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Infants' use of category knowledge and object attributes when segregating objects at 8.5 months of age

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Abstract

The current research investigates infants' perception of a novel object from a category that is familiar to young infants: key rings. We ask whether experiences obtained outside the lab would allow young infants to parse the visible portions of a partly occluded key ring display into one single unit, presumably as a result of having categorized it as a key ring. This categorization was marked by infants' perception of the keys and ring as a single unit that should move together, despite their attribute differences. We showed infants a novel key ring display in which the keys and ring moved together as one rigid unit (Move-together event) or the ring moved but the keys remained stationary throughout the event (Move-apart event). Our results showed that 8.5-month-old infants perceived the keys and ring as connected despite their attribute differences, and that their perception of object unity was eliminated as the distinctive attributes of the key ring were removed. When all of the distinctive attributes of the key ring were removed, the 8.5-month-old infants perceived the display as two separate units, which is how younger infants (7-month-old) perceived the key ring display with all its distinctive attributes unaltered. These results suggest that on the basis of extensive experience with an object category, infants come to identify novel members of that category and expect them to possess the attributes typical of that category.

Keywords: Infant; Concepts; Perception

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1. Introduction

Does an observer's knowledge about objects influence the way he or she perceives them? How our knowledge supports and interacts with our perception of objects has been a topic of some interest over the past 30 years (Dretske, 1990, 1995; Gibson, 1969; Marr, 1982; Rock, 1983; Shepard, 1983). When an object is categorized, knowledge about that category allows the observer to produce expectations about aspects of the object that are not directly perceivable (e.g., Baldwin, Markman, & Melartin, 1993; Greco, Hayne, & Rovee-Collier, 1990; Mandler, 1998, 2000). For example, when faced with a novel object that you categorize as a blender, you would be able to predict where it comes apart into smaller pieces (the lid comes off of the container, the container comes off of the motorized base), how it can be used (to make milk shakes), and what kind of noise it would make when turned on (a loud motor sound). At what point in development do infants begin using category knowledge to help them understand new instances of known categories?

Some researchers have argued that it is not until infants know the names for objects that they have category knowledge that is useful for cognitive tasks such as object individuation, object segregation, and inductive generalizations (e.g., Xu & Carey, 1996; Xu, Carey, & Welch, 1999). It may be that language plays a role in tasks involving complex objects for which multiple possible parses exist. However, at least two kinds of findings argue that knowing the words for things cannot be an essential component to success in these tasks, regardless of the complexity of the displays: (a) successful object segregation by (nonlinguistic) nonhuman primates (Munakata, Santos, Spelke, Hauser, & O'Reilly, 2001), and (b) successful performance in segregation tasks involving simple, generic objects by infants too young to have much receptive vocabulary (e.g., Needham, 1999). More recent findings have gone further to say that infants, like adults, have more than generic parsing principles (akin to gestalt principles of perceptual organization) to facilitate their organization of the three-dimensional world. They also learn about and apply knowledge gained from exposures to specific categories of objects (Goldstone, 2000; Needham, Dueker, & Lockhead, 2005; Palmer, 1999; Quinn & Schyns, 2003; Schyns, Golstone, & Thibaut, 1998; Shiffrin & Lightfoot, 1997).

Could similar findings be obtained using a category of object that is familiar to most infants? Key rings seemed like a good category of object to examine, because infants have experienced (via the visual, manual, and even oral modalities) key ring rattles and their parents' key rings. So, exposure to the category happened outside the lab, during the course of normal everyday events. Also, because the physical connection between the keys and ring is at odds with the perceptual similarity between these two parts, the display allowed us to determine how infants would resolve this conflict. We know that infants attend to object attributes when determining likely connections between object parts by about 4 months of age or soon thereafter (e.g., Johnson & Aslin, 1995, 1996; Johnson, Bremner, Slater, & Mason, 2000; Needham, 2000; Vishton, Ware, & Badger, 2005).

In the present research, the object categorization task was embedded within an object segregation/object unity task. In many cases, our prior knowledge of objects can influence how we parse them. For instance, a gravy boat is comprised of a bowl for the gravy and a saucer underneath is that is often attached to the bowl. It is a single object made up of two parts. In the case of a key ring, the keys and ring may be seen as connected like the bowl and saucer of the gravy boat, or they may be seen as separate from each other, depending on what the prior experience of the observer happens to be.

Previous research has shown that infants can use their category knowledge to help them perceive the visible portions of a partly occluded display as connected: infants will unify the visible portions of a partly occluded object if the object is a human face, but not if it is a checkerboard pattern or a smeared unidentifiable face (Schwartz, 1982; Vishton, Stulac, & Calhoun, 1998). Here, we ask whether infants would see the visible portions of a partly occluded key ring as connected, despite their strikingly different shapes, colors, and patterns.

