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The emergence of kind-based object individuation in infancy

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Abstract

Four experiments investigated whether 12-month-old infants use perceptual property information in a complex object individuation task, using the violation-of-expectancy looking time method (Xu, 2002; Xu & Carey, 1996). Infants were shown two objects with different properties emerge and return behind an occluder, one at a time. The occluder was then removed, revealing either two objects (expected outcome, if property differences support individuation) or one object (unexpected outcome). In Experiments 1–3, infants *failed* to use color, size, or a combination of color, size, and pattern differences to establish a representation of two distinct objects behind an occluder. In Experiment 4, infants *succeeded* in using cross-basic-level-kind shape differences to establish a representation of two objects but *failed* to do so using within-basic-level-kind shape differences. Control conditions found that the methods were sensitive. Infants *succeeded* when provided unambiguous spatiotemporal information for two objects, and they encoded the property differences during these experiments. These findings suggest that by 12 months, different properties play different roles in a complex object individuation task. Certain salient shape differences enter into the computation of numerical distinctness of objects before other property differences such as color or size. Since shape differences are often correlated with object kind differences, these results converge with others in the literature that suggest that by the end of the first year of life, infants' representational systems begin to distinguish kinds and properties.

Keywords: Object individuation; Property representations; Kind representations

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1. Introduction

Human perception and cognition rests, in part, on a fundamental capacity to segregate visual arrays into individual objects (object segregation) and to keep track of these objects through time and space (object individuation). Object segregation processes assign surfaces to distinct objects, whereas object individuation processes assign segregated objects seen on different occasions to single or multiple objects. In this paper, we are concerned with the problem of *object individuation*, the problem that arises when we see a dog on Monday in the park and a dog on Tuesday in the park—Have we seen one and the same dog or two different ones?

Adults use at least three sources of information in solving the problem of object individuation and numerical identity: spatiotemporal information, perceptual property information, and kind/sortal information. Spatiotemporal information includes specification of location and paths. Adults arrive at a representation of two distinct objects if there is no spatiotemporally continuous path that could unite them. Perceptual property information includes dimensions such as color, size, texture, and shape. Adults conclude that a blue cup must be a different object from a previously seen red cup because of the perceptual difference of color. Lastly, kind/sortal information specifies categorization under concepts such as *duck*, *ball*, and *car*, categories of objects united by functional/causal features as well as by perceptual features. Adults draw on kind/sortal information in object individuation when they conclude that the dog that went behind a tree cannot be the same individual as the cat we found in the same location at a later time.

Recent evidence suggests that infants as young as 2 months of age use spatiotemporal information in establishing object identity. When spatiotemporal discontinuity is detected, very young infants establish a representation of two numerically distinct objects (at 2 months: Aguiar & Baillargeon, 1999; at 4 months: Spelke, Kestenbaum, Simons, & Wein, 1995; at 5 months, Wynn, 1992; at 10 months: Xu & Carey, 1996). In contrast, two series of experiments from our laboratories suggest that it is not until 12 months of age that infants can draw on property or kind information in establishing representations of numerical identity (Van de Walle, Carey, & Prevor, 2000; Xu & Carey, 1996). In Xu and Carey (1996) infants were shown an event in which an object, say a yellow toy duck, emerged from behind a screen then returned behind it, followed by an object, say a red ball, emerging from behind the same screen then returning behind it. Adults draw on kind differences (duck/ball) or property differences (yellow/red, duck-shaped/round) to conclude that two numerically distinct objects are involved in this event. The screen was then removed to reveal either both objects (the duck and the ball; the expected outcome) or just one of the two objects (the duck or the ball; the unexpected outcome). At 10 months, infants did not look longer at the unexpected outcome of a single object, suggesting that they did not use the property or kind differences between these objects to conclude that there were two distinct objects behind the screen. By 12 months of age, infants succeeded at this task—they looked longer at the unexpected, single object outcome (for a replication of the 10–12 months shift, see Wilcox & Baillargeon, 1998a, Experiments 1 and 2; for a replication of the failure at 9–10 months, see Bonatti, Frot, Zangl, & Mehler, 2002; Fineberg, 2003; Krojgaard, 2000; and Xu, 2002).

