) of an object and show viewpoint-independent performance in a priming task, then this would suggest that object constancy is relatively well-developed. If not, then it would suggest that infant performance at this age may be influenced by other factors, such as memory for specific features or feature relations (Bhatt & Rovee-Collier, 1997) or the ability to integrate perceptual features into a representation of an object (Bhatt, 1997), and a priming task in particular may prove to be sensitive to changes in view.

This paper presents a test of infants' responses to a change in view, when that change in view was introduced in the context of a priming task. Stimulus features changed across views, but the identity of the object did not. If, like adults, the implicit perceptual system of the infant is insensitive to these types of view-specific changes, then priming with a novel view should elicit the same performance as priming with a familiar view (showing object constancy). If, however, the infant's attention to the details of an object are sufficiently specific that priming is not at the level of the parts or the whole object, but is instead at the level of the features (i.e., line orientation and length, vertex type and number), then, as was found to be the case for a discrimination task with a short range of training views, the priming task may elicit view-specific performance.

This issue was investigated in three-month-old infants using simple (single-part) 3D objects. Infants were trained for this test using an operant procedure in which the infant learns to kick to move an overhead mobile (Kraebel, Fable, & Gerhardstein, 2004; Rovee & Rovee, 1969;

[2] Varying static viewpoints and motion information are not the same.

Rovee-Collier & Gekoski, 1979). This procedure includes two consecutive days of training, during which the infant is reinforced with motion and sound for kicking. Priming was introduced through the use of a reactivation procedure (Campbell & Jaynes, 1966; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980; Spear, 1973; Spear & Parsons, 1976) in which, following training, the infant was allowed to forget the training (through the introduction of a delay), and then, just prior to testing, was given a reactivation (priming) exposure to either the same view of the familiar object, a novel view of the familiar object, or a novel object. The infant was then tested with the training stimulus in its familiar view. If the reactivation (priming) treatment is successful, the infant will exhibit behavior indicating retention of the previously-forgotten training event, but if not, then the event will not be retrieved and the infant will demonstrate behavior indicating lack of retention.

Method

Participants. Forty 3-month-olds, (n = 8 per group, 26 males, 14 females), with a mean age of 88.40 days (*SD* = 9.38) on the first day of training were randomly assigned to one of five experimental conditions as they became available. Parental education ranged from 10 to 16 years (*M* = 14.39 years, *SD* = 1.96) as reported by 90% of the parents, and their mean socioeconomic status (Nakao & Treas, 1992) was 63.49 (*SD* = 19.54) as reported by 73% of the parents. Infants were Asian American (*n* = 1), Caucasian (*n* = 36), Native-American (*n* = 2), and other (*n* = 1). Additional infants were dropped from the final sample due to fussiness, defined as crying for longer than 2 consecutive min. (*n* = 6), falling asleep (*n* = 2), parental interference (*n* = 2), illness (*n* = 1), equipment problems (*n* = 2), or failing to meet the learning criterion (*n* = 6).

Apparatus and Stimuli. Mobiles displaying 5 shapes (cylinders or bricks; 7.62 x 3.81 x 3.81 cm) made of lightweight balsa wood served as stimuli. All objects in each mobile were suspended from a 16-in. white circular plastic shield with clear fishing line. Objects were suspended so as to present either a 45° view or a nearly flat (0°) view to the infant (see Fig. 1). During training, the mobiles wiggled through an amount equal to the larger range of motion (approximately ±10°) reported by Kraebel and Gerhardstein (2006), allowing exposure to a relatively wide range of views during acquisition (see below).

The distance from the infant's head to the mobile was maintained at approximately 20–25 cm. The mobile hung from a microphone stand, which was modified to hold a motor, speaker, battery, and switching circuit, and which was interfaced to a portable computer. A wireless computer mouse was suspended from another microphone stand, and connected to a modified dog leash apparatus (see Kraebel & Gerhardstein, 2006, for a complete description of the apparatus) positioned near the infant's feet. A ribbon was attached to one ankle, which allowed the infant to move the wireless mouse by kicking its foot. The mouse was connected to a laptop computer that recorded kicking and reinforced the infant for kicking. The computer activated a motor and played a 1-sec. segment of a children's song on a CD when a kick was detected. Reinforcement was provided only at certain times during the procedure (see below), but kicks were recorded at all times.