The primary display in this research consisted of a partly occluded key ring, with the keys on one side of the occluder and the ring on the other side (Key Ring Display see Fig. 1A). Because the contact point between the keys and ring remained hidden throughout these experiments, the infants would have to *infer* the existence (or lack of existence) of a connection between the two portions of the display.

Infants' perception of this display was assessed in the following manner. After a familiarization trial in which the infants saw the display stationary, infants saw test events in which a gloved hand took hold of the ring portion of the display and slid it away from the infant, producing movement in depth from the infant's perspective (Fig. 2). In a between-subjects design, infants saw one of two potential outcomes for this movement: either the whole key ring moved as one rigid unit (Move-together event; Fig. 2C) or the ring moved, but the keys remained stationary throughout the event (Move-apart event; Fig. 2B). Our reasoning was that infants would respond to the event with lengthened looking if it depicted an outcome they did not expect. If infants perceived the display using generic parsing principles operating on the visual attributes of shape, color, and texture, they would presumably perceive it as composed of (at least) two separate pieces behind the screen. In contrast, if infants incorporated their category knowledge, in top-down fashion, into their interpretation of the display, they should see the visible portions as part of the same object despite their differences in shape, color, and texture. Which of these two interpretation strategies would infants employ?

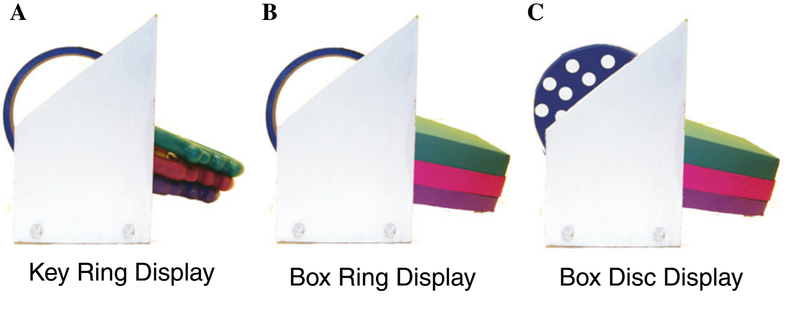

Fig. 1. Displays used in Experiments 1–4 with the central occluder, as they were presented to the infants. In the Move-apart events, the ring moved away from the infant while the "keys" were stationary whereas in the Move-together events, the ring and "keys" simultaneously moved away from the infants. (A) Key Ring Display (Experiments 1 and 4) consisting of a blue ring and toothed keys. (B) Box Ring Display (Experiment 2) consisting of blue ring and a tri-color box. (C) Box Disc Display (Experiment 3) consisting of a blue disc with white dots and a tri-color box. (For interpretation of the references to colours in this figure legend, the reader is referred to the web version of this paper.)

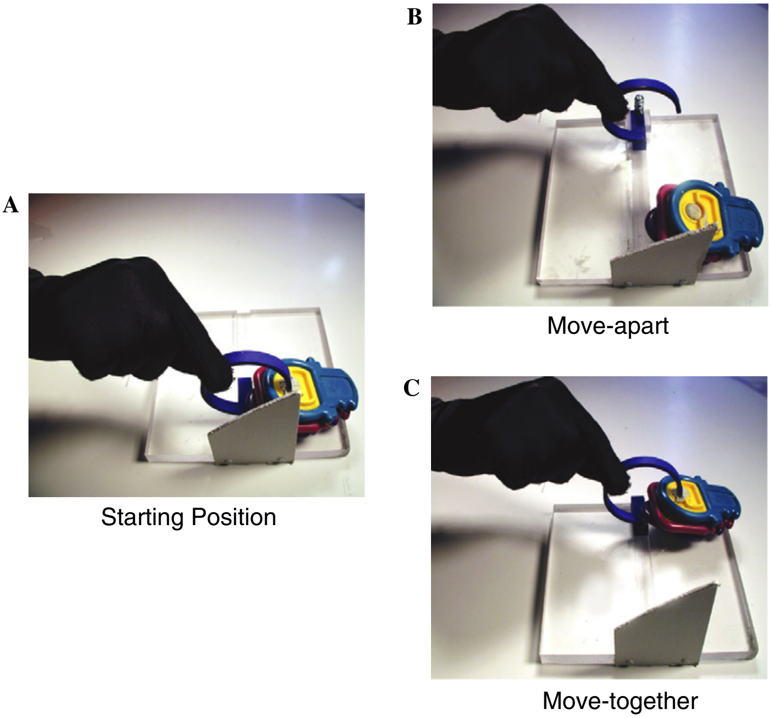

Fig. 2. High front view of starting positions of keys and ring (A), and backmost positions of the object(s) in the Move-apart (B) and Move-together (C) test events. The screen has been bent down to reveal the mechanism that allowed controlled movement of the display in both the Move-apart and Move-together conditions. These photos were taken from a position somewhat higher than the infants' eye level, again to allow easy viewing of the hidden mechanism.