A task with manual search as the dependent measure provided convergent evidence for the emergence of the capacity to use property/kind information as a basis of object individuation at around 12 months (Van de Walle et al., 2000). Ten- and 12-month-old infants were taught to retrieve objects from a box into which they could reach but could not see. Then they were given different types of information concerning the number of objects in the box (one or two). In the property/kind condition, they were shown a ball removed from and replaced into the box, followed by a duck removed from and replaced into it. In the Spatiotemporal Condition, in contrast, they were shown the ball and the duck simultaneously before each object was removed and replaced into the box. After the first object had been retrieved, persistence and duration of search into an empty box was taken as evidence for having established a representation of two distinct objects. The 10-month-old infants showed no evidence of representing two numerically distinct objects in the property/kind condition; they did not search for the second object persistently. In contrast, the 12-month-olds succeeded robustly on this task.

We drew two conclusions from these results. First, infants use spatiotemporal information for establishing distinct objects before they draw on property or kind information. Second, we concluded that infants are unable to use property or kind information to establish numerically distinct objects until about 12 months of age. Subsequent studies have shown this second conclusion to be untenable. In particular, Wilcox and Baillargeon (1998a, 1998b) suggested that if the object individuation task was simplified in various ways, younger infants were able to use property/kind information for object individuation and identity. Wilcox and Baillargeon conducted two sets of studies: the "narrow/wide screen experiments" and the "single trajectory experiments." The single-trajectory experiments" brought the age of success down to 9.5 months. Infants were shown a box moving from one side of the stage and disappearing behind a screen, followed by a ball emerging from the other side of the screen. The screen was then lowered and the infant saw *only* the ball on the stage. Infants looked longer at this outcome relative to a condition where the same ball disappeared behind the screen and reappeared from the other side. Wilcox and Baillargeon concluded that infants must have used the property/kind differences between the ball and the box to establish representations of two distinct objects, such that the outcome revealing only the ball on the stage was unexpected. Several additional studies have also shown that infants younger than 12 months of age are able to use property/kind information to establish representations of two distinct objects. In a simplified manual search study, in which infants see one object (e.g., a cup) placed into the box but retrieve a different object (e.g., a toy car) when they reach inside (object-switch paradigm), subsequent search shows they expect a second object in the box (Xu & Baker, 2003). Using the complex procedure of Xu and Carey (1996), Xu (2002) showed that 9-month-old infants succeeded in establishing a representation of two distinct objects if the objects were given distinctive labels (e.g., "Look, a duck!" vs. "Look, a ball!"). Furthermore, 10-month-old infants succeed without labeling if the contrast is between a doll's head and an inanimate object or a doll's head and a dog's head (Bonatti et al., 2002). Taken together, these studies suggest that by 9–10 months of age, infants are able to use property/kind information in the service of object individuation under some circumstances. (Wilcox and Baillargeon also conducted several "narrow/wide screen experiments" that showed even earlier success. See Appendix A for an alternative interpretation of these results.)

Thus we have at hand three sets of results making conflicting claims on when and how infants are able to use property/kind information for object individuation. (1) Using the complex object individuation task, infants do not success until about 12 months, in both looking time and manual search paradigms (Van de Walle et al., 2000; Wilcox & Baillargeon, 1998a, Experiments 1 and 2; Xu & Carey, 1996). (2) Using the simplified object individuation task, infants succeed at 9.5 or 10 months (Wilcox & Baillargeon, 1998a, Experiments 7 and 8; Xu & Baker, 2003). (3) Using the complex object individuation task, infants succeed at 9 months if given contrastive labels (Xu, 2002) or if given contrasts between a human doll head and a toy dog's head (Bonatti et al., 2002). How do we interpret all these results together? We see at least two possible resolutions of these conflicting data. The first appeals to complexity alone, and is suggested by Needham and Baillargeon (2000) and Wilcox and Baillargeon (1998a, 1998b). The second appeals to a conceptual distinction between kind and property representations. The experiments reported here are directed at a prediction from the complexity alone hypothesis.

As pointed out by Wilcox, Baillargeon, and colleagues, Xu and Carey (1996) used more complicated experimental procedures (single trajectory vs. multiple reversals of trajectory), thus imposing higher information processing demands on the infants than did those of Wilcox and Baillargeon's studies. Van de Walle et al.'s procedure went further still, employing multiple reversals of trajectory and imposing a requirement that the representations be held in short term memory in a form that could support search. A second respect in which the experiments of Xu and Carey and of Van de Walle et al are more complex than those of Wilcox and Baillargeon is that the former used more complex objects—multi-parted, functional objects that offered contrasts on many distinct features (e.g., a duck, a cup, an elephant, a truck), whereas the latter used simple geometric figures that provide contrasts on just a few features (e.g., a blue box and a red ball).

