Title

Using object history to predict future behavior: Evidence for essentialism at 9 months of age

Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 40(0)

Authors

Cheng, Chen
Kaldy, Zsuzsa
Blaser, Erik

Publication Date

2018

Using object history to predict future behavior: Evidence for essentialism at 9 months of age

Chen Cheng (Chen.Cheng001@umb.edu)
Zsuzsa Kaldy (Zsuzsa.Kaldy@umb.edu)
Erik Blaser (Erik.Blaser@umb.edu)
Department of Psychology, University of Massachusetts Boston, 100 Morrissey Blvd., Boston, MA 02139

Abstract

Preschool-age children show essentialism (Gelman, 2003), ascribing an essence to an object that includes its history, and which can determine behavior. While infants show the precursors of essentialism, such as maintaining object representations during naturalistic occlusion (6-month-olds; Kaufman, Csibra, & Johnson, 2005), and resisting individuating two disparate appearances of an object when shown that one can change into the other (14-month-olds; Cacchione, Schaub, & Rakoczy, 2013), the implicit precursors of essentialist reasoning in infants have not been directly studied. Here we tested whether young infants could use an object's prior history to predict its behavior, even after it had changed into a novel shape. Critically, the object either smoothly morphed into the novel shape (facilitating an essentialist interpretation) or was replaced by a new shape (discouraging essentialist interpretation). Results showed that 9-month-old infants (N = 22) in the *Morph* condition predicted the novel object would have the same behavior as the pre-transformation object; an essentialist interpretation. However, in the *Replace* condition (N = 22), predictions for the novel object were at chance; infants seemed to have lost the link to the pre-transformation object. Furthermore, results from a group of 6-month-olds (N = 15) showed that they failed to maintain this link, even in the *Morph* condition (which may indicate a failure to apply essentialist reasoning, or, more likely, a failure to adequately remember the pre-transformation object and/or apply the matching rule to predict post-transformation behavior).

Keywords: object representation; spatial-temporal continuity; conceptual development; essentialism; object cognition

Introduction

Objects may undergo radical changes in appearance as they deform, develop, or reconfigure, yet retain their identity, history, and behavior. We know that older children appreciate this stability (Gelman, 2004) - they are not confused as ice cream melts or a robot hero is transformed into a car. In both situations, perceptual features have changed, but, functionality (edible), identity and behavior (justice seeking) remain. What is the developmental course of this 'essentialism'? Evidence from object permanence has shown that 3.5-month-old infants assume an object still exists when it is not perceptually accessible (Baillargeon & DeVos, 1991; Wynn, 1992); similarly, infants as young as 4-months old can keep track of an object while it undergoes a brief occlusion (Johnson, Amso, & Slemmer, 2003). Even in situations where precise information about an object's features are lost during occlusion, 6-month old infants still maintain a 'placeholder' for the object, and are surprised if no object is found behind the occluder (Kibbe & Leslie, 2011). To individuate an object, and maintain its representation, the visual system relies on a continuous spatial-temporal history (Scholl & Leslie, 1999), and a cohesive object boundary (Spelke, 1990; Spelke, 2000). In adults, violation of these principles disrupts mid-level visual processing (Mitroff, Wynn, & Scholl, 2004) and object tracking (Scholl & Pylyshyn, 1999). In infants, when object cohesion is violated, infants lose track of the representation - when presented with a big cracker that is split into two small pieces, 11-month-old infants cannot represent the relative quantity of the crackers (Cheries, Wynn, & Scholl, 2006; Cheries et al., 2008).

Putting together, what seems to matter is how an object becomes perceptually inaccessible. For instance, infants who observed a ball disappear behind an occluder naturalistically looked to the other side of the occluder more often than the other group of infants who observed the object disappear via 'implosion' as it met the occluder. Apparently, the naturalistic occlusion served as a cue that spatial-temporal continuity was not really being violated, thereby helping infants maintain object permanence (Bertenthal, Longo, & Kenny, 2007). In another study where the object disappeared via a natural (but invisible) occlusion, a neural signature showed that 6-month-olds' representation of the object was maintained, yet when the object disappeared via 'disintegration', the neural signature indicated the representation was lost (Kaufman, Csibra, & Johnson, 2005).