2. Experiment 1

2.1. Method

2.1.1. Participants

Participants were 16 infants (9 male) ranging in age from 8 months, 15 days to 8 months, 29 days ($M = 8$ months, 22 days, $SD = 5.3$ days). Half of the infants saw the Move-apart test event, and half saw the Move-together test event. All of the infants had extensive experience with key rings prior to their visit to our lab, according to their parent.

Infants' names in this experiment and the following experiments were obtained from the Durham County (North Carolina) vital records office and were contacted via letter and follow-up phone call. Parents were offered reimbursement for their travel and were given an infant T-shirt featuring our lab logo to thank them for their participation.

2.1.2. Apparatus

The apparatus consisted of a wooden cubicle 200 cm high, 106 cm wide, and 49.5 cm deep. The infant faced an opening 46 cm high and 52 cm wide in the front wall of the apparatus. The floor, back, and side walls of the apparatus were white.

The display consisted of three plastic keys, a wooden ring, a clear Plexiglas base, and a triangular screen (Fig. 1A). The keys were approximately 7.5 cm long and 5.5 cm wide at their widest point. There was bright yellow plastic in the center of the top portion of each key, and the bottom portions were made of brightly colored plastic (one green, one pink, and one purple). These bottom portions had one, two, or three 'bumps' on them that roughly corresponded to the 'teeth' of normal keys. The keys were stacked (green-top, pink-middle, purple-bottom) and firmly attached to each other using rubber cement. The ring was made of wood that was 3 mm thick, 1 cm wide, and 6.5 cm in diameter. It was painted bright blue. The ring was firmly mounted on top of a small wooden block ($4 \times 1 \times 1$cm), which slid smoothly within a 3×8 mm channel cut into the Plexiglas base. The base was 15 cm^2, 12 mm thick, and translucent. The movement of the block through the channel created a back-and-forth track of motion for the ring that was silent, smooth, straight, and consistent. Small guides at the top of the block on both sides kept the block straight in the channel. Small weights on the hidden part of the ring ensured that it remained in place appropriately during the Move-apart event. The screen was made of wood and was 6 cm wide and 8 cm tall at its tallest point. It was mounted on the front of the base. Together, the keys and ring measured 11 cm across. The display was roughly centered on the apparatus floor, with the keys 19 cm from the right wall and the ring 24 cm from the left wall.

To produce the Move-together event, the ring was permanently affixed to the keys with rubber cement. An identical apparatus was created to produce the Move-apart event, with one exception: the ring was cut away from the keys so that it could move separately from them, and the keys were permanently affixed to the base with rubber cement. These two pieces of equipment were closely monitored throughout these studies to ensure that they were kept clean and free from extraneous markings that could influence infants' attention. The key ring display subtended about 23° (horizontal) and 16° (vertical) of visual angle from the infants' viewpoint. Fig. 2 depicts a top-down view of these two events.

In both events, the movement of the soft wood block through the Plexiglas channel was silent and smooth. Soft bumpers at each end of the channel ensured that the block stopped at the same spot each time; this change in direction had no sounds associated with it.

In each test event, the ring was moved by an experimenter's hand wearing a 59-cm-long purple spandex glove. The hand entered the apparatus through a wall opening that was partially hidden by a white curtain; the infant could not see the experimenter's face through this opening.

The infants were tested in a brightly lit room, with four clip-on lights attached to the back and side walls of the apparatus to provide additional light. Two wooden frames, 200 cm high and 69 cm wide and covered with blue cloth, stood on either side of the apparatus to isolate the infants from the experimental room. At the end of each trial, a white curtain was lowered to cover the opening to the apparatus.

2.1.3. Procedure

Each infant sat on his or her parent's lap in front of the apparatus. The infant's head was approximately 48.5 cm from the key ring. The infant's looking behavior was monitored by two observers who viewed the infant through peepholes on either side of the apparatus. The observers were not told and could not see which test event the infant was shown (when the primary (more experienced) observers were asked to guess which of the two test events the infant saw, their accuracy was approximately 50%, which is chance performance). Each observer held a joystick connected to a computer and depressed the trigger whenever the infant attended to the events, keeping the trigger depressed for the duration of looking. Each trial was divided into intervals of 100-ms duration. For each interval, the computer determined whether the two observers agreed on the direction of the infant's gaze. Inter-observer agreement was calculated for each trial as the number of intervals in which the computer registered agreement, out of the total number of intervals in the trial. Agreement in each experiment averaged 91% per trial per infant. The input from the primary observer was used to determine the end of the trials.