Procedure. All infants received two 15-min training sessions for two consecutive days and a 3-min delayed recognition test following a delay of 15 days in most cases (see Table 1). Infants were tested in their homes at a time chosen by the parents, with the stipulation that the parent would attempt to select a potentially good playtime. The time of day varied across infants, but remained fairly constant across sessions for each individual infant.

Sessions consisted of 3 phases; a 3-min non-reinforced phase, a 9-min *acquisition phase (reinforced)*, and another 3-min non-reinforced phase. The initial phase on day 1 served as a measure of *baseline* kicking; mean kicks/min during this phase were taken to indicate the pre-training level of activity for each infant. The final non-reinforced phase on day 2 served as an *immediate retention test* (IRT), measuring learning and retention with no manipulation of the stimuli and no delay. All infants (excepting only the reactivation control group-- see below) received the same day 1 and day 2 training. Infants were then subjected to a 2-week delay, a period over which complete forgetting has been found to occur for most stimuli at 3-months of age (Rovee-Collier & Sullivan, 1980; Rovee-Collier, 1997). A reminder procedure was administered at the end of the delay; this procedure varied by group (see below), but all infants received a procedurally identical test session, of 3 phases, as described above. The first 3-min period of the test session served as a test of *long-term retention test* (LTRT); a measure of the infant's retention of the test mobile after a 14-day delay.

Reactivation (Priming) Procedure: Two weeks after the second training session, infants were given a 3-min reminder. This reminder cue consisted of re-exposure to the conditions of training (a moving mobile), but without kicking-contingent reinforcement. Visual motion during this session was produced by the computer at times programmed to correspond to the same infant's kick rate during the last 3-min of acquisition on the second day of training. In this way, the infant was merely re-experiencing the same training context without the possibility of new learning (a control condition was included to demonstrate that no new learning occurred). Thus, the reminder mobile served to reactivate, or prime, the forgotten memory of the training experience. Infants were given a retention test session 24-hrs after the reminder treatment, using the original training mobile (see Rovee-Collier et al, 1980, for an explanation of the choice of a 24-hr delay). Note that stimulus changes were introduced only during the stimulated remembering- reactivation session, in which the priming mobile could differ from the training/testing mobile.

Design. (See Table 1.) Five independent groups of infants were run in this experiment. Exposure to the different brick and cylinder shapes were counterbalanced within each group. Infants in one experimental group, *reactivation view-change*, were trained with mobiles displaying bricks or cylinders at a particular angle for 15-min sessions on two consecutive days. They were then primed two weeks after the second training session with a mobile displaying the same shapes at a different angle, and tested 24-hr following the prime with a mobile displaying the shapes at the training angle. Infants in the other experimental group, *reactivation object-change,* received a prime with a mobile displaying a different shape from the training and test mobile (e.g., an infant trained with a mobile displaying bricks would be primed with a 'cylinder' mobile, and tested with a 'brick' mobile). The purpose of this group was to ensure that any retention displayed by infants in the reactivation view-change group was due to object constancy, and not due to simple generalization to any mobile displaying, for example, red objects.

Three control groups were also included in the design. Infants in the *forgetting control group* were trained and tested, but not primed, to demonstrate that infants forgot the training experience after two weeks. A *reactivation control group* received the 3-min prime and 24-hr test, but did not receive prior training. Each infant in this group was yoked to a corresponding infant in a reactivation no-change or reactivation view-change group to ensure equal amounts of reinforcement during the priming session. A baseline kick rate was assessed prior to the prime, and the test was given 24-hr after the prime to determine if new learning occurred. Infants in the *reactivation no-change group* were identical to the reactivation view-change group, except they viewed the same mobile throughout the procedure. This group was included to ensure that the reactivation procedure, using the computer mobile apparatus, was effective, as well as to provide a baseline for comparison with the experimental group.

Table 1. A example listing of groups, with details for each. Note that object 1 and 2 were counterbalanced within groups in the actual experiment.