It may be the case that the greater information processing demands masked the infants' competence to use property/kind information for object individuation. This is undoubtedly part of the story, as shown by Wilcox and Baillageon's contrast between single trajectory events and events with multiple reversals of trajectory, and by the contrast between the Van de Walle et al. manual search procedure and the switch procedure of Xu and Baker (2003). Infants of 9.5 or 10 months of age succeed only in the single trajectory and the switch experiments.

Although the age of success is correlated with the information processing demands of the task, there are some reasons to doubt the *complexity alone hypothesis*. The *complexity alone hypothesis* does not account for the other successes at 9 and10 months of age in which the tasks with greater information processing demands were deployed. Adding labels to the task increases the information processing demands since the infants have to process both visual and auditory information simultaneously (Xu, 2002), and the human/doll head experiments used multi-parted complex objects (Bonatti et al., 2002).

The *complexity alone hypothesis* makes a prediction that has not been tested, namely once the infants are able to process complex experimental procedures (i.e., multiple reversals of trajectory) and complex objects (e.g., a duck and a cup) at 12 months, they should succeed in using single property contrasts (e.g., a red ball vs. a green ball; a small red ball vs. a large red ball) for object individuation as well. After all, a single property contrast imposes less information processing demands on the infant. The experiments reported here test this prediction directly. In addition, these experiments also provide an indirect test for an alternative hypothesis—that the basis of success at 12 months in the complex object individuation tasks depends on a conceptual distinction between properties and kinds. This alternative hypothesis—*the emerging kind representations hypothesis*—is indirectly tested by asking the infants to use color or size contrasts alone and shape contrasts alone in the service of object individuation.

The distinction between property vs. kind is difficult to draw, but most will agree that color and size are clear cases of perceptual properties whereas shape is often correlated with kind membership (see e.g., Bloom, 2000; Landau, Smith, & Jones, 1988; Soja, Carey, & Spelke, 1991; among others). Thus *the emerging kind representations hypothesis* makes a counterintuitive prediction: 12-month-old infants, who succeed on the complex individuation tasks, may nevertheless fail the same task if provided with objects that contrast in a single property, say color or size. Furthermore, they may succeed in using shape contrast alone for object individuation when shape is correlated with kind membership.

The general design of the present set of experiments was as follows. Infants were shown four baseline trials at the beginning in order to establish any intrinsic preference for the one-object and two-object outcomes. After the baseline trials, encoding trials began. In these trials infants were given perceptual information about the actual objects that were to be revealed behind the screen. For example, in the encoding trials of the Different Color Condition, infants were shown two objects, say a red ball and a green ball, emerging from behind a screen one at a time and returning behind it. Once the infants were familiarized with the objects, test trials began. On each test trial, the screen was removed to reveal either two objects (a red ball and a green ball; the expected outcome) or a single object (a red ball or a green ball; the unexpected outcome). By the logic of the violation-of-expectancy looking time method, infants should look longer at the unexpected outcome (relative to their intrinsic preference for one or two objects, as was established during the baseline trials) if they had established a representation of two distinct objects behind the screen on the basis of the color difference.

In the four experiments reported below, we asked the infants to use color, size, a combination of size, color, and pattern, and shape differences for object individuation. In addition, we included two types of control conditions. One type of control condition, the Same Condition, was included to ensure that infants encoded the perceptual property differences between the objects. For example, the encoding trials of the infants who saw two different color objects (Different Color Condition) were compared to those who saw a single object over and over again (Same Color Condition). If the infants had encoded the color differences between the objects, we predict that it would take them longer to habituate to a sequence of say, red ball, green ball, red ball, green ball, etc. than to a sequence of say, red ball, red ball, red ball, etc. The other type of control condition, namely the Spatiotemporal Condition, was included to ensure that our method was a sensitive one for measuring object individuation in infants. Previous studies (Bonatti et al., 2002; Xu, 2002; Xu & Carey, 1996) have found that infants tend to look longer at two objects on the baseline trials. Since the unexpected outcome on the test trials was the one-object outcome, the infants will have to overcome, or at least reduce, their preference for two objects in order to succeed at this task. If infants fail to use say, color differences for object individuation in our task, the failure is only interpretable against a control condition in which they succeed; otherwise it could simply be a matter of not being able to overcome their baseline preference for two objects. As in previous studies, we included a Spatiotemporal Condition in which the two objects were shown *simultaneously* for a brief 2 or 3 s prior to test trials, and we expect infants to succeed in this condition if our methods provide a sensitive measure of infants' ability to establish representations of distinct objects in an event.