Each infant first received one familiarization trial in which only the stationary key ring display could be seen. The trial ended when the infant (a) looked away from the display for 2 consecutive seconds after having looked at it for at least 10 cumulative seconds or (b) looked at the display for 30 cumulative seconds without looking away for 2 consecutive seconds.

Following the familiarization trial, each infant saw either the Move-apart or the Move-together test event (see below for description of test events) on each of two successive trials. Each test trial ended when the infant (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 8 cumulative seconds (the length of one event cycle) or (b) looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds. Each infant completed the full set of 2 test trials.

2.1.4. Events

2.1.4.1. Move-together event. At the start of each test trial, the curtain was raised and the infant could see the experimenter's hand on the floor of the apparatus about half way between the key ring and the opening in the left wall. After 1 s, the hand grasped the ring (1 s) and slid it 10 cm directly away from the infant at the approximate rate of 5 cm/s (2 s). The keys moved with the ring as a single, rigid unit. The hand paused for 1 s and then slid the ring and keys back to their starting positions (2 s). The hand then resumed its initial position on the apparatus floor (1 s). Each event cycle thus lasted about 8 s. Cycles were repeated without stop until the computer signaled that the trial had ended. When this occurred, a second experimenter lowered the curtain in front of the apparatus.

2.1.4.2. Move-apart event. The Move-apart event was identical to that just described except that only the ring moved and the keys remained stationary throughout the trial. In subsequent experiments, the Apparatus, Procedure, and Events were identical to those just described unless noted.

2.2. Results

2.2.1. Preliminary analyses

The effects of Familiarization Trial, Sex, and Test Trial were investigated via analysis of variance (ANOVA). The infants looked about equally at the familiarization trial, regardless of whether they would see the Move-apart ($M = 12.9$ s, $SD = 2.8$ s) or the Move-together ($M = 11.2$ s, $SD = 0.7$ s) test event ($F(1, 14) = 2.7$, $p = .12$). A main effect of Sex was observed, with females looking longer overall than males (37 and 20 s, respectively; $F(1, 12) = 9.6$, $p = .009$). However, there was no significant effect of Sex on the infants' looking times at the two test events ($F(1, 12) < 1$). The data were therefore collapsed across these variables for subsequent analyses. We will henceforth only report findings from these analyses and other analyses that are reliable.

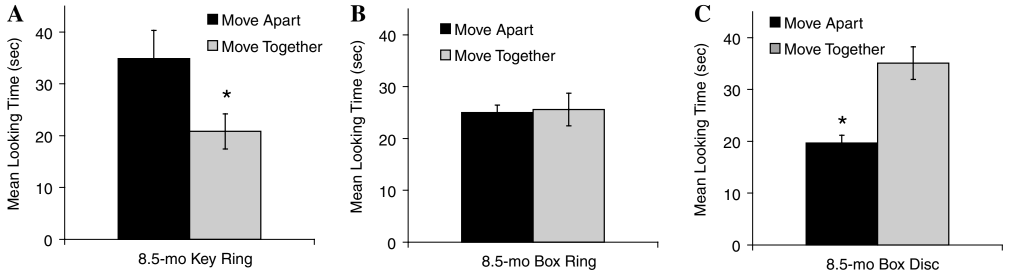

Fig. 3. Mean looking times from 8.5-month-old infants for Move-apart and Move-together events in (A) Experiment 1 with the Key Ring Display, (B) Experiment 2 with the Box Ring Display, and (C) Experiment 3 with the Box Disc Display. Results suggest that infants perceived the Key Ring Display as a single unit, the Box Ring display as ambiguous, and the Box Disc Display as two separate units.

2.2.2. Primary analyses

The infants' mean looking times at the two test events are shown in Fig. 3A. The infants' looking times at the two test events were submitted to a 1-factor ANOVA, with Test Event as the between subjects factor. This analysis yielded a significant main effect of Test Event, with the infants who saw the Move-apart event ($M = 34.9$ s, $SD = 15.3$ s) looking reliably longer than the infants who saw the Move-together event ($M = 20.8$ s, $SD = 9.6$ s), $F(1, 14) = 4.81$, $p < .05$. The data from subsequent experiments were analyzed in this same fashion.