Group	Training Mobile	Delay	Reactivation	Test
Reactivation View-Change	Object 1, Training View	2 weeks	Object 1, Novel View	Object 1, Train. View
Reactivation Object-Change	Object 1, Training View	2 weeks	Object 2, Train. View	Object 1, Train. View
		Control Groups		
Reactivation No-Change	Object 1, Training View	2 weeks	Object 1, Train. View	Object 1, Train. View
Forgetting Control	Object 1, Training View	2 weeks	None	Object 1, Train. View
Reactivation Control	None	None	Object 1, Train. View	Object 1, Train. View

Results and Discussion

The results of this test demonstrated that, in a priming task, infants are capable of viewpoint-insensitive recognition at three months of age. Specifically, the outcome of the reactivation no-change and the reactivation view-change manipulations showed that the reactivation procedure was successful in reminding infants of their training experience, whether the prime displayed the same view as in training or a novel view. The results of the object-change group indicated that the results of the first two groups were not due to a general acquisition of a mobile displaying any shape, but were due to memories of the specific training shape (i.e. this group did not show retention of the task).

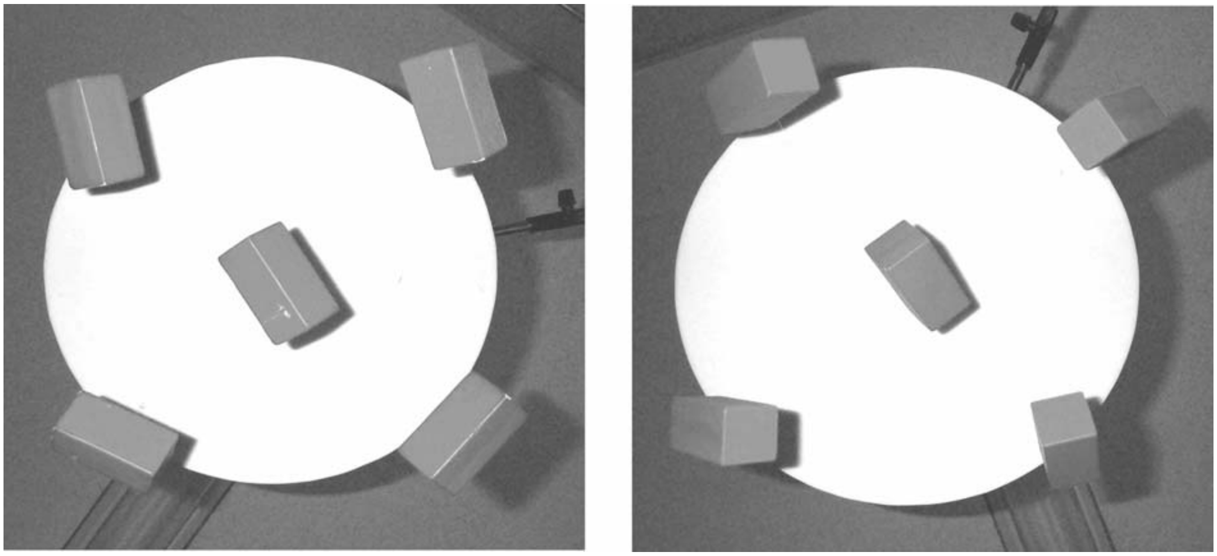

Figure 1. The brick stimulus used in training and testing infants. Both views used are shown. Note that each infant was trained with only one view. See the text for a description of priming conditions.

A two-way ANOVA on Group (no-change, object-change, view-change, reactivation-control, forgetting control) and Phase (baseline, IRT, LTRT) over the raw kick data yielded no significant differences among the five groups during baseline phase or among the four groups with training (reactivation control group excluded) during the immediate retention test, ($F < 1$). There was no main effect of group, ($F < 1$) and no phase x group interaction ($F < 1$), but there was a significant main effect of Phase $F(2, 32) = 14.21$, $p < .001$, which demonstrates that infants showed learning. This indicates that there were no differences between the groups before or after training, so differences in retention cannot be attributed to differences in unlearned activity or differences in level of learning.

The overall ANOVA, however, does not address the question of whether the groups showed reactivation of a memory for the training event or not. This question was addressed using directional t-tests to compare the mean baseline and retention ratios against a theoretical population value of 1.00. These ratios are calculated as follows:

Baseline Ratio (BR): LTRT/Baseline

[Long-Term Retention Kickrate / Baseline Kickrate]

This ratio has a theoretical minimum of 1.0, as baseline is assumed to be the infant's lower bound of kicking, but in practice, the ratio can drop below 1.0, so all t-tests are conducted 2-tailed. Training causes the infant's kicking to increase, and if the training event is accessible at test, the infant will kick at that elevated rate, resulting in a BR significantly higher than 1.0. If the training event is not accessible, then the BR will not rise significantly above 1.0. To summarize, a BR that is significantly greater than 1.0 indicates remembrance of the training event.