2. Experiment 1

Experiment 1 investigated whether 12-month-old infants could use color difference alone for object individuation. That is, if shown a red ball emerging from behind a screen and returning behind it, followed by a green ball emerging from behind the same screen and returning, would infants this age conclude that there are two numerically distinct balls behind the screen?

Three conditions were included in this experiment: Different Color Condition, Same Color Condition, and Spatiotemporal Condition. In the encoding trials of the Different Color Condition, infants were shown two objects differing in color alone emerging and returning behind a screen *one at a time*. On the test trials, the screen was removed to reveal these two objects or just one of them. In the encoding trials of the Same Color Condition, infants were shown two identical objects emerging and returning behind a screen. On the test trials, the screen was removed to reveal one or two identical objects. By comparing the encoding trials of this condition with those of the Different Color Condition, we will be able to tell whether infants had encoded the color differences between the two objects. The Same Color condition also allowed us to explore whether seeing identical objects emerge from both sides of the screen would lead the infants to establish a representation of one object behind the screen. Lastly, the Spatiotemporal Condition was included to ensure that our methods were sensitive and infants could overcome/reduce a potential baseline preference for two objects. In this condition, the infants were shown both objects *simultaneously* for a brief 2 or 3 s. Given that both 10- and 12-month-old infants succeeded in the Spatiotemporal Conditions of Xu and Carey (1996) and Bonatti et al. (2002), we expected the infants in this condition to succeed.

2.1. Method

2.1.1. Participants

Seventy-two full-term 12-month-old infants (34 girls and 38 boys) participated in the study (mean age 12;14 [months;days], ranging from 11;29 to 13;05). Roughly equal numbers of boys and girls were randomly assigned to each of three conditions, Different Color Condition (mean age 12;14), Same Color Condition (mean age 12;15), and Spatiotemporal Condition (mean age 12;13). Infants were recruited by obtaining their birth records from town halls in the Greater Boston area and subsequently contacting their parents by mail and phone. Ten additional infants were excluded because of fussiness (6) or parental interference (4).

2.1.2. Materials

Three pairs of objects were used in the study: Two bottles (19 cm tall, 5.5 cm in diameter), one primarily blue with small pink bears and one primarily green with small tan-colored bears; two tennis balls (6 cm in diameter), one with green and pink stripes and one with purple and orange stripes; and two sippy cups with two handles (10 cm tall and 10 cm at their widest). One cup was pink and one yellow. Each cup had a small blue bear on the front. Each object had a stick attached to the bottom so it can be moved along a slit across the stage.

Four foam core screens (red, lavender, orange, and pink), each measuring 34 cm wide and 26 cm tall, were used in the experiment.

2.1.3. Apparatus

The events were presented on a three-sided, 80 cm × 31 cm × 30 cm (length × width × height) stage with a light blue surface. A black curtain hung behind the stage to make the objects and background contrast prominent and to conceal the movement of the experimenter. Another black curtain hung from the bottom of the stage to conceal the video camera underneath. A third black curtain in front of the stage hung from the ceiling to 24 cm from the stage floor, preventing the experimenter from seeing the infant's face and the infant from seeing the experimenter. The display area measured 80 cm in width and 24 cm in height. A slit ran across the floor of the stage so the objects could be moved when they were put on sticks.

The video camera was connected to a 19 in. color TV that was placed in one corner of the room. An observer watched the infant on the TV monitor and recorded the looking times. The observer could not see what was presented on the stage and was blind to which condition the infant was in. A push button was connected to a computer that recorded looking times. A computer program written specifically for looking time studies (Xhab 2.0; Pinto, 1995) was used to record the looking times in all the experiments. White noise masked any sounds produced by the movements of the experimenter.

The stage was lit from above and from the two sides; otherwise the room was dark. The infant sat in a high chair, about 70 cm from the stage, with eye level slightly above (about 5 cm) the floor of the stage. The parent sat next to the infant with his/her back toward the stage, and was instructed not to look at the displays and not to draw the infant's attention in any way. A video camera was set up under the stage, focusing on the infant's face and recording the entire session. The videotape record provided no information about what was presented on the stage so an observer scoring from the videotapes was completely blind to the condition or the order of the trials.