2.3. Discussion

The infants looked reliably longer at the Key Ring Display when the ring moved apart from the keys than when the keys and ring moved together in test, indicating that they grouped the visible portions of the Key Ring Display into a single unit and did not expect the ring to move apart from the keys. On what basis did infants form their expectations? There are many demonstrations in the literature that infants use similarities and dissimilarities in object attributes to determine object boundaries by 8.5 months of age (Johnson & Aslin, 1996; Needham, 1998, 1999, 2000). So, these findings are unlikely to reflect a basic inability to process the attributes of the display. However, this argument would be strengthened by evidence that removing the attributes that help identify the display as a key ring (e.g., the bumpy edges or 'teeth' of the keys, the open ring that holds the keys together) would alter the infants' perception of the display. This strategy was taken up in Experiments 2 and 3.

3. Experiment 2

If removing some of the identifying attributes of the Key Ring Display alters infants' perception of the display (and thus their responses to the test events), we can be more confident that these attributes were critical to the formation of the percept in the first place. In Experiment 2, a small cover was placed over the portion of the display visible to the right of the screen—the "keys" portion of the display. This manipulation ensured that the overall size, colors, and spatial configuration of the keys were maintained, but the attributes by which the keys would be identified as keys (e.g., the bumpy edges of the keys that were facing the infant and the boundary seams between each key in the stack) were missing (see Fig. 1B, Box Ring Display). If infants used these attributes to determine that the Key Ring Display used in Experiment 1 was composed of a single unit, the removal of these attributes should change infants' percept of the display. If these attributes were not used, there should be no difference between the infants' responses to the Box Ring Display and their responses to the Key Ring Display used in Experiment 1.

3.1. Method

3.1.1. Participants

Participants were 16 infants (8 male) ranging in age from 8 months, 15 days to 8 months, 29 days ($M = 8$ months, 22 days, $SD = 4.1$ days). Half of the infants saw the Move-apart test event, and half saw the Move-together test event. Two additional infants were tested but their data were eliminated, one due to fussiness and one due to experimenter error. All of the infants had extensive experience with key rings prior to their visit to our lab, according to their parent.

3.1.2. Apparatus, procedure, and events

The keys portion of the display was replaced with a box of the same approximate overall dimensions as the keys in the display used in Experiment 1. The box was decorated with stripes that were the same in size and color as the keys in the key portion of that display. The stripes were roughly horizontal, in emulation of the keys in the original display. Thus, the visual attributes of this display were very similar to that in Experiments 1 and 2, but it looked like two geometric objects (or possibly a geometric object on a ring) rather than a key ring.

3.2. Results

The infants' mean looking times at the two test events are shown in Fig. 3B. The analyses of the infants' looking time at the test events yielded no significant effects ($F(1,14) = .01$, $p = .92$), suggesting that the infants looked about equally at the Move-apart ($M = 25.0$ s, $SD = 11.9$) and the Move-together test events ($M = 25.6$ s, $SD = 12.3$), $F(1,14) = .01$.

3.3. Discussion

The infants in Experiment 1 perceived the Key Ring Display to be a connected unit, and this finding was hypothesized to be a result of infants' knowledge of the key ring category. The results of Experiment 2 supported this interpretation: when the display was altered such that the "key" portion no longer had the distinctive attributes of keys, the 8.5-month-old infants looked about equally at the two test events, suggesting that their interpretation of the display was not of a single object or of two separate objects, but rather of an indeterminate display. It is possible, given the presence of the ring in the display, that some infants regarded the display as connected pieces. Objects other than keys are sometimes put on rings, especially for infant rattles. Perhaps eliminating this "objects on a ring" interpretation as a possibility would lead the infants to parse the display into two separate pieces. This possibility was investigated in Experiment 3 by covering the ring with a solid front surface with texture elements (Box Disc Display, see Fig. 1C). Perhaps infants would perceive this display, devoid of attributes that could allow an observer to identify it as a key ring, as composed of two separate units.

4. Experiment 3

4.1. Method

4.1.1. Participants

Participants were 16 infants (9 male) ranging in age from 8 months, 14 days to 8 months, 29 days ($M = 8$ months, 24 days, $SD = 4.4$ days). Half of the infants saw the Move-apart test event, and half saw the Move-together test event. Two additional infants were tested but their data were eliminated, one because its average looking time was over 2 standard deviations from the mean, and one due to the infant's grasping of the test display during the study. All of the infants had extensive experience with key rings prior to their visit to our lab, according to their parent.

4.1.2. Apparatus, procedure, and events

The apparatus, procedure, and events used in Experiment 3 were the same as those used in Experiment 2, with the following exceptions. The ring part of the display was covered with blue craft foam (similar to construction paper), to create a solid front surface for the ring part of the key ring. This blue surface was highlighted with small white circular texture elements ("dots"). Thus, the visual attributes of this display were very similar to that in Experiment 2, but now there was no possibility of interpreting the display as an object on a ring as there was in Experiment 2. The most likely interpretation of the Box Disc Display was of two geometric objects.