Retention Ratio (RR): LTRT/IRT

[Long –Term Retention Kickrate / Immediate Retention Kickrate]

This ratio has a theoretical upper limit of 1.0, as IRT represents the infant's learned (elevated) level of kicking, but in practice, the ratio can increase above 1.0, so again, all tests are 2-tailed. Training causes the infant's kicking to increase, and if the training event is accessible at test, the infant will kick at that elevated rate, resulting in a RR that does not differ significantly from 1.0. If the training event is not accessible, then the RR will drop as LTRT drops, resulting in a significant drop relative to 1.0. So in effect, an RR that is significantly less than 1.0 indicates forgetting. (Note that both BR and RR measures are needed to claim a positive effect of retaining and/or a positive effect of forgetting. For instance, one cannot claim retention from a null effect of a RR that is not significantly different from 1.0.)

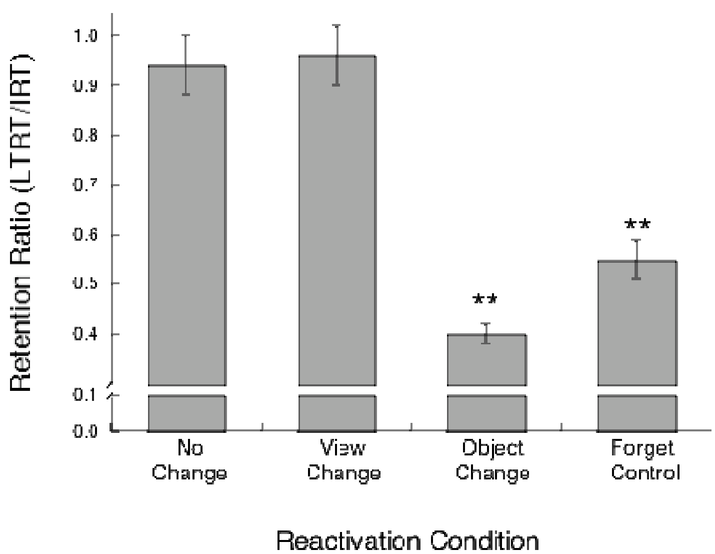

Figure 2. Results of the reactivation (priming) test in all conditions. Asterisks indicate a significant lack of retention. Error bars reflect ±1 SEM.

The reactivation no-change group had a mean baseline ratio of 2.00, significantly greater than 1.0 (*SD* = 1.27; $t(7) = 2.23$, $p < .05$). The mean retention ratio of .94 (*SD* = .44) was not significantly less than 1.0 ($t<1$) for this group. These results indicate that these infants showed good retention of their training, meaning that the reactivation treatment was successful. The reactivation view-change group had a mean baseline ratio of 2.40 (*SD* = 1.75) which was significantly greater than 1.0 ($t(7) = 2.26$, $p < .05$). A mean retention ratio of .96 (*SD* = .40) was not significantly less than 1.0 ($t < 1$), indicating that the novel view of the training shape successfully reactivated the infants' memory for the training event (see Fig. 2).

The reactivation object-change group had a mean baseline ratio of 1.03 (*SD* = .73), which was not significantly above 1.0 ($t < 1$). This indicates that these infants did not show significantly greater responding at test in comparison to baseline. These infants had a mean retention ratio of .40, significantly below 1.0 (*SD* = .17), $t(7) = 10.17$, $p < .0001$, demonstrating that the novel object failed to reactivate, or prime, the infants' memory for the training event.

The forgetting control group and the reactivation control group exhibited no retention; the mean baseline ratios of these groups were not significantly greater than 1.0 (t's < 1). The reactivation control group did not have a retention ratio because there was no original training, but the forgetting control group had a mean retention ratio of .55 (*SD* = .32), significantly below 1.0, $t(7) = 4.03$, $p < .005$. These results indicate that infants forgot the mobile game between training and testing. Overall, the data from these two groups indicate that reactivation did not occur spontaneously (in the absence of a priming exposure or training). Thus, as expected, priming and training are both necessary for the reactivation of memory in 3-month-olds after a two-week delay (see also Campbell & Jaynes, 1966; Rovee-Collier & Sullivan, 1980; Rovee-Collier et al., 1980; Rovee-Collier, & Cuevas, 2006; Spear, 1973).