Through daily observation and experience, infants' expectations about an object can be less superficial. Several studies have demonstrated that infants can individuate objects as same or different based on what they have learned through interacting (i.e. going beyond outward appearance) with the objects (Cacchione, Schaub, & Rakoczy, 2013; Woods & Schuler, 2014). For example, even at 8.5-months, once infants learn that a set of objects can change their shapes, they no longer use shape as an individuating feature (Woods & Schuler, 2014). Using a manual search task, 14-month-old infants who were presented with a toy that can be folded understood that a single object could appear in two forms, yet maintain its 'identity' and not trigger the expectation that a new object had appeared (Cacchione, Schaub, & Rakoczy, 2013).

Demonstrating the deeper properties/relations of an object can induce similar robust representations. When adults shared causal information about how a toy works (e.g., functionality), 11-12-month-old infants quickly pick it up and use the information as the categorization cue (Träuble & Pauen, 2007), since its functionality intrinsically defines the object. Similarly, when 3-year-olds were explained why two visually distinct artifacts share the same name, they then used the creator's intent to extend the naming scheme, overriding physical similarities (Diesendruck, Markson, & Bloom, 2003). Furthermore, a recent study has shown that ostensive communication could trigger the learning of hidden dispositional properties, which helped 11-month-old infants to disambiguate 'kind' representations of objects, and overcome salient surface features (Kovács et al., 2017).

Taken together, there is considerable evidence that infants and toddlers can build durable representations of objects that go beyond perceivable characteristics. Our study is concerned with objects' behavior: is a transformed object expected to maintain its behavior (e.g., does melting ice cream stay sweet? does a robot hero still seek justice when configured as a car?)? This has been addressed in the theory of psychological essentialism (Gelman, 2003). While the literature has mostly studied preschoolers and involved language, one study examined 14-month-olds' object reasoning based on external and internal features (Newman et al., 2008). They found that infants expected objects, that exhibited self-generated motion, to behave congruently to one another if they shared an internal feature (in their 'stomach') but not if they only shared an external feature (on their 'hat'), suggesting the emerging concept of essentialism. Moreover, a recent study in apes has suggested that even in the absence of language, apes show evidence of essentialist reasoning (Cacchione et al., 2016).

Here, we tested 9-month-old infants' ability to predict an object's behavior after they have seen it transform into a novel shape (e.g., a heart, which always moves home to its matching heart-box, and not the star-box, has now turned into an oval: Where will it go?). This ability to maintain an object's representation (that includes its behavior) in spite of changing appearance would seem a critically important faculty for interacting with a dynamic, evolving visual scene. We also contrasted whether the nature of the transformation influenced infants' prediction of how the object will move. In our *Morph* condition, spatial-temporal continuity was maintained during the object transformation. In the *Replace* condition, continuity was broken.

From previous studies, we have seen evidence that preverbal infants used objects' internal features to individuate and categorize an object between the ages of 8.5 and 14 months (Newman et al., 2008; Cacchione, Schaub, & Rakoczy, 2013; Woods & Schuler, 2014; Kovács et al., 2017). The present study primarily focused on 8- to 10-month olds, aiming to provide evidence of the early onset of this ability. We hence hypothesized that the more naturalistic *Morph* transformation would facilitate an essentialist interpretation of the change, promoting maintenance of the object representation, allowing for predictions of its behavior; while the spatiotemporal break in the *Replace* condition would leave infants with a compromised basis for predicting the behavior of the new object.

Experiment 1

Method

Participant Forty-four 8- to 10-month-old healthy, full-term infants were recruited from Greater Boston area, and tested at University of Massachusetts Boston. Participants were randomly assigned to one of the two conditions: *Morph* (M_{age} = 9.2 months, SD = 0.87) and *Replace* (M_{age} = 9.0 months, SD = 0.76). An additional 9 infants were tested, but excluded due to insufficient data (each infant needed to complete a minimum of three test trials to be included in further analyses: 4 infants in the *Morph* condition and 5 infants in the *Replace* condition).

Stimuli Infant participants sat on their caregivers' lap in a dimly lit testing room and watched the experimental stimuli on a computer screen. A Tobii T120 eye-tracker (Tobii Technology, Stockholm, Sweden) tracked their gaze. The caregivers were asked to wear a visor to cover their eyes, and not to interact with their infant during the experiment. We used the standard Tobii 5-point infant calibration. Animated virtual objects served as experimental stimuli: a heart-shape, a star-shape, and an oval shape. Two 'boxes' also appeared on screen, one marked with a heart, and one with a star.