4.2. Results

The infants' mean looking times at the two test events are shown in Fig. 3C. Analyses of the infants' looking time at the test events yielded a significant effect of Test Event, indicating that the infants looked reliably longer at the Move-together ($M = 35.1$ s, $SD = 5.6$ s) than at the Move-apart test event ($M = 19.7$ s, $SD = 2.6$ s), $F(1, 14) = 6.21$, $p < .05$.

4.3. Discussion

As mentioned in the discussion of Experiment 2, it is possible that covering only the keys portion of the display left open the interpretation that the Box Ring Display was some sort of toy on a ring (perhaps a rattle of some kind). Support for this possibility came when our results revealed that a change in the display that removed more of the attributes that could be used to identify it as a key ring led to another change in the infants' percept—the infants perceived the visible portions of the Box Disc Display as disconnected. Together, the results of Experiments 1–3 suggest that the 8.5-month-old infants in Experiment 1 recognized the Key Ring Display as a known object, and used their category knowledge to determine that the keys and ring were part of a single object.

However, one might still be concerned that the changes made to the Key Ring Display to produce the Box Ring and the Box Disc Displays did not just remove the identifying attributes of the key ring, but also introduced new attributes that could have influenced the infants' percepts as well. To address this potential problem, a group of younger infants was tested with the Key Ring Display. If our stimulus manipulations across Experiments 1–3 did serve to tap infants' knowledge of key rings differentially, and if these younger infants have not yet developed this category knowledge, they should perceive the Key Ring Display much like the older infants perceived the Box Disc Display (as two separate objects). However, if our attempts to remove the identifying attributes of a key ring across Experiments 1–3 were somehow misdirected, the younger infants' percept of the Key Ring Display may be somewhat different.

5. Experiment 4

5.1. Method

5.1.1. Participants

Participants were 16 infants (8 male) ranging in age from 7 months, 2 days to 7 months, 26 days ($M = 7$ months, 12 days, $SD = 7.5$). Half of the infants saw the Move-apart test event, and half saw the Move-together test event. One additional infant was tested but his data were eliminated, because of experimenter error. All of the infants had extensive experience with key rings prior to their visit to our lab, according to their parent.

5.2. Results

The infants' mean looking times at the two test events are shown in Fig. 4. Analyses of the infants' looking time at the test events yielded a significant effect of Test Event, with the infants who saw the Move-together event ($M = 34.6$ s, $SD = 9.9$ s) looking reliably longer than the infants who saw the Move-apart event ($M = 20.3$ s, $SD = 11.2$ s), $F(1, 14) = 7.29$, $p < .05$.

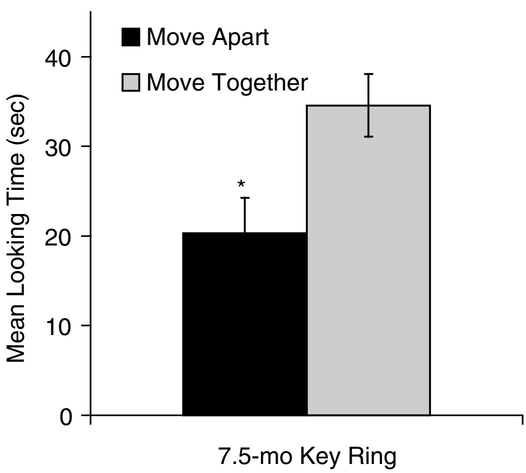

Fig. 4. seven-month-old infants' mean looking times at the two test events in Experiment 4. This pattern of results suggests that infants perceived the Key Ring Display as two separate units.

5.3. Discussion

The 7-month-old infants perceived the Key Ring Display as composed of two separate units, a finding consistent with a number of studies in the literature showing that young infants do not unify the visible portions of partly occluded objects if their visible surfaces are dissimilar in their visual attributes such as orientation, shape, color, and pattern/texture (e.g., Johnson & Aslin, 1996; Needham, 1998; Needham, Baillargeon, & Kaufman, 1997). These results suggest that the stimulus manipulations introduced to the Key Ring Display to produce the Box Ring and Box Disc displays were in fact tapping infants' key ring category knowledge differentially. Much like the 8.5-month-old infants in Experiment 3, who saw a display that was missing the identifying attributes of a key ring, the younger infants in the current experiment also did not perceive the visible portions of the display as connected. The infants apparently saw no meaningful relation between the keys and the ring, but rather perceived them as separate objects.