Discussion

Familiar objects both in the same view and in the novel view successfully primed the memory of the three-month-olds. In contrast, infants primed with a novel object showed no retention upon subsequent testing. Furthermore, control groups demonstrated that the delay was of sufficient length to cause forgetting to occur and that the priming treatment alone (i.e., without training) was ineffective. These findings showed that the familiar object, irrespective of view, was the only effective memory prime for these three-month-olds. This investigation differed from one particular test examining object perception in infants (Kellman, 1984; see also Ruff, 1978, 1980) both in the nature of the stimulus used (2D as compared to 3D physical objects) and the delay intervals tested (seconds as compared to 24-hr). This test extends the findings of Kraebel and Gerhardstein (2006), demonstrating that the ability to perceive the distal 3D shape of an object is accessible to both the explicit memory system, (i.e., Kraebel & Gerhardstein, 2006), and the implicit memory system, as shown by the reactivation test presented above.

Together, previous findings (Kraebel & Gerhardstein, 2006; Kraebel et al., *in press*) and the present finding on object constancy demonstrate that three-month-old infants can generalize to novel views following experience with a range of motion-based views during training. Are there limits to this ability to generalize, and if so, what types of information are truly necessary to achieve the representation that infants are acquiring in this test? The answer to the first question may lie in the types of views tested: Biederman and Gerhardstein (1993; 1995) showed that adult identification of objects is sensitive to changes in view that resulted in the accretion or deletion of parts (due to occlusion by other parts). Tests in which the visible parts of an object are manipulated (i.e., exposed or hidden) are lacking in the infant literature; further investigation on infant object constancy should examine the effects of this type of manipulation on infant perceptual performance.

The issue of whether motion information is needed, however, is a significant question in the developmental arena. Multiple findings in the literature (Arterberry & Bornstein, 2002; Arterberry & Yonas, 2000; Johnson & Mason, 2002; Johnson, Bremmer, Slater, Mason, & Foster, 2002; Johnson, Cohen, Marks, & Johnson, 2003; Kellman, 1984; Kellman, Spelke, & Short, 1986) suggest an important role for motion in infant perception of objects. Kellman (1984) in particular argued that infants require motion to establish an abstract representation of shape; Kraebel and Gerhardstein (2006) and Kraebel et al. (*in press*) found support for this position, with the qualification that the range of motion needed is limited. Johnson (2000) has argued that motion is only one of a set of sources of information recruited by the infant perceptual system, and that when enough information is available, infants will succeed at this type of task, regardless of the nature of the information. The present outcome, as with the previous findings regarding infants' long-term memory capacity for transfer of training to novel views, suggests that infants are capable, at three months, of accessing an object percept through a static (non-moving) test stimulus following a 24-hr delay, but that motion may, as suggested by previous findings, be necessary for infants' acquisition of an object representation (since motion was present during training).

Careful manipulations of stimuli are needed to investigate these questions. Arterberry and Bornstein (2002) in particular used a powerful manipulation of stimulus type (dynamic or static), and showed that infants do not show transfer of a dynamically acquired category to a static exemplar until nine months when the dynamic stimulus contained only motion information. The present data argue that infants are capable of this dynamic-to-static transfer earlier in life, provided that the training/test stimuli are not abstract forms. The present outcome can be seen as a categorization response (see Palmeri & Gauthier, 2004 for a suggestion that the process of linking multiple views of an object connects to the process of perceptual categorization), and Johnson's (2000) perspective would suggest that the multiple sources of information available in the stimuli of the current study would explain the performance difference between the present study and that of Arterberry and Bornstein (2002). While the present test does not offer strong controls over stimulus presentation (the infant is free to move its head during the test, for example), the outcome, along with those of Kraebel and Gerhardstein (2006) and Kraebel et al (in press), offers support for the view that infants possess a capacity to access a memory, once formed, through a static stimulus presentation across a significant delay. This observation suggests that motion is primarily an encoding imperative at this point in development. Note that adults would have no difficulty in performing this task on either the encoding or the retrieval side without the aid of motion, demonstrating that the infant mechanism, while functional, is clearly immature at this age.

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