Published in final edited form as:

Infant Behav Dev. 2014 May ; 37(2): 178–186. doi:10.1016/j.infbeh.2014.01.005.

Experience with Malleable Objects Influences Shape-based Object Individuation by Infants

Rebecca J. Woods and Jena Schuler

North Dakota State University

Abstract

Infants' ability to accurately represent and later recognize previously viewed objects, and conversely, to discriminate novel objects from those previously seen improves remarkably over the first two years of life. During this time, infants acquire extensive experience viewing and manipulating objects and these experiences influence their physical reasoning. Here we posited that infants' observations of object feature stability (rigid versus malleable) can influence use of those features to individuate two successively viewed objects. We showed 8.5-month-olds a series of objects that could or could not change shape then assessed their use of shape as a basis for object individuation. Infants who explored rigid objects later used shape differences to individuate objects; however, infants who explored malleable objects did not. This outcome suggests that the latter infants did not take into account shape differences during the physical reasoning task and provides further evidence that infants' attention to object features can be readily modified based on recent experiences.

Keywords

object individuation; object features; infant cognition; learning; shape

1. Introduction

The ability to remember objects, people, and scenery, and conversely, to correctly identify as new any information that has never been previously experienced underlies humans' capacity to learn about the world. Knowledge vital to human existence is dependent on memory-based processes, as without them, we would be incapable of learning from previous encounters with people, objects and other components of the environment. Despite substantial research investigating the development of these and related perceptual-cognitive abilities (Baillargeon, 2004; Leslie, Xu, Tremoulet, & Scholl, 1998; Rose, Feldman, & Jankowski, 2004; Spelke, 1996; Van de Walle, Carey, & Prevor, 2000; Wang & Mitroff, 2009; Wilcox & Baillargeon, 1998a; Xu & Carey, 1996), much is yet to be learned about the experiences that lead humans to recognize the information within the environment that is

Correspondence concerning this article should be addressed to Rebecca Woods, Department of Human Development and Family Science, North Dakota State University, Dept. 2615, P.O. Box 6050, Fargo, ND 58108-6050, U.S.A. Phone: +1 701-231-9791. Fax: +1 701-231-9645. rebecca.woods@ndsu.edu.

Rebecca J. Woods, Department of Human Development and Family Science, North Dakota State University; Jena Schuler, Department of Psychology, North Dakota State University.

Jena Schuler is now at Department of Psychology, University of North Dakota.

most reliably used to identify a percept or distinguish it from other previously experienced entities. The most reliable information, information that is consistent within and across situations, is often given priority by adults when making same-different judgments. However, infants' sensitivity to the usefulness of various sources of information that can be used to make same-different judgments is less certain. In this study, we investigated the possibility that, like adults, infants are responsive to consistency of information and that useful information is attended when establishing that a percept is the same or different from one previously experienced.

1.1 Object Individuation

Similar to adults, infants and toddlers possess the ability to distinguish new from previously experienced perceptual information and they use this information to determine when a new object has been encountered (Krøjgaard, 2007; Leslie, et al., 1998; Van de Walle, et al., 2000; Wang & Mitroff, 2009; Wilcox & Baillargeon, 1998a; Xu & Carey, 1996). This ability, termed object individuation, relies on both attention and memory processes; it requires the ability to encode and maintain representations of individual objects as well as the ability to mentally compare an object representation to a currently perceived object. As such, assessment of object individuation abilities in infancy aids in elucidating the development of these processes. The ability to make this same-object versus different-object distinction provides a foundation for the perception of a stable world assembled from objects continuing through time.

One source of information to which infants attend when individuating and identifying objects is object features, such as shape or color (Kaldy & Leslie, 2003; Krøjgaard, 2007; Wilcox & Baillargeon, 1998a; Wilcox, 1999; Zosh & Feigenson, 2012). Attention to featural information allows infants as young as 4.5 months to individuate objects in a variety of situations (Wilcox, 1999; Wilcox, Smith, & Woods, 2011). Studies investigating the development of object individuation have revealed that infants' use of features as a basis for individuation is inconsistent; infants show evidence of utilizing some feature changes to individuate objects, but not others. For example, Wilcox (1999) demonstrated that infants attended to a shape difference (cube versus sphere) during an object individuation task at 4.5 months but not a pattern difference (dots versus stripes).

Research investigating the processes through which infants become sensitive to feature information has revealed that infants' attention to object features is flexible and can be altered by recent experiences (Kingo & Krøjgaard, 2011; Wilcox, Woods, & Chapa, 2008; Woods & Wilcox, 2012). For example, Wilcox and Chapa (2004) demonstrated that 7.5- and 9.5-month-old infants can be primed to attend to color differences and 4.5- and 5.5-month-olds to attend to pattern differences to individuate objects. Prior to an object individuation task, infants were presented with events in which a specific color or pattern was associated with a distinct function. Infants saw a green cup pound a wooden peg and a red cup pour salt into a container. Infants subsequently used these same color differences as the basis for object individuation. This study, together with related studies, demonstrates that infants can be primed to attend to features to which they do not spontaneously attend when

individuating objects. One question that we ask here is whether infants can learn to disregard object features that they typically use as a basis for object individuation.

1.2 Object Feature Stability

Many studies demonstrate that across varying domains infants attend to consistencies in their environment (Aslin, 2011; Gopnik, et al. 2004; Kirkham, Slemmer, & Johnson, 2002; Saffran, 2003; Wu, Gopnik, Richardson, & Kirkham, 2011). As a result, information that infants have observed to be inconsistent or unpredictable may be disregarded. When reasoning about objects, if infants detect and attend to the stability of object properties, particular properties may appear predictable while other object properties may appear less predictable. A three-dimensional shape is generally perceived by infants and adults to be rigid and unchanging, and thereby, relatively stable. Shape constancy, present from birth (Slater & Morison, 1985), aids in the perception of shape as a stable property. Even when viewed from various angles, objects are perceived as being comprised of a single shape; this stable percept occurs despite the numerous images that may be projected onto the retina as an object is rotated or seen from multiple perspectives. Adding to the perceived predictability of shape, the majority of objects experienced or perceived do not change shape or do so at an imperceptible rate. As a result, one may, with considerable accuracy, predict whether an object in view will be recognizable later based solely on shape.