2.1.4. Design and procedure

Twenty-four infants were randomly assigned to each of three conditions: the Different Color Condition, the Same Color Condition, and the Spatiotemporal Condition. The experimenter began by waving a set of keys at all six corners of the stage (the top and bottom of left, right, and center of the stage) in order to draw the infant's attention to the stage as well as to define the window of looking for the observer. During this calibration process and throughout the experiment, only the experimenter's hands were visible to the infant. After calibration, infants in all conditions saw four baseline trials, followed by six encoding trials, and then four test trials.

2.1.5. Different Color Condition

Baseline trials. Each infant received four baseline trials. On each trial, the experimenter lowered a screen onto the stage with some objects hidden behind it. The screen was then turned to the side, revealing one or two objects. As the experimenter turned the screen, she/he drew the infant's attention by saying, "Look, [baby's name]." The word "now" was used to signal the observer to start timing in all trials. Looking time was then recorded. When the infant had looked for at least .5 s and then looked away for 2 consecutive seconds, the trial ended. The computer beeped to signal the end of the trial. At the end of each trial, the screen was put back to its original position and the experimenter removed the objects and the screen. A different screen was used each time.

The objects used during this phase of the experiment were the ones that were not used in the test trials for a particular infant. For example, if the two balls were to be used as the test stimuli for a given infant, the two bottles and the two cups were used during the baseline trials. Which pair of objects was shown first, which side the single object was on, and the order of the presentation (1, 2, 2, 1, or 2, 1, 1, 2) were counterbalanced across infants. These baseline trials provided a measure of the infants' intrinsic preference for one or two objects.

Encoding trials. Six encoding trials followed the baseline trials (Fig. 1). For each trial, the experimenter lowered the screen with two objects hidden behind it. The first object, say the green and pink tennis ball, was brought out from behind the screen. About 1 cm of the stick was visible to the infant. The experimenter tapped the object a few times on the stage, drew the infant's attention by saying "Look, [baby's name]," left the object stationary, and signaled the observer to start timing. When the infant looked away as signaled by the beep from the computer, the experimenter brought the object back behind the screen. The second object was then brought out to the other side of the stage. Again the experimenter tapped it a few times, drew the infant's attention to it, and left it stationary for the infant to look at. When the infant looked away, the object was brought back behind the screen. Each object was