Procedure The experiment consisted of three phases: familiarization, training and testing session. In the 6 familiarization trials, an object (either the heart or the star) entered the top of the screen, then two boxes entered the bottom of the screen, one marked with a heart and one with a star. After that, the object moved to the center of the screen, and then approached the box with the matching shape (*Match*). Following this, a reward animation was presented at that location (e.g. fireworks at the box's location). In the subsequent 6 training trials, after the object moved to the center, it paused for 2 s, during which time we monitored anticipatory eye movements to the two boxes (see Figure 1a). Training was identical in both the *Morph* and *Replace* conditions.

Following familiarization and training, 12 test trials were presented. In test trials, the object (heart or star) first entered from the top of the screen. Then the object underwent a transformation. In the *Morph* condition, pieces of the object sloughed off, 'whittling' it down to an oval-shaped object. In the *Replace* condition, the object 'disintegrated', disappearing completely, then, after 1 s, an oval coalesced in its place (see Figure 1b). After the transformation interval, the procedure was the same as the training trials: the (now, oval) object moved to the center of the screen, paused for 2 s ("response interval"), then moved to the 'matching' box. This allowed us to measure anticipatory looks during the response interval: would infants expect the oval to behave the same as

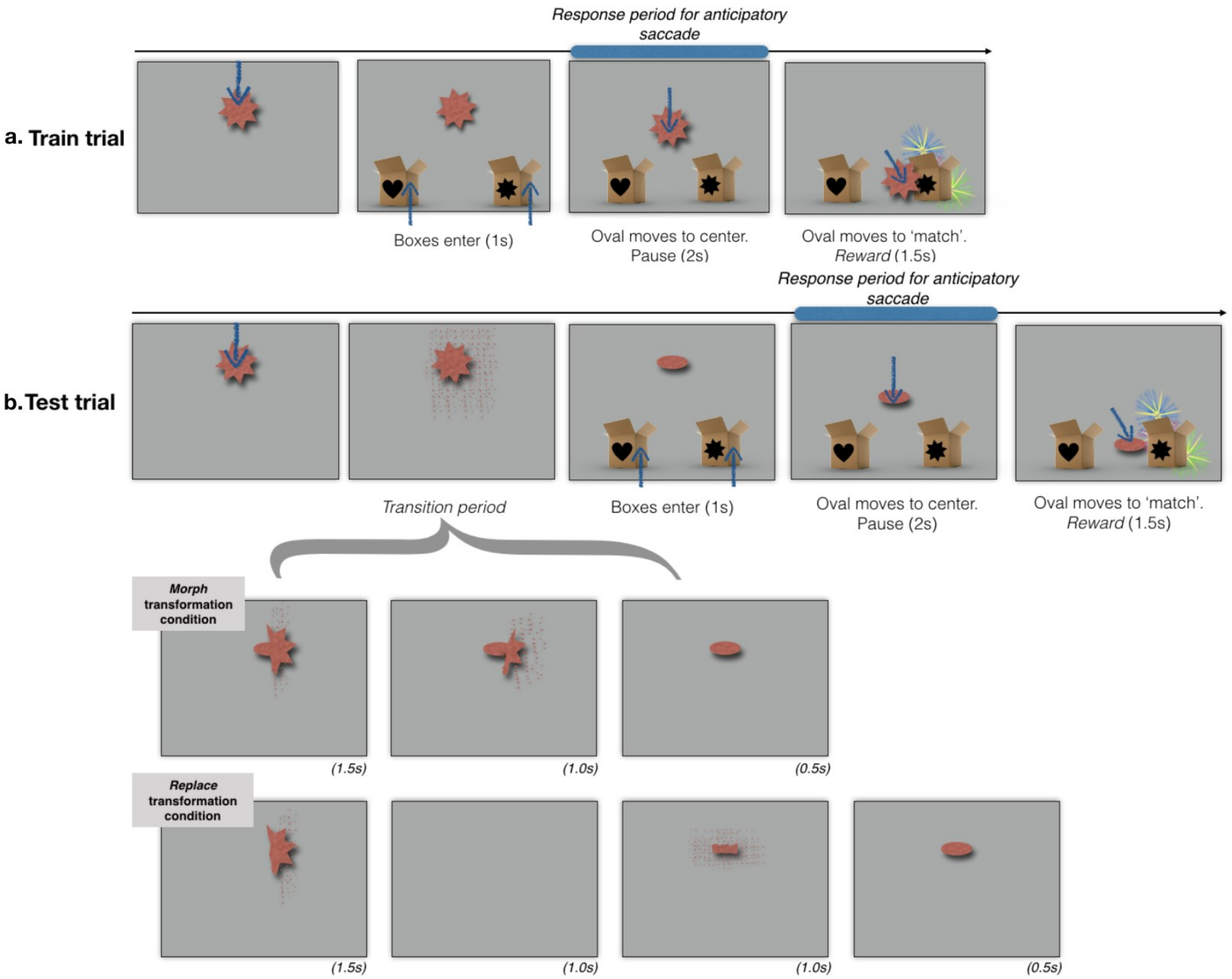

Figure 1a. Typical training trial; Figure 1b. Typical test trial for Experiments 1 and 2. In the *Morph* condition, the object is whittled down to an oval-shape object; in the *Replace* condition, the object disintegrates, and an oval-shape coalesces in its place.

the pre-transformation object, that is, to move toward the box that matched the pre-transformation object, and would one of the transformations facilitate that assumption? Throughout the block, an attention grabber appeared on the screen every three trials to engage infants. As well, we counterbalanced, over trials, the object type (heart or star), the side of the *Match* and *Non-Match* box (left or right), and the reward animation type, to avoid any side or order bias.

Data analysis and Results