5.3.1. Cross-experiment analyses

To compare the results of these experiments more directly, two cross-experiment analyses were performed. In the first, the looking times of the 8.5-month-old infants in Experiments 1–3 were compared via a between-subjects ANOVA with Display (Key Ring, Box Ring, and Box Disc) and Event (Move-apart or Move-together) as factors. This analysis yielded a significant Display × Event interaction, $F(2,42) = 5.61$, $p < .01$. Fisher's LSD post hoc tests revealed that the infants who saw the Key Ring Display looked reliably longer when it broke apart than the infants who saw the Box Disc Display (Experiment 3) when it broke apart, ($t = 6.38$, $p < .05$), whereas the infants who saw the Box Ring Display were not reliably different from either of these other Move-apart groups. Likewise, the infants who saw the Box Disc Display looked reliably longer when the visible portions moved together than the infants who saw the Key Ring Display ($t = 4.72$, $p < .05$). The infants who saw the Box Ring Display were not reliably different from either of these Move-together groups.

In the second analysis, the looking times of the infants in Experiments 1, 3, and 4 were compared (those of Experiment 2 were not included because they were not significantly different from either of the other groups in the analysis just described and seemed unlikely to reveal any interesting differences in this analysis either). Recall that the groups of 8.5- and 7-month-old infants in Experiments 1 and 4 both saw the Key Ring Display and the 8.5-month-old infants in Experiment 3 saw the Box Disc Display. An ANOVA for Display (Key Ring or Box Disc) × Event (Move-apart or Move-Together) produced a significant interaction between Display and Event, $F(2,42) = 7.79$, $p < .005$. Fisher's LSD post hoc tests revealed that the 8.5-month-old infants who saw the Key Ring display break apart looked reliably longer than either the 7-month-old infants who saw the same display move apart ($t = 4.7$, $p < .05$) or the 8.5-month-old infants who saw the Box Disc Display move apart ($t = 6.38$, $p < .05$). Similarly, the 8.5-month-old infants who saw the Key Ring Display move together looked reliably less than the 7-month-old infants who saw the same display move together ($t = 7.94$, $p < .05$) and the 8.5-month-old infants who saw the Box Disc Display move together ($t = 4.72$, $p < .05$). The responses of the 8.5-month-old infants to the Box Disc Display were indistinguishable from the responses of the 7-month-old infants to the Key Ring Display, supporting our conclusion that the older infants used the identifying attributes of the Key Ring to identify it, but the younger infants did not.

6. General discussion

These results indicate that 8.5-month-old infants identified the novel key ring shown in the Key Ring Display as part of a known category of objects and that this identification allowed infants to infer that the keys and ring were connected. Without this knowledge of key rings, infants would presumably have parsed the display into two separate units (as the 7-month-old infants did) using generic parsing principles.

Experiments 2 and 3 provided support for an identification-based interpretation of the results by delivering evidence that systematically removing the identifying attributes of a key ring produced a significant change in how the infants parsed the display—from a single unit (with identifying attributes of both keys and ring present) to indeterminate (with the identifying attributes of the keys removed) to clearly two separate units (with identifying attributes of both keys and ring removed).

Remarkably, the 7-month-old infants responded to the Key Ring Display in much the same way that the 8.5-month-old infants responded to the Box Disc Display. These findings indicate that the 7-month-old infants did not regard the identifying attributes of the Key Ring Display as meaningful in the same way that the older infants did. Why? We doubt that there is a qualitative change in infants' cognitive ability between 7 and 8.5 months of age, but rather the additional time gives infants more of a chance to encounter more key ring exemplars and create a representation that is more generalizable. Perhaps infants at both ages have a key ring category, but the younger infants may not be able to extend this representation to the novel exemplar used in our key ring display as readily as the older infants could. Thus, if the display consisted of their own key ring toy, perhaps they would be able to make this judgment successfully.

Questions about whether it is the amount or kind of experience or amount or kind of consolidation opportunities will be addressed in a training study in which 7-month-old infants are given carefully timed exposure(s) to a single key ring or a group of key rings, to determine the critical experiences for formation and use of this knowledge. Further interesting comparisons could be made between visual only, manual only, and visual-manual experiences to determine whether handling keys might confer an advantage over visual experience alone.

The present findings (like those of Munakata et al., 2001) call into question the strong form of (Xu & Carey's (1996, 2000); Xu et al., 1999) argument, that success on a variety of cognitive tasks (e.g., segregation, individuation) critically depends upon infants' knowledge of the words for the objects involved in the task. Success in the task used in the present research were more likely due to the development of representations formed as a result of infants' observations of and interactions with key rings rather than knowing the word for this object. The MacArthur scale for receptive vocabulary indicates that 18.6% of 8-month-old infants' parents and 26.1% of 9-month-old infants' parents report that their infant knows the word "keys" (Dale & Fenson, 1996). Thus if language facilitates representation, some of our infants may know the word keys and may use this representation to help them form a lasting concept of keys or key ring. Of course, there is the possibility that our infants' parents spoke to them about keys while they played with keys—parents may have explicitly labeled keys for their infants. However, it is not clear how to explain our age effect from this perspective. Our view is that language may well facilitate representational abilities, but language is not the "key" that makes useful representation possible.