Patterns, in contrast, may have the appearance of being relatively unpredictable object features. Because the patterns visible on objects' surfaces can include shadows or refracted light from prisms, objects' surface patterns can give the impression of being readily altered. Misperceptions of visually specified surface pattern may be particularly prevalent in infants, who have poor visual acuity and contrast sensitivity (Skoczenski, 2002; Skoczenski & Norcia, 2002). A consequence of these immaturities may be that infants have difficulty interpreting patterns or identifying pattern origins, whether from object surfaces (e.g., pigment) or lighting conditions (e.g., shadows), because the visual information used by adults to differentiate patterns created by shadows from other patterns is often dependent on the perception of fine details (Cavanagh & Leclerc, 1989). Infants' confusion regarding visible surface patterns is apparent in their considerable difficulty in comprehending shadows (Imura, et al., 2006; Van de Walle, Rubenstein, & Spelke, 1998; Yonas & Granrud, 2006).

Infants' sensitivity to the shapes and patterns of objects corresponds to the perceptible stability of these features; infants are considerably responsive to the shape of objects and less so to the visible patterns on objects' surfaces. Shape is used by infants to parse objects in a visual scene, as well as to individuate, identify, and categorize objects (Kaldy & Blaser, 2009; Kaldy & Leslie, 2003; Leslie & Chen, 2007; McMurray & Aslin, 2004; Needham, 1999; Tremoulet, Leslie, & Hall, 2000; Wilcox, 1999), and is prioritized over other object properties during early word learning (e.g., Gershkoff-Stow & Smith, 2004; Samuelson & Smith, 2005). Patterns, in contrast are used less frequently or not at all.

Further evidence of the importance of object feature stability in determining infants' sensitivity to particular features comes from a study by Schaub and her colleagues (Schaub, Bertin, & Cacchione, 2013). Using a search task, Schaub demonstrated that when an object's

shape is shown to be changeable, 12-month-old infants show indications that they perceive a single object, despite seeing two different shapes. In their study, Schaub and colleagues presented 12-month-olds with either a rigid or malleable object and then hid the object in a box. When infants subsequently searched for the object in the box, they retrieved an object that was either the same shape or a different shape than the one initially hidden. Afterward, infants were given the opportunity to search in the box a second time. Those who had been presented with the rigid object searched in the box longer than infants who had been presented with a malleable object. The explanation offered for this outcome was that upon perceiving a different object than the one that was initially hidden, infants who had been presented with an object that was rigid returned to the box to search for the first object. Infants who had been presented with the malleable object, however did not perceive the presence of a new object, so search behavior was not motivated by the expectation that a second object remained hidden in the box. These findings suggest that at least by 12 months, infants are sensitive to the predictable nature of shape.

1.3 The Present Research

In the present study, we assessed object individuation by infants on the basis of shape information following their observations of shape's stability (unchanging versus changing). This study extended the findings of Schaub and colleagues (2013) in two ways. Our first goal was to determine whether younger infants (i.e., 8.5-month-olds) were attentive to and influenced by shape's malleability. Our second goal was to examine the extent to which infants' experiences with malleable objects can be generalized. If use of object features can be influenced by experiences of feature stability in 8.5-month-olds, repeated demonstrations of instability should attenuate use of a particular feature as a basis for object individuation, whereas demonstrations of stability should preserve or enhance use of a feature. We assessed the flexibility with which infants individuate objects based on feature stability by testing infants' use of object shape, a feature typically used by infants to keep track of objects across viewings. In a series of demonstration sessions, an experimenter presented infants with objects of various shapes and then deformed and reformed each object or performed similar actions without deforming the objects. These sessions displayed how object shape was or was not changeable. The deformable objects were fashioned from a solid, non-rigid substance that had the capacity to change shape when manipulated. Previous research investigating infants' perception of non-rigid objects demonstrates that infants are able to distinguish rigid from non-rigid objects (Gibson, Owsley, Walker, & Megaw-Nyce, 1979; Palmer, 1989; Walker, 1980), and maintain representations of non-rigid entities provided they remain cohesive units (Huntley-Fenner, Carey, & Solimando, 2002). Furthermore, the perception of an object's rigidity has been shown to inform and guide infants' interpretations of physical events (Aguiar & Baillargeon, 1998; Schweinle & Wilcox, 2004). If, as these studies suggest, infants perceive the malleable shapes used in the current study as unified objects and maintained mental representations of the malleable objects, information regarding shape's variability has the potential to be applied to new objects in different contexts.

We explored possibility that infants' experiences of malleability with one set of objects would generalize to new objects that had not previously been seen. Evidence suggests that

infants are capable of generalizing learning to new situations and contexts (Bahrick, 2002; Bauer & Dow, 1994; Hayne, Barr & Herbert, 2003; McDonough & Mandler, 1998) and that generalization can be facilitated through the use of multiple exemplars (Smith, 2003; Son, Smith, & Goldstone, 2008; Wilcox, Woods & Chapa, 2008). Information that is common across exemplars is extracted while the impact of other information is reduced. We propose that if we provide infants sufficient evidence that an object's shape can transform by presenting multiple exemplars of malleable objects, infants will generalize learning of shape's instability to new objects.

To assess this possibility, following the demonstrations, infants' use of shape in an object individuation task was assessed using two new objects that had not previously been seen. Three primary methods used to assess object individuation in infant populations are search tasks, event-mapping tasks, and event-monitoring tasks (Hall, Corrigan, Rhemtulla, Donegan, & Xu, 2008; Krøjgaard, 2004; Van de Walle, et al., 2000; Wilcox & Baillargeon, 1998a, 1998b; Zosh & Feigenson, 2012). We chose to use the narrow-screen task, an event-monitoring task, because it is one of the least cognitively demanding of the object individuation assessments and is appropriate to this age group (Wilcox & Baillargeon, 1998b; Wilcox & Woods, 2009). The narrow-screen task is a violation-of-expectation task in which infants see either a 'expected' or an 'unexpected' event. According to the reasoning of violation-of-expectation tasks, if infants perceive the event in the same way as adults, the 'expected' event should elicit only mild interest, but the 'unexpected' event should elicit intense interest, as measured by prolonged looking, as a signal that the event was contrary to their expectation.

In the narrow-screen task, depicted in Figure 1, infants see one object move across a platform and behind a screen (see Figure 1a). After the object is fully hidden, a new object emerges from behind the screen following the same trajectory as the first (see Figure 1b). The trajectory is then reversed and repeated several times. The objects differ in some critical way, such as in color or shape. Some infants see the objects move behind a wide screen (see Figure 1d), one that is wide enough to hide both objects. This is the 'expected' event. Other infants see the objects move behind a narrow screen that is too narrow for both objects to hide simultaneously (see Figure 1c). This is the 'unexpected' event. Infants' looking to the event is monitored and if infants look longer at the 'unexpected' event than to the 'expected' event, it is taken as evidence that infants individuated the objects based on the key difference in the two objects. That is, when the new object appeared, infants saw the object as an entity distinct from the object they had seen previously. In event-monitoring tasks, such as this one, the violation occurs within a single event. Event-mapping tasks, in contrast, require infants to map information from one event to a different event. For example, they may see the same object-hiding event described above, but afterward an additional event occurs; the screen rotates down revealing a single object. To detect a violation, infants must map the information from the first event (i.e., two objects sequentially traversing a platform from behind a screen) to the second event (i.e., a single object revealed). Krøjgaard (2004) provides further discussion on the various methods used to assess object individuation and the assumptions underlying each.

Our hypothesis was that following the demonstration sessions, if 8.5-month-old infants detect and attend to feature stability and if they generalize to other objects, infants will look longer to the narrow- than the wide-screen event indicating that they use shape to individuate objects only when shape is shown in the demonstration trials to be rigid and unchanging. When shape is shown to be changeable, they will not. Rather, we propose that when shape is shown to be malleable, infants' looking to the narrow or wide screen events will be similar suggesting that they did not use the shape differences as a cue for individuating the objects.

2. Method

2.1 Participants

Forty-eight 8.5-month-old infants ($M = 8$ months, 14 days; range = 8 months, 1 day to 8 months, 28 days), half male, 47 Caucasian and one Hispanic were pseudo-randomly assigned (i.e., an attempt was made to balance the number of males and females in each condition) to one of four conditions ($n = 12$) formed by crossing demonstration-session objects (rigid or malleable) by the screen size (narrow or wide) used for the object-individuation assessment. Six additional infants were tested but eliminated from the sample due to sickness ($N = 1$), distractions ($N = 1$), failure to complete the study ($N = 2$), and computer error ($N = 2$).

2.2 Apparatus and Stimuli

Objects for the demonstration sessions were six rigid objects made of wood or plastic and six comparable malleable objects formed from Crayola Model Magic[®], each approximately 5 cm in size (see Figure 1). Objects were arranged into four sets. Two sets, one set crafted of Model Magic and one set of wood, included a sphere, cylinder, and cube. The other two sets, one set made of Model Magic and one set made of plastic, included a squiggle, elongated star, and bee hive. Crafting of the malleable stimuli prior to each trial was supervised by senior research assistants to ensure consistency.

During the familiarization and test trials of the narrow-screen task, the objects used were a plastic ball 10.25 cm in diameter and box 10.25 cm cubed, each attached to a clear Plexiglas base 3.5 x 25.5 cm. Both objects were painted with Ceramcoat[®] Jubilee Green acrylic paint. A puppet-stage-like apparatus, 60 cm high x 105 cm wide x 25 cm deep, sat on a table 72 cm high. The side walls were wood grain and the back wall was a gray marbled pattern. The stage was lit with 16-watt fluorescent bulbs affixed to the side walls and six 25-watt halogen bulbs across the ceiling. Centered on the gray laminate floor was a gray felt platform 60 cm wide x 15 cm deep with an 11 cm gap in the center. At the gap was a 14 cm high and 15 cm deep recess in the floor, allowing an experimenter to hide an object below floor level. Infants viewed the events through an opening in the front of the apparatus 52 cm high and 80 cm wide. A panel was lowered over the opening to signal the end of each trial. To each side of the stage a canvas-covered frame (146 cm x 88 cm) concealed an observer and shielded infants from the experimental room.

A yellow matte board familiarization screen measured 41 x 30 cm. Two dark blue matte board test screens, one narrow (41 x 17 cm) and one wide (33 x 30 cm), were decorated with

small gold stars (see Figure 1c, d). During each trial, a screen was centered in front of the platform thereby concealing the recess.

2.3 Events and Procedure

The experiment began with a two-minute demonstration session during which infants were given one set of objects appropriate for their condition, either rigid or malleable. Twenty-four infants played with one of the rigid object sets (12 with the rigid sphere, cylinder and tube, and 12 with the rigid squiggle, elongated star, and bee hive). Another twenty-four infants played with the malleable versions of the same objects (see Figure 2). Each object was presented for 40 seconds starting with the infants' first look resulting in sessions that lasted approximately 120 second. The demonstration session alternated between experimenter-guided and infant-guided exploration. During experimenter-guided exploration, the experimenter engaged in a variety of behaviors including rubbing the objects between her hands, tapping, twisting or stretching, and reshaping the objects into a similar or a new shape. Each object was first presented to the infant by holding at his or her eye level. Once the infant had looked at the object, the experimenter encouraged the infant to take the object. After approximately five seconds, the experimenter performed a deforming action (squeeze and twist the object). The experimenter then allowed the infant to independently explore the object for 5 to 10 seconds. This procedure was repeated for each behavior. Behavior motions were performed for both treatments, and when possible, while the infant held the object. If the infant refused to take the object within the first five seconds, the experimenter performed the first action while the infant watched. The experimenter then once more encouraged the infant to take the object. Infants were not allowed to mouth the objects; when necessary, the experimenter quickly placed her hand between the object and the infant's mouth to prevent mouthing. When an infant started to lose interest, the experimenter called his or her name or said, "Look!" to regain the infant's attention and tapped on the object. Written procedures and a training video were used as a reference to maintain consistency in procedures over time.

Following the demonstration sessions, infants moved to a separate testing room to watch a modified narrow-screen task (Wilcox & Baillargeon, 1998a, 1998b). Infants sat on a parent's lap approximately 80 cm from the display objects. Two observers monitored infants' looks through peepholes in frames positioned to either side of the apparatus by depressing a button connected to a computer. Interobserver agreement averaged 90% per trial.

Infants first saw a familiarization event on six successive trials (see Figure 1a, b). The familiarization began with the ball resting to the left of the familiarization screen and the box hidden in the recess in the apparatus floor. After infants had looked at the ball for at least 1 second, the trial began. The ball paused (1 second) then moved to the right until it was concealed behind the familiarization screen. When the ball was positioned directly above the box, the experimenter simultaneously lifted the ball and box until the box was even with the platform. Then the box moved to the right emerging from behind the screen and coming to rest at the right end of the platform. Four seconds elapsed from onset of the ball's movement until the box came to rest and paused (1 second). Both objects moved 12

cm per second. The objects' movement was then reversed and repeated until the end of the trial. Each trial ended when the infant looked away for 2 seconds after having looked for at least 10 seconds or looked for a total of 60 seconds without having looked away for 2 seconds.

Next infants saw four test trials. Test trials were identical to the familiarization except that the familiarization screen was replaced by either the narrow- or wide-test screen. Two objects could fit behind the wide, but not the narrow screen, therefore we expected infants to look longer to the narrow-screen event if they attended to the shape difference. Each test trial ended when the infant looked away for 2 seconds after having looked for at least 5 seconds or looked for a total of 60 seconds without having looked away for 2 seconds.

3. Results

Looking times obtained by the primary observer during the familiarization and test trials were averaged across trials and mean scores were analyzed using a 2 x 2 analysis of variance (ANOVA) with demonstration-session type (rigid or malleable objects) and test-screen size (narrow or wide) as between-subjects factors. Results for the familiarization trials indicated no main effects (demonstration, $F(1, 44) = 1.72, p = .20, \eta_p^2 = 0.04$; test-screen size, $F(1, 44) = 0.21, p = .65, \eta_p^2 = 0.005$), nor an interaction, $F(1, 44) = 0.13, p = .72, \eta_p^2 = 0.003$, indicating that infants looked about equally at the familiarization events (rigid-object, narrow-screen, $M = 31.89, SD = 7.46$; rigid-object, wide-screen, $M = 30.23, SD = 9.38$; malleable-object, narrow-screen, $M = 28.46, SD = 5.97$; malleable-object, wide-screen, $M = 28.26, SD = 4.95$; see Figure 3). This outcome was expected given that all infants saw the same familiarization event.

Analysis of test trials revealed a significant main effect of test-screen size, $F(1, 44) = 12.42, p = .001, \eta_p^2 = 0.22$, and a demonstration-session by test-screen size interaction, $F(1, 44) = 5.65, p = .022, \eta_p^2 = 0.114$. Planned comparisons indicated that, following the rigid-object demonstrations, infants who saw the narrow-screen test event looked significantly longer ($M = 23.39, SD = 9.63$) than those who saw the wide-screen test event ($M = 13.18, SD = 3.81$), $F(1, 22) = 11.64, p = .003, \eta_p^2 = 0.35$. However, following malleable-object demonstrations, infants looked equally to the two test events, $F(1, 22) = 1.30, p = .27, \eta_p^2 = 0.06$, (narrow-screen, $M = 17.05, SD = 4.97$; wide-screen, $M = 15.07, SD = 3.38$; see Figure 3). This same pattern of results was obtained for each set of demonstration session stimuli (sphere, cylinder, and tube versus squiggle, elongated star, and bee hive) when analyzed separately.

To ensure that infants who saw the rigid or malleable demonstration sessions were equally engaged, infants' object-exploration time (duration of looking to and touching the object) was coded from video recordings. Inter-coder agreement averaged 96%. Total object-exploration time in seconds was analyzed using a one-way ANOVA with demonstration-session as the between-subjects factor. Results indicated no significant differences in exploration time, $F(1, 45) = 0.009, p = .93, \eta_p^2 = 0.00$, (rigid-objects, $M = 118.10, SD = 20.40$; malleable-objects, $M = 117.47, SD = 25.69$; range for both, 71.8 to 215.6), suggesting

that infants were similarly engaged during object exploration and had sufficient exposure to the objects.¹

Taken together, these results suggest that infants who explored rigid objects throughout the demonstration sessions attended to the objects' shape differences during the occlusion event. Infants expected the differently shaped objects to hide behind the wide, but not the narrow screen. Infants who played with the malleable objects during the demonstration session, however, did not take into account the differences in shape; they showed no evidence that their expectations had been challenged by either event outcome.

4. Discussion

This study assessed the extent to which demonstrations of the stability of objects' shapes influence 8.5-month-old infants' use of shape differences to individuate objects. The focus was on shape, an object feature that both adults and infants typically experience as stable and predictable. In this study, infants were presented with the possibility that the shapes of simple, 3-dimensional objects may be unpredictable; sometimes objects are capable of changing shape within a matter of seconds. Our hypothesis was that following this demonstration, shape information would not be used by infants to individuate novel objects. Results supported this hypothesis. After watching an experimenter deform and reform a set of objects, infants showed no evidence of utilizing shape differences during a subsequent object individuation task involving a different set of objects. In contrast, infants who explored rigid, non-malleable objects utilized shape information and expected the existence of two distinct objects within the display.

These findings confirm and extend previous studies suggesting that when forming new representations of individual items, infants bring to bear information that they have learned from recent encounters with objects, even when these encounters are relatively brief (Schaub et al., 2013; Wilcox et al., 2007; 2008; 2011). Results from this study also provide support for the proposition that in addition to factors such as the perceptual salience of a feature and the distinctiveness of a feature change (Kaldy & Blaser, 2009; Kaldy, Blaser, & Leslie, 2006; Zosh & Feigenson, 2012), infants' utilization of object features to individuate objects can be influenced by information about a feature's stability. Based on previous studies demonstrating that infants spontaneously individuate objects based on shape (Kaldy & Leslie, 2003; Wilcox, 1999), we surmise that infants came into the laboratory-based demonstration sessions with the expectation that shape would be a consistent object property. In the eight months of exposure to shape in the natural world, infants had the opportunity to observe within and across multiple senses that the shapes of toys, simple 3-dimensional objects, generally remain unchanging and that, in all probability, viewing a new

¹No further coding of infants' self-guided exploratory behaviors in response to the two types of objects (e.g., behaviors related to the characteristics or affordances of the objects) was conducted as such analyses are outside the purpose and scope of this study. To our knowledge, no study has made a detailed comparison of the characteristics of infants' self- or adult-guided visual-manual exploration of rigid and playdough-like objects, though it offers an interesting topic for future research. There is, however, a good deal of research demonstrating that infants' exploratory behaviors vary with object affordances (e.g., Gibson & Walker, 1984). Furthermore, we direct the reader to Ruff (1984) and Morange-Majoux (2011) for an investigation and discussion of infants' object exploration in relation to other properties of objects.

shape denotes the presence of a novel object with potentially new properties and affordances.

However, during the malleable object demonstration sessions, infants were presented with a series of shapes that were not stable; shape was altered via manipulation. This demonstration was presented both visually and haptically, allowing confirmation across senses of shape's instability. This information was then applied to two previously unseen objects within the individuation tasks, indicating that the information generalized to other objects presented in the lab setting. Furthermore, the demonstration sessions and individuation tasks occurred in different rooms, showing infants' knowledge transferred to a new context.

These findings are in line with research demonstrating infants' capacity for generalizing new information to other within-category exemplars (Bahrick, 2002; Bauer & Dow, 1994; Hayne, Barr & Herbert, 2003; Mandler & McDonough, 1996). Infants categorize objects on the basis of similarities and generalize object properties and affordances as well as the actions that can be performed on objects to other members of the same category (Madole & Oakes, 1999; McDonough & Mander, 1998; Younger, 1990). The objects seen in the demonstration sessions were perceptually similar to those seen later in the individuation task (i.e., simple 3-dimensional objects) and conceivably from the same category. According to this line of reasoning, after a brief presentation of shape's capability for rapid transformation, knowledge about the nature of the objects experienced (i.e., their shape can be variable) was generalized and applied to the previously unseen objects in the narrow-screen task. The extension of information regarding shapes' variability to the objects used in the object individuation task may have been facilitated by the use of a set of objects rather than a single object for the demonstration sessions. When infants are presented with multiple exemplars, properties that are common across exemplars are extracted and then may be generalized to other objects within the same category (Bauer & Dow, 1994; Bornstein & Mash, 2010; Son, Smith, & Goldstone, 2008; Wilcox, Smith, & Woods, 2011). Further strengthening generalization, the sets of objects used during the demonstration sessions were comprised of objects of various shapes and colors. Variability in category exemplars promotes the formation of broader categories and supports generalization to a wide range of exemplars (Oakes, Coppage, & Dingel, 1997; Ribar, Oakes, & Spalding, 2004).

During the demonstration sessions in the present study, infants had the opportunity to explore the objects visually and manually and information specifying the flexible nature of shape was redundant across sensory modalities. Even very young infants generalize knowledge obtained as a result of information synchronized across two sensory modalities to new objects or contexts (Bahrick, 2002; Morrongiello, Lasenby, & Lee, 2003). For example, in one study, 3.5-month-old infants were presented with objects that were dropped onto a surface thus producing a particular sound (Bahrick, 2002). Sometimes a cluster of objects were dropped and sometimes a single object was dropped. As such, information about the objects' composition (singular or clustered) was presented via two senses, vision and hearing; the object composition information was redundant across senses. Infants later generalized this knowledge to a new situation in which the objects differed in color and shape. In the present study with much older infants, information specifying the composition of the objects, their form, texture, and rigidity, could be obtained both visually and

haptically, thus reinforcing learning based on object shape (Hernandez-Reif & Bahrick, 2001). This information was then transferred to the new objects and contexts. In some cases, information that is presented via two senses can be remembered by infants for an extended period (Morrongiello, Lasenby, & Lee, 2003), suggesting that this knowledge could even be transferred for some time after it was presented.

This study provides clear evidence that by 8.5 months infants can learn about the potential volatility of shape and that this knowledge is applied to novel objects. However, several questions remain to guide future research. One important question concerns the duration of the effect. How long does the effect persist once infants are exposed to the possibility that shape is unstable; does exposure to malleable objects disrupt shape-based object individuation for a brief or an extended period of time (e.g., hours, days, weeks)? We suspect that persistence of the effect depends on the number of counter-experiences with objects, rather than on a specific period of time per se. Because infants learn and reason based on probabilities (Aslin, 2011; Fiser & Aslin, 2002; Gopnik, et al. 2004; Saffran, 2003), we postulate that the information most frequently experienced over time (e.g., the shape of toys and similar objects is rigid and unchanging), will ultimately overpower any brief experiences to the contrary.

Another topic for future research is to identify more precisely how the object representation may have been affected by infants' experience. One possibility is that the demonstration of the unpredictable nature of the malleable objects' shape resulted in the formation of an object representation comprised of other identifying information, such as color, in lieu of shape information. Another equally conceivable possibility is that shape was represented but that infants simply perceived a single object that had changed shape. This possibility had been presented in the demonstration sessions while infants directly observed several objects change shape. In either case, shape had lost its ability to signal the presence of distinct objects.

In conclusion, this study provides valuable information regarding the experiences that influence the formation of new object representations. We demonstrate that by 8.5 months infants are sensitive to information specifying the stability of object shape and that to some extent this information regulates object individuation. This outcome shows that infants are capable of learning about shapes' instability quite rapidly and this knowledge generalizes to new objects and contexts. These findings provide evidence that infants' attention to object features is continually updated and revised based on their experiences. If infants are similarly observant of the potential volatility of other object characteristics, such as pattern or color, we might expect individuation of objects to fluctuate based on recent experiences of those features as well. Finally, this outcome is consistent with research indicating that infants identify and attend to regularities in their environment. Typically, shape is tightly correlated with object identity, particularly of small objects such as toys, with which infants have extensive visuo-haptic experience. When shape is irregular or changeable, viewing a new shape does not reliably signal the presence of a new object distinct from previously perceived objects. This study demonstrates that as early as 8.5 months, infants appear to be sensitive to this regularity and violations of it.

Acknowledgments

This research was supported in part by National Institute of Health grant P20 RR016471 from the INBRE program of the National Center for Research Resources and by an Institutional Development Award (IDeA) from the National Institute of General Medical Sciences of the National Institutes of Health under grant number P20 GM103505. We would also like to thank Ben Balas, Joel Hektner, and Tara Zolnikov as well as the research assistants at North Dakota State University and the parents of the infants who participated in this research.

References

- Aguiar A, Baillargeon R. Eight-and-a-half-month-old infants' reasoning about containment events. *Child Development*. 1998; 69(3):636–653.10.2307/1132195 [PubMed: 9680677]
- Aslin R. Perceptual organization of visual structure requires a flexible learning mechanism. *Infancy*. 2011; 16:39–44.10.1111/j.1532-7078.2010.00053.x
- Bahrack L. Generalization of learning in three-and-a-half-month-old infants on the basis of amodal relations. *Child Development*. 2002; 73:667–681.10.1111/1467-8624.00431 [PubMed: 12038544]
- Baillargeon R. Infants' reasoning about hidden objects: Evidence for event-general and event-specific expectations. *Developmental Science*. 2004; 7:391–414.10.1111/j.1467-7687.2004.00357.x [PubMed: 15484586]
- Bauer PJ, Dow GA. Episodic memory in 16- and 20-month-old children: Specifics are generalized but not forgotten. *Developmental Psychology*. 1994; 3:403–417.10.1037/0012-1649.30.3.403
- Bornstein M, Mash C. Experience-based and on-line categorization of objects in early infancy. *Child Development*. 2010; 81:884–897.10.1111/j.1467-8624.2010.01440.x [PubMed: 20573111]
- Cavanagh P, Leclerc YG. Shape from shadows. *Journal of Experimental Psychology: Human Perception and Performance*. 1989; 15:3–27.10.1037/0096-1523.15.1.3 [PubMed: 2522531]
- Fiser J, Aslin RN. Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences*. 2002; 99:15822–15826.10.1073/pnas.232472899
- Gershkoff-Stowe L, Smith LB. Shape and the first hundred nouns. *Child Development*. 2004; 75:1098–1114.10.1111/j.1467-8624.2004.00728.x [PubMed: 15260867]
- Gibson EJ, Owsley CJ, Walker A, Megaw-Nyce J. Development of the perception of invariants: Substance and shape. *Perception*. 1979; 8:609–619.10.1068/p080609 [PubMed: 530802]
- Gopnik A, Glymour C, Sobel D, Schultz L, Kushnir T, Danks D. A theory of causal learning in children: Causal maps and Bayes nets. *Psychological Review*. 2004; 111:3–32.10.1037/0033-295X.111.1.3 [PubMed: 14756583]
- Gibson EJ, Walker AS. Development of knowledge of visual-tactual affordances of substance. *Child Development*. 1984; 55:453–460.10.2307/1129956 [PubMed: 6723444]
- Hall D, Corrigan K, Rhemtulla M, Donegan E, Xu F. Infants' use of lexical-category-to-meaning links in object individuation. *Child Development*. 2008; 79:1432–1443.10.1111/j.1467-8624.2008.01197.x [PubMed: 18826534]
- Hayne H, Barr R, Herbert J. The effect of prior practice on memory reactivation and generalization. *Child Development*. 2003; 74:1615–1627.10.1046/j.1467-8624.2003.00627.x [PubMed: 14669885]
- Hernandez-Reif M, Bahrack LE. The development of visual-tactual perception of objects: Amodal relations provide the basis for learning arbitrary relations. *Infancy*. 2001; 2:51–72.10.1207/S15327078IN0201_4
- Huntley-Fenner G, Carey S, Solimando A. Objects are individuals but stuff doesn't count: Perceived rigidity and cohesiveness influence infants' representations of small groups of discrete entities. *Cognition*. 2002; 85:203–221.10.1016/S0010-0277(02)00088-4 [PubMed: 12169409]
- Imura T, Yamaguchi MK, Kanazawa S, Shirai N, Otsuka Y, Tomonaga M, Yagi A. Perception of motion trajectory of object from the moving cast shadow in infants. *Vision Research*. 2006; 46:652–657.10.1016/j.visres.2005.07.028 [PubMed: 16153676]
- Kaldy Z, Blaser E. How to compare apples and oranges: Infants' object identification tested with equally salient shape, luminance, and color changes. *Infancy*. 2009; 14:222–243.10.1080/15250000802707088 [PubMed: 20161281]

- Kaldy Z, Blaser EA, Leslie AM. A new method for calibrating perceptual salience across dimensions in infants: the case of color vs. luminance. *Developmental Science*. 2006; 9:482–489.10.1111/j.1467-7687.2006.00515.x [PubMed: 16911450]
- Kaldy Z, Leslie AM. Identification of objects in 9-month-old infants: Integrating ‘what’ and ‘where’ information. *Developmental Science*. 2003; 6:360–373.10.1111/1467-7687.00290
- Kingo OS, Krøjgaard P. Object manipulation facilitates kind-based object individuation of shape-similar objects. *Cognitive Development*. 2011; 26:87–103.10.1016/j.cogdev.2010.08.009
- Kirkham NZ, Slemmer JA, Johnson SP. Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*. 2002; 83:B35–B42.10.1016/S0010-0277(02)00004-5 [PubMed: 11869728]
- Krøjgaard P. A review of object individuation in infancy. *British Journal of Developmental Psychology*. 2004; 22:159–183.10.1348/026151004323044555
- Krøjgaard P. Comparing infants’ use of featural and spatiotemporal information in an object individuation task using a new event-monitoring design. *Developmental Science*. 2007; 10:892–909.10.1111/j.1467-7687.2007.00640.x [PubMed: 17973803]
- Leslie AM, Chen ML. Individuation of pairs of objects in infancy. *Developmental Science*. 2007; 10:423–430.10.1111/j.1467-7687.2007.00596.x [PubMed: 17552932]
- Leslie AM, Xu F, Tremoulet PD, Scholl BJ. Indexing and the object concept: Developing ‘what’ and ‘where’ systems. *Trends in Cognitive Science*. 1998; 2:10–18.10.1016/S1364-6613(97)01113-3
- Madole KL, Oakes LM. Making sense of infant categorization: Stable processes and changing representations. *Developmental Review*. 1999; 19:263–296.10.1006/drev.1998.0481
- Mandler JM, McDonough L. Drinking and driving don’t mix: Inductive generalization in infancy. *Cognition*. 1996; 59:307–335.10.1016/0010-0277(95)00696-6 [PubMed: 8706380]
- McDonough L, Mandler JM. Inductive generalization in 9- and 11-month-olds. *Developmental Science*. 1998; 1(2):227–232.10.1111/1467-7687.00035
- McMurray B, Aslin RN. Anticipatory eye movements reveal infants’ auditory and visual categories. *Infancy*. 2004; 6:203–229.10.1207/s15327078in0602_4
- Morange-Majoux F. Manual exploration of consistency (soft vs hard) and handedness in infants from 4 to 6 months old. *Laterality*. 2011; 16:292–312.10.1080/13576500903553689 [PubMed: 20628962]
- Morrongiello BA, Lasenby J, Lee N. Infants’ learning, memory, and generalization of learning for bimodal events. *Journal of Experimental Child Psychology*. 2003; 84:1–19.10.1016/S0022-0965(02)00162-5 [PubMed: 12553915]
- Needham A. The role of shape in 4-month-old infants’ object segregation. *Infant Behavior & Development*. 1999; 22:161–178.10.1016/S0163-6383(99)00008-9
- Oakes LM, Coppage DJ, Dingel A. By land or by sea: The role of perceptual similarity in infants’ categorization of animals. *Developmental Psychology*. 1997; 33:396–407.10.1037/0012-1649.33.3.396 [PubMed: 9149919]
- Palmer CF. The discriminating nature of infants’ exploratory actions. *Developmental Psychology*. 1989; 25:885–893.10.1037/0012-1649.25.6.885
- Ribar RJ, Oakes LM, Spalding TL. Infants can rapidly form new categorical representations. *Psychonomic Bulletin & Review*. 2004; 11:536–541.10.3758/BF03196607 [PubMed: 15376807]
- Rose SA, Feldman JF, Jankowski JJ. Infant visual recognition memory. *Developmental Review*. 2004; 24:74–100.10.1016/j.dr.2003.09.004
- Ruff HA. Infants’ manipulative exploration of objects: Effects of age and object characteristics. *Developmental Psychology*. 1984; 20:9–20.10.1037/0012-1649.20.1.9
- Saffran JR. Statistical language learning: Mechanisms and constraints. *Current Directions in Psychological Science*. 2003; 12:110–114.10.1111/1467-8721.01243
- Samuelson LK, Smith LB. They call it like they see it: Spontaneous naming and attention to shape. *Developmental Science*. 2005; 8:182–198.10.1111/j.1467-7687.2005.00405.x [PubMed: 15720376]
- Schaub S, Bertin E, Cacchione T. Infants’ individuation of rigid and plastic objects based on shape. *Infancy*. 2013; 18:629–638.10.1111/infa.12023

- Schweinle A, Wilcox T. Intermodal perception and physical reasoning in young infants. *Infant Behavior and Development*. 2004; 27:246–265.10.1016/j.infbeh.2003.11.001
- Skoczenski, AM. Limitations on visual sensitivity during infancy: Contrast sensitivity, vernier acuity, and orientation processing. In: Fagan, J.; Hayne, H., editors. *Progress in infancy research*. Mahwah, NJ: Lawrence Erlbaum Associates; 2002. p. 169-214.
- Skoczenski AM, Norcia AM. Late maturation of visual hyperacuity. *Psychological Science*. 2002; 13:537–541.10.1111/1467-9280.00494 [PubMed: 12430838]
- Slater AM, Morison V. Shape constancy and slant perception at birth. *Perception*. 1985; 14:337–344.10.1068/p140337 [PubMed: 4088795]
- Smith LB. Learning to recognize objects. *Psychological Science*. 2003; 14:244–250.10.1111/1467-9280.03439 [PubMed: 12741748]
- Son JY, Smith LB, Goldstone RL. Simplicity and generalization: Short-cutting abstraction in children's object categorizations. *Cognition*. 2008; 108:626–638.10.1016/j.cognition.2008.05.002 [PubMed: 18565504]
- Spelke, ES. Early cognitive development: Objects and space. In: Gelman, R.; Kit-Fong, T., editors. *Perceptual and cognitive development*. San Diego, CA: Academic Press; 1996. p. 71-114.
- Tremoulet PD, Leslie AM, Hall DG. Infant individuation and identification of objects. *Cognitive Development*. 2000; 15:499–522.10.1016/S0885-2014(01)00038-7
- Van de Walle GA, Carey S, Prevor M. Bases for object individuation in infancy: Evidence from manual search. *Journal of Cognition & Development*. 2000; 1:249–280.10.1207/S15327647JCD0103_1
- Van de Walle GA, Rubenstein JS, Spelke ES. Infant sensitivity to shadow motions. *Cognitive Development*. 1998; 13:387–419.
- Walker AS. Detection of elasticity as an invariant property of objects by young infants. *Perception*. 1980; 9:713–718.10.1068/p090713 [PubMed: 7220243]
- Wang S, Mitroff SR. Preserved visual representations despite change blindness in infants. *Developmental Science*. 2009; 12:681–687.10.1111/j.1467-7687.2008.00800.x [PubMed: 19702760]
- Wilcox T. Object individuation: Infants' use of shape, size, pattern, and color. *Cognition*. 1999; 72:125–166.10.1016/S0010-0277(99)00035-9 [PubMed: 10553669]
- Wilcox T, Baillargeon R. Object individuation in infancy: The use of featural information in reasoning about occlusion events. *Cognitive Psychology*. 1998a; 37:97–155.10.1006/cogp.1998.0690 [PubMed: 9878104]
- Wilcox T, Baillargeon R. Object individuation in young infants: Further evidence with an event-monitoring paradigm. *Developmental Science*. 1998b; 1:127–142.10.1111/1467-7687.00019
- Wilcox T, Chapa C. Priming infants to attend to color and pattern information in an individuation task. *Cognition*. 2004; 90:265–302.10.1016/S0010-0277(03)00147-1 [PubMed: 14667698]
- Wilcox T, Smith T, Woods R. Priming infants to use pattern information in an object individuation task: The role of comparison. *Developmental Psychology*. 2011; 47:886–897.10.1037/a0021792 [PubMed: 21142357]
- Wilcox, T.; Woods, R. Experience primes infants to individuate objects: Illuminating learning mechanisms. In: Woodward, A.; Needham, A., editors. *Learning and the infant mind*. New York, NY: Oxford University Press; 2009. p. 117-143.
- Wilcox T, Woods R, Chapa C. Color-function categories that prime infants to use color information in an object individuation task. *Cognitive Psychology*. 2008; 57:220–261.10.1016/j.cogpsych.2008.02.001 [PubMed: 18378222]
- Wilcox T, Woods R, Chapa C, McCurry S. Multisensory exploration and object individuation in infancy. *Developmental Psychology*. 2007; 43:479–495.10.1037/0012-1649.43.2.479 [PubMed: 17352554]
- Woods RJ, Wilcox T. Posture support improves object individuation in infants. *Developmental Psychology*. 2012 Advance online publication. 10.1037/a0030344
- Wu R, Gopnik A, Richardson DC, Kirkham NZ. Infants learn about objects from statistics and people. *Developmental Psychology*. 2011; 47:1220–1229.10.1037/a0024023 [PubMed: 21668098]

- Xu F, Carey S. Infants' metaphysics: The case of numerical identity. *Cognitive Psychology*. 1996; 30:111–153.10.1006/cogp.1996.0005 [PubMed: 8635312]
- Yonas A, Granrud CE. Infants' perception of depth from cast shadows. *Perception & Psychophysics*. 2006; 68:154–160.10.3758/BF03193665 [PubMed: 16617839]
- Younger BA. Infants' detection of correlations among feature categories. *Child Development*. 1990; 61:614–620.10.2307/1130948 [PubMed: 2364738]
- Zosh JM, Feigenson L. Memory load affects object individuation in 18-month-old infants. *Journal of Experimental Child Psychology*. 2012; 113:322–336.10.1016/j.jecp.2012.07.005 [PubMed: 22932473]

Figure 1.

Schematic of a the first (a) and second (b) trajectories of the familiarization, and the narrow screen (c) and wide screen (d) used during test trials. Dashed arrows indicate direction of object motion.

Figure 2.

Photographs of infants' visual and haptic exploration of the rigid (a) and malleable (b) objects during demonstration sessions. Infants were shown three of the six possible objects appropriate for their session type.

Figure 3.

Mean looking times in seconds with standard error bars during the familiarization and test trials (narrow- and wide-screen) for infants who saw rigid or malleable objects during the demonstration sessions.