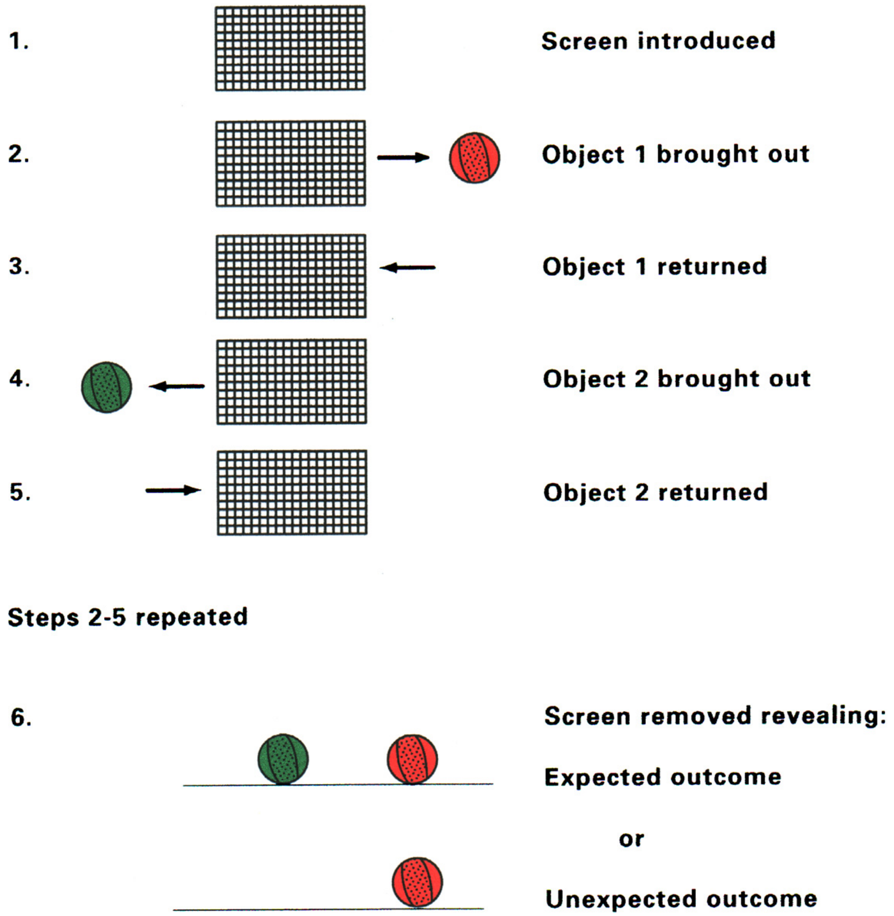

Fig. 1. Schematic representation of the events in Experiment 1: Different Color Condition.

brought out three times for a total of six encoding trials. Which object was brought out first and on which side of the stage were counterbalanced across infants.

Test trials. At the end of the encoding trials, each object was brought out briefly (for 2 or 3 s), one at a time, to remind the infant what each object looked like ("a reminder"), then the screen was turned to the side, revealing one or two objects. As the screen was turned, the experimenter drew the infant's attention, "Look, [baby's name]." Looking time was then recorded. At the end of each trial, the stage was cleared. A screen of a different color was then lowered onto the stage with the same two objects hidden behind it. Each object was again shown briefly before the screen was turned to the side to reveal the objects. Each infant was shown four test trials, alternating between two outcomes. In the expected outcome, the infant was shown two objects sitting side by side when the screen was turned; in the unexpected outcome, the infant was shown only one of the two objects (the other object had been surreptitiously removed by the experimenter). The experimenter went through the motion of removing the object even on the expected trials in order to equate the timing of all the test trials. The order of outcome (1 2 1 2 or 2 1 2 1) and which object was the single object were counterbalanced across infants.

2.1.6. Same Color Condition

Baseline trials. The baseline trials were the same as those in the Different Color Condition, with one important difference. Instead of using two objects that differed in color, e.g., a pink cup and a yellow cup, two identical objects were used on the two-object trials. These trials provided a baseline measure for the infant's intrinsic preference for one or two objects.

Encoding trials. These trials were the same as the encoding trials in the Different Color Condition, except that two identical objects were brought out one at a time for a total of six times.

Test trials. Four test trials followed. They were identical to the test trials of the Different Color Condition except that two identical objects were shown on the two-object trials. The order of outcome and which side the single object was on were counterbalanced across infants.

2.1.7. Spatiotemporal Condition

Baseline trials. The baseline trials were identical to those in the Different Color Condition.

Encoding trials. The encoding trials were the same as those in the Different Color Condition, except for one important difference. At the beginning of these trials, the two objects were brought out *simultaneously* for a brief 2 or 3 s; each object was tapped on the stage before it was returned behind the screen. Thus the infants had unambiguous spatiotemporal information that there were two objects behind the screen. Six encoding trials followed, in which the objects were brought out one at a time and left stationary until the infant looked away.

Test trials. Four test trials followed. They were identical to the test trials in the Different Color Condition except that instead of showing each object one at a time briefly before revealing the outcomes, the two objects were shown simultaneously ("a reminder") for 2 or 3 s before being returned behind the screen. The screen was then removed to reveal one or two objects.

2.2. Results

The main results of Experiment 1 are shown in Fig. 2. An α level of 0.05 was used in all statistical analyses. Preliminary analyses found no effects of sex, order of outcome, which object was the single object, and stimulus pair. Subsequent analyses collapsed over these variables.

Two types of data analyses are reported below. First, did infants encode the perceptual dimension of color under the conditions of this experiment? To this end, we compared the encoding trials of the Different Color Condition with those of the Same Color Condition. Encoding trials were divided into three blocks (first pair,

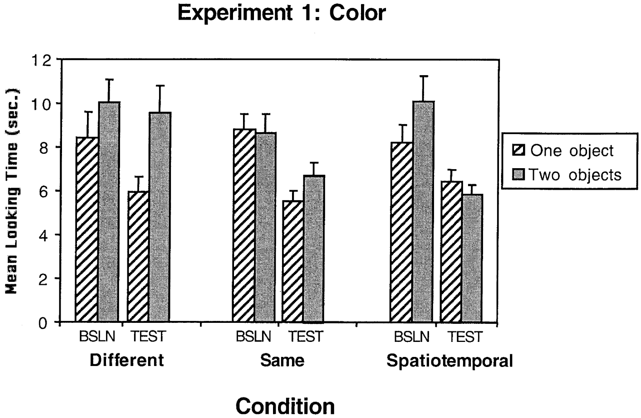

Fig. 2. Mean looking times of Experiment 1.