6.1. What is the nature of the representation?

In order to show evidence of categorization, one must show that a new instance of the category is included in the representation and that an instance outside the category is not included. Our results show evidence for both—that 8.5-month-old infants regard the novel key ring shown in the Key Ring Display as part of a known category and that they reject the objects shown in the Box-Ring and Box-Disc displays as part of this category. However, one question we have not addressed is whether the category representation that allows for the accurate perception of the novel key ring is better thought of as perceptual or conceptual in nature. Many researchers of adult perception and cognition are skeptical of such dichotomies arguing that there is no difference in the fundamental nature of perceptual and conceptual representations (Barsalou, 1999; Goldstone & Barsalou, 1998). In the infant literature these differences carry more meaning, in part because of Piaget's well-known assertion that children were not capable of true representation and therefore true conceptual activity until 1.5–2 years of age.

The field of infant categorization has been rife with disagreement about whether early categorization is grounded in the conceptual or the perceptual world (Mandler, 2004; Quinn & Johnson, 2000), and although the findings in this paper bear upon this argument, they are not likely to resolve it. We do present evidence of the development of a category representation that is not based solely on perceptual information; the keys and ring look nothing alike and so could not be grouped together based on similarity. Instead, this grouping must be produced by a representation of some other aspect of infants' experience with objects like the key ring display. Our interpretation is that this is evidence for the development of object knowledge. By 8.5 months of age, on average, infants have knowledge about key rings that they apply to this novel key ring.

One might argue that the representation used to interpret this novel instance of a key ring as a single object contains only "perceptual" information, such as the physical dimensions on which previously viewed key rings are known to vary. Our data show that infants expected the keys and ring to move as one connected unit, and this expectation is a kind of functional knowledge about a key ring. Although at a global level, we might think of the function of keys being to open doors or start cars, at a more local level, the key ring itself functions to hold keys together as a unified whole. Is this conceptual or purely perceptual? We think it is a kind of functional information—or at the very least a gray area between perceptual and conceptual information.

A clearer demonstration of function would be obtained from infant responses regarding the canonical use of a key ring, such as to unlock a door. Although one might be skeptical that functional categorization could happen this early in life, a demonstration of this phenomenon was reported a number of years ago by Greco et al., 1990. In this study, 3-month-old infants treated a distinctive butterfly windchime hanging from the mobile stand as something that could be moved via their kicking movement if they saw the windchime moving as the training mobiles had moved, but not if they did not see this movement. Although the specifics of these two paradigms are obviously very different, future experiments will determine whether they share a conceptual link.. In our paradigm, we could provide 7-month-old infants with different kinds of exposure to key rings (e.g., purely visual and static vs. moving as when unlocking a door) to see whether certain kinds of experience are more useful than others in contributing to cognitive structures that facilitate these categorization judgments.

6.2. What kinds of input support learning?

What do we know about the exposure our infants received to key rings? We asked parents to indicate how often their infant saw or played with a key ring toy (e.g., rattle, other kind of noise maker) or saw or played with a caregiver's real keys. All parents indicated that their baby received either visual or manual experience with either real keys or a key ring toy at least once a week, and most encountered key rings on a daily basis. In other research examining parents' judgments about which objects their infants had seen, we found that 82% of the 3-month-old infants ($N = 45$) had likely seen at least one key ring, and from 4 months on, 100% of parents judged that their infant had seen a key ring. These responses show that exposure to key rings is quite prevalent even in infants somewhat younger than those in this study. Future research should quantify this exposure more precisely and determine the relations between amount and kind of exposure and the utility of the resulting representation.

6.3. Conclusions

These results suggest that on the basis of typical experience with members of the key ring category, infants can identify a novel member of the category and expect it to have the physical structure that other category members have. These findings add to the body of literature indicating that infants understand much about objects prior to the time they know the words for these objects (e.g., Baillargeon, 1995; Carver & Bauer, 1999; Greco et al., 1990; Mandler, 2004; Schilling & Clifton, 1998; Wilcox, 1999). Further research is needed to understand how infants come to regard object categories as familiar, what information they store about these categories, and how broadly they use this knowledge. Answers to these questions will provide important insights into the origins and developmental trajectory of the interactions between higher and lower level perceptual and cognitive processes. Mapping out these relations will bring us closer to an understanding of the ways in which infants learn about the world and the ways in which this knowledge is used to create solutions to problems regarding understanding the world, how the world looks, and how to act within the world.

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