Objects and boxes were each bounded by a rectangular area of interest subtending 7 x 9 deg. We calculated difference scores over the training trials and the test trials. Difference scores were based on which of the boxes (the *Match* or the *Non-Match* box) received the first look during the 2 s response interval [(number of trials with first look to the *Match* box minus number of trials with first looks to the *Non-Match* box) divided by (number of trials with first looks to either the *Match* or the *Non-Match* box summed)]. If the infant did not look at either of the boxes during the response interval, the trial could not be analyzed and was excluded[1].

Positive difference scores indicate that infants looked more often to the *Match* box, while negative scores indicate that infants looked more often to the *Non-Match* box. To compare these difference scores with chance (difference score = 0), we performed a one-sample t-test. In the *Morph* condition, infants looked to the *Match* box significantly more often than the *Non-Match* box, showing that they predicted the (transformed, oval-shaped) object would approach the box marked with the 'matching' pre-transformation shape (t(21) = 2.38, p = 0.027, Cohen's d = 1.04, Difference score = 0.20). In the *Replace* condition, the difference score was not different from chance (t(21) = 1.20, p > 0.05, Cohen's d = 0.52, Difference score = - 0.10), suggesting that infants did not make a consistent prediction.

---

[1] On average, infants completed 6.9 valid test trials in *Morph*, and 7.5 valid test trials in *Replace* condition. There were no difference between the number of valid test trials completed between conditions (t(42) = 0.71, p>0.05).

Next, we tested whether there was a learning effect over the block of 12 trials. Splitting the block in half, we calculated difference scores in the first half of the block of trials (trials 1-6) versus the second half of the block (trials 7-12), and again compared difference scores to chance. The *Morph* condition showed evidence of learning, with infants looking more often to the *Match* box in the last six trials (t(20) = 3.14, p = 0.03, Cohen's d = 1.02, difference score = 0.24), but not in the first 6 trials. In the *Replace* condition, the difference score in the last half of the test trials was not above chance (in fact, it was marginally below chance (t(20) = 1.97, p = 0.07, Cohen's d = 0.89, difference score = -0.26) (see Figure 2).

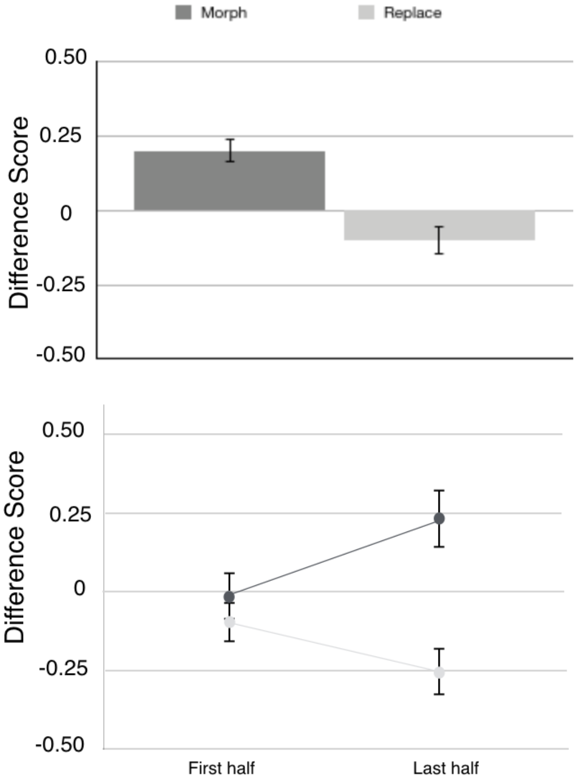

Figure 2. Results of Experiment 1. The top panel shows infants' difference scores in the *Morph* and the *Replace* conditions over 12 test trials. The bottom shows infants' difference scores in first and last half block of the test trials in *Morph* (indicated as dark grey) and *Replace* (light grey) condition. Error bars indicate standard error.

We analyzed performance during training trials as well. Since training trials preceded test trials, and were the same for both conditions, data from the two conditions were collapsed. Looking at difference scores, there was no preference to look at the *Match*, (t(43) = 0.40, p = 0.69, difference score = 0.02). As this was unexpected, we then performed a time course analysis to assess looking trends over the trial that might have been missed by the first look-based difference scores. The time course analysis, for each moment of the response interval, contrasts whether the subject was fixating the *Match* or the *Non-match*, forming a record of the proportion of time participants spent on one item versus the other, as the anticipation interval unfolds. Throughout the response interval (over 1.7 s of the 2 s interval), participants were more likely to fixate the *Match* (Figure 3). A functional t-test (Jackson & Sirois, 2009; Ramsay & Silverman, 1997) showed this difference reaching significance approximately 1 s after the start of the anticipation interval.

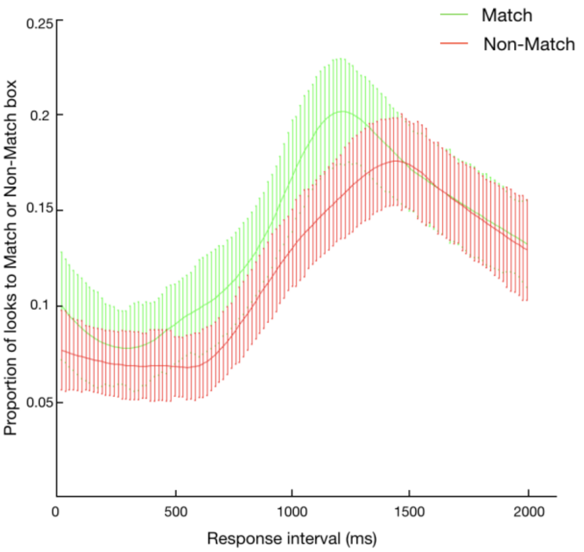

Figure 3. Proportion of looks to *Match* (indicated as green) and *Non-Match* (indicated as red) box during response interval in training session. Error bars indicate standard error.

Experiment 2

Experiment 1 showed that 9-month-olds could use an object's perceptual history to predict its behavior, even after it had transformed in appearance, but only when that transformation maintained spatiotemporal continuity (*Morph* condition). To investigate the age at which this ability emerges, we tested a younger group of 6-month-olds, in the *Morph* condition of Experiment 1.

Method

Participants Fifteen 5- to 7-month old (M_{age} = 6.2 months, SD = 0.87) healthy, full-term infants were recruited from the Greater Boston area, and tested at University of Massachusetts Boston. One additional infant was excluded from further data analysis due to fussiness.

Stimuli, Procedure, and Data Analysis Stimuli, procedure, and data analysis were identical to the *Morph* condition in Experiment 1.

Results

Our results showed that 6-month-old infants did not make any consistent predictions about the object's behavior after it had undergone a transformation in appearance in our task: there was no significant preference for the *Match* or the *Non-Match* box (t(14) = 0.37, p > 0.05, Cohen's d = 0.13, difference score = - 0.05) during the test trials. When we restricted our analyses to the last half of the test trials, in an effort to capture potential learning effects, the results remained the same (t(14) = 0.84, p > 0.05, Cohen's d = 0.45, difference score = 0.13).

An analysis of the difference scores during the training trials showed no evidence that the infants learned the matching rule (t(14) = 0.4, p > 0.05). We again performed a time-course analysis, but there was no time period when infants looked significantly more toward the *Match* than the *Non-Match* box.

General Discussion

Previous studies have shown that by 4 years of age, children are 'essentialists', able to base object representations on properties like functionality, ownership, and behavior, even as appearance changes (Gelman, 2003; Keil, 1989). However, little research has looked at the origins of essentialistic reasoning in preverbal infants. In our study, we provided evidence that - even when an object changed appearance - 9-month-old infants were able to use spatial-temporal history to predict its behavior.

In this study, participants were familiarized with the idea that objects had a predictable behavior: they always moved toward a box that was marked with a symbol that matched the object's shape (so, the heart moved toward the box with the heart on it, and not the box with the star on it). We were able to assess whether infants learned this contingency by measuring how often they made an anticipatory eye movement toward the matching box, prior to the object's movement to that location. In our main manipulation, prior to starting its trajectory toward the boxes, the object underwent a brief, animated transformation, changing into a novel, oval shape. In the *Replace* condition, during this transformation, the object disintegrated, momentarily disappearing, and then an oval coalesced in its place. In the *Morph* condition, the animation was visually similar, but the object only disintegrated away its outer contour, and was whittled down to the oval shape. We hypothesized that this *Morph* condition would facilitate an essentialist interpretation of the change, with infants assuming the presence of a single object that had just changed appearance. This would mean attributing the behavior of the original object, for instance, the heart, to the oval, prompting anticipatory eye movements toward the 'matching' heart-box. On the other hand, we hypothesized that the *Replace* condition, given the violation of spatiotemporal continuity, better supported the interpretation that the original object had gone missing, leaving no basis for a prediction about which box the new, oval object will approach.

Our study is the first, to our knowledge, to provide evidence of emerging an essentialist-like reasoning towards objects in young infants. In Experiment 1, 9-month-old participants' results were positive in the Morph condition, with infants making predictions about the oval shape based on the identity of the pre-transformation shape. Our finding was also in line with previous evidence, suggesting that infants' representation of objects identity can be flexibly updated based on experience with specific events (Cacchione, Schaub, & Rakoczy, 2013; Woods & Schuler, 2014; Kovács et al., 2017). In contrast, we found negative results in the Replace condition, that is, infants did not anticipate that transformed object would behave the same as the pre-transformation object. In fact, in the last 6 test trials, infants' prediction of the transformed object's trajectory was marginally toward the Non-Match box. Further study is required to confirm the robustness of this trend, so here we can only speculate, but it may indicate a 'mutual exclusivity' (Halberda, 2003) strategy at work. Given that there are only two objects in this study (heart and star), if one, say, the heart, disappears, then a rational interpretation of the proximal (oval) object would be that it would exhibit 'star-like' behavior. This reasoning strategy has recently been demonstrated in infants as young as 12 months of age (Cesana-Arlotti et al., 2018).

6-month-old infants, in Experiment 2, failed to predict the matching behavior of the transformed object in the Morph condition. This may reflect a failure of essentialism, or the processes that underlie it, such as, in our case, memory and rule learning. It is possible that 6-month-olds could represent the continued identity of the transformed object in our Morph condition, but for successful performance, they also had to remember both the identity of the original object and the rule ("star goes to the star-box"). Since their performance in the training trials showed that these younger infants had difficulty learning the matching rule, that is the most likely explanation for the negative results. Further study, with more extensive or efficient training, is needed in order to test this explanation definitively.

The current evidence shows not only that infants exhibit behavior consistent with the essentialist reasoning by 9 months, but also that the persistent attribution of an object's behavior can be robust to radical transformations in appearance. Here, we have argued that the nature of the transformation matters for whether the essentialist reasoning is encouraged or discouraged. Objects disappearing magically (Kaufman, Csibra, & Johnson, 2005), or breaking into pieces (violating object cohesion (Spelke, 1990; Spelke, 2000; Mitroff et al., 2004; Cheries et al., 2008), are more likely to reflect a fundamental loss of the original object. Yet in the natural world, infants frequently encounter enduring objects that do not maintain a stable appearance; the 'sloughing off' transformation in the *Morph* condition alters shape, but maintains spatiotemporal continuity, like petals falling from a flower. This encourages the maintenance of the representation of the object, including properties like intention and behavior.

Acknowledgments

This work was supported by NIH (R15HD086658) and a Dissertation Grant from University of Massachusetts Boston. We warmly thank all participating parents and children to the Baby Lab at UMass Boston. Thanks to all research staff and assistants for help with data collection.

References

Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child development*, *62*(6), 1227-1246.

Bertenthal, B. I., Longo, M. R., & Kenny, S. (2007). Phenomenal permanence and the development of predictive tracking in infancy. *Child development*, *78*(1), 350-363

Cacchione, T., Hrubesch, C., Call, J., & Rakoczy, H. (2016). Are apes essentialists? Scope and limits of psychological essentialism in great apes. *Animal cognition*, *19*(5), 921-937.

Cacchione, T., Schaub, S., & Rakoczy, H. (2013). Fourteen-month-old infants infer the continuous identity of objects on the basis of nonvisible causal properties. *Developmental psychology*, *49*(7), 1325.

Cesana-Arlotti, N., Martín, A., Téglás, E., Vorobyova, L., Cetnarski, R., & Bonatti, L. L. (2018). Precursors of logical reasoning in preverbal human infants. *Science*, *359*(6381), 1263-1266.

Cheries, E. W., Mitroff, S. R., Wynn, K., & Scholl, B. J. (2008). Cohesion as a constraint on object persistence in infancy. *Developmental Science*, *11*(3), 427-432.

Cheries, E. W., Wynn, K., & Scholl, B. J. (2006). Interrupting infants' persisting object representations: an object-based limit?. *Developmental Science*, *9*(5).

Diesendruck, G., Markson, L., & Bloom, P. (2003). Children's reliance on creator's intent in extending names for artifacts. *Psychological Science*, *14*(2), 164-168.

Gelman, S. A. (2003). *The essential child: Origins of essentialism in everyday thought*. Oxford Series in Cognitive Dev.

Gelman, S. A. (2004). Psychological essentialism in children. *Trends in cognitive sciences*, *8*(9), 404-409.

Halberda, J. (2003). The development of a word-learning strategy. *Cognition*, *87*(1), B23-B34.

Jackson, I., & Sirois, S. (2009). Infant cognition: going full factorial with pupil dilation. *Developmental science*, *12*(4), 670-679.

Johnson, S. P., Amso, D., & Slemmer, J. A. (2003). Development of object concepts in infancy: Evidence for early learning in an eye-tracking paradigm. *Proceedings of the National Academy of Sciences*, *100*(18), 10568-10573.

Kaufman, J., Csibra, G., & Johnson, M. H. (2005). Oscillatory activity in the infant brain reflects object maintenance. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(42), 15271-15274.

Keil, F. C. (1989). The MIT Press series in learning, development, and conceptual change. Concepts, kinds, and cognitive development.

Kibbe, M. M., & Leslie, A. M. (2011). What do infants remember when they forget? Location and identity in 6-month-olds' memory for objects. *Psychological Science*, *22*(12), 1500-1505.

Kovács, Á. M., Téglás, E., Gergely, G., & Csibra, G. (2017). Seeing behind the surface: communicative demonstration boosts category disambiguation in 12-month-olds. *Developmental science*, *20*(6).

Newman, G. E., Herrmann, P., Wynn, K., & Keil, F. C. (2008). Biases towards internal features in infants' reasoning about objects. *Cognition*, *107*(2), 420-432.

Ramsay, J. O., & Silverman, B. W. (1997). Functional Data Analysis Springer-Verlag. *New York*.

Scholl, B. J., & Pylyshyn, Z. W. (1999). Tracking multiple items through occlusion: Clues to visual objecthood. *Cognitive psychology*, *38*(2), 259-290.

Scholl, B. J., & Leslie, A. M. (1999). Explaining the infant's object concept: Beyond the perception/cognition dichotomy. *What is cognitive science*, 26-73.

Spelke, E. S. (1990). Principles of object perception. *Cognitive science*, *14*(1), 29-56.

Spelke, E. S. (2000). Core knowledge. *American psychologist*, *55*(11), 1233.

Träuble, B., & Pauen, S. (2007). The role of functional information for infant categorization. *Cognition*, *105*(2), 362-379.

Woods, R. J., & Schuler, J. (2014). Experience with malleable objects influences shape-based object individuation by infants. *Infant Behavior and Development*, *37*(2), 178-186.

Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*(6389), 749.