second pair, and third pair). Pairs of objects are the relevant unit of analysis because there are two distinct objects being encoded in the Different Color Condition. Two sub-questions were addressed by the statistical analyses: (i) Did infants habituate more slowly in the Different Color Condition than those in the Same Color Condition? We addressed this question by comparing the first and second blocks of encoding trials. This was to show that infants did notice the color differences. (ii) Did infants habituate to the same extent by the end of the encoding trials? We addressed this question by comparing the first and third blocks of the encoding trials. This was to ensure that by the end of habituation, both groups of infants had habituated to the same extent so we can compare their performance on the test trials.

Second, did infants use the perceptual dimension of color to establish a representation of two distinct objects behind the screen? For each of the three conditions, we compared the infants' baseline preference for one or two objects with their looking times for one or two objects on the test trials. It was necessary to include the baseline preference in the main analysis because how much the infants looked longer at two objects on the baseline trials differed across conditions due to the different stimuli we showed them. For example, the infants in the Different Color Condition tended to have a larger preference for two objects because the two objects differed in color (e.g., a red ball and a green ball), whereas the infants in the Same Color Condition tended to have a smaller preference for two objects because the two objects were identical (e.g., two red balls). Thus, the analysis that reveals whether infants used the information provided in the encoding trials for object individuation is a comparison of the looking times at the two outcomes in the baseline trials with those of the test trials. Success consists of an interaction between trial type (Baseline vs. Test) and outcome (1 vs. 2 objects) such that the preference for two is significantly less during test trials than during baseline trials.

To anticipate the main results: on the encoding trials, the infants in the Different Color Condition habituated more slowly than those in the Same Color Condition, suggesting that they had encoded the color differences between the two objects. By the end of the encoding trials, both groups of infants had habituated to the same extent. On the test trials, the infants in the Different Color Condition did *not* look longer at the one-object outcome relative to their baseline preference, suggesting that they *failed* to use the color differences to establish a representation of two objects behind the screen. Similarly, in the test trials of the Same Color Condition the infants did not differentiate the one-object and the two-object outcomes, suggesting that they did not use the sameness in color (in fact, identity in all properties) to establish a representation of a single object behind the screen. In contrast, on the test trials of the Spatiotemporal Condition, infants reversed their baseline preference for two objects, looking longer at the one-object, unexpected outcome. That is, infants were able to use the spatiotemporal information to establish a representation of two numerically distinct objects.

2.2.1. Encoding trials: Different Color vs. Same Color Conditions

In order to establish whether the infants had encoded the color differences between the objects, an analysis of variance examined the effects of condition (Different Color vs. Same Color) and of trial block (first vs. second) on looking times during the encoding trials. There was a main effect of block, $F(1,46) = 12.922$, $p < .001$. Infants looked longer in the first block of encoding trials ($M = 16.7$ s, $SD = 10.0$) than the second block ($M = 11.8$ s, $SD = 8.9$). More importantly, there was an interaction between the two variables, $F(1,46) = 6.266$, $p < .02$. In the Different Color Condition, the average looking times for the first and second blocks of encoding trials did not differ from each other (15.6 s vs. 14.1 s), whereas in the Same Color Condition, the two blocks of encoding trials differed from each other (17.7 s vs. 9.4 s). The infants in the Different Color Condition encoded the distinct colors of the objects.

To see if the infants had habituated to the same extent by the end of the encoding trials, an ANOVA examined the effects of condition (Different Color vs. Same Color) and the effect of trial block (first vs. third) on looking times during the encoding trials. There was a main effect of block, $F(1,46) = 41.402$, $p < .0001$. Infants looked longer in the first block of encoding trials ($M = 16.7$ s, $SD = 10.0$) than the third block ($M = 9.5$ s, $SD = 6.5$). More importantly, there was no interaction between the two variables, $F(1,46) = 1.927$, $p > .1$. In other words, the infants did habituate to the same extent in the two conditions by the end of the encoding trials.[1]

2.2.2. Baseline trials and test trials

An ANOVA examined the effects of condition (Different Color vs. Same Color vs. Spatiotemporal), trial type (Baseline vs. Test), and outcome number (1 vs. 2 objects) on looking time (Fig. 2). There was a main effect of trial type, $F(1,69) = 17.187$,

[1] We had no prediction concerning the habituation rate in the Spatiotemporal Condition relative to the Different Color and Same Color Conditions because infants saw two different-colored objects *simultaneously* before being shown each object emerging from behind the screen. Two additional planned ANOVAs examined the effects of condition (Different vs. Spatiotemporal, Same vs. Spatiotemporal) and trial number. There were no interactions between the two variables (all p's $> .1$). Their looking times during familiarization trials appeared to be in between the other two conditions (see Table 1).

$p < .0001$. Infants looked overall longer during the baseline trials ($M = 9.2$ s, $SD = 4.7$) than in the test trials ($M = 6.8$ s, $SD = 3.8$). This was probably because two pairs of new objects were introduced during the baseline trials, whereas infants had been familiarized with the objects that were revealed on the test trials. There was a main effect of outcome number, $F(1, 69) = 15.675, p < .0001$. Infants looked overall longer at two objects ($M = 8.6$ s, $SD = 4.8$) than one object ($M = 7.4$ s, $SD = 3.9$). There was also an interaction between condition and outcome number, $F(2, 69) = 3.990, p < .05$. This interaction was best understood in light of the three-way interaction between condition, trial type, and outcome number ($F(2, 69) = 5.943, p < .005$).

Three planned comparisons examined the three conditions separately and enabled us to understand the three-way interaction.

2.2.3. Different Color Condition

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome number (1 vs. 2 objects) on looking times. There was a main effect of outcome number, $F(1, 23) = 12.114$, $p < .005$. Infants looked longer at the two-object display ($M = 10.1$ s, $SD = 6.0$) than the one-object display ($M = 7.6$ s, $SD = 5.2$). More importantly, there was no interaction between trial type and outcome number, $F(1, 23) = 1.521$, $p = .233$. On the baseline trials, the mean looking times for the one-object and two-object displays were 9.3 s ($SD = 6.1$) and 10.1 s ($SD = 5.4$), respectively. On the test trials, the mean looking times for the one-object and two-object displays were 5.9 s ($SD = 3.5$) and 10.1 s ($SD = 6.6$), respectively. Exactly half (12 out of 24) infants had a larger preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -.840$, $p = .4$).

2.2.4. Same Color Condition

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome (1 vs. 2 objects) on looking times. There was a main effect of trial type, $F(1, 23) = 20.985$, $p < .001$. The infants looked overall less on the test trials ($M = 5.9$ s, $SD = 2.2$) than on the baseline trials ($M = 8.6$ s, $SD = 3.4$). There was no interaction between the two variables, $F(1, 23) = 1.152, p = .294$. On the baseline trials, the mean looking times for the one-object and two-object displays were 8.5 s ($SD = 3.1$) and 8.6 s ($SD = 3.8$), respectively. On the test trials, the mean looking times for the one- and two-object displays were 5.4 s ($SD = 1.9$) and 6.4 s ($SD = 2.4$), respectively. Thirteen of the 24 infants had a larger preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -.877$, $p = .38$).

2.2.5. Spatiotemporal Condition

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome (1 vs. 2 objects) on looking times. There was a main effect of trial type, $F(1, 23) = 13.275$, $p < .001$. The infants looked overall less on the test trials ($M = 6.5$ s, $SD = 2.1$) than on the baseline trials ($M = 9.4$ s, $SD = 4.8$). More importantly, there was a significant interaction between the two variables, $F(1, 23) = 5.061, p < .05$. On the baseline trials, the mean looking times for the one-object and the two-object displays were 8.4 s ($SD = 3.8$) and 10.4 s ($SD = 5.4$), respectively. On the test trials, the mean looking times for the one-object and the two-object displays were 7.0 s ($SD = 2.5$) and 6.1 s ($SD = 1.6$), respectively. Nineteen of the 24 infants had a larger preference for one object on the test trials than on the baseline trials (Wilcoxin $z = -1.979$, $p < .05$). When infants were given clear spatiotemporal evidence that there were two distinct objects, they reversed their pattern of looking on the test trials compared to the baseline trials.

2.3. Discussion

In Experiment 1, 12-month-old infants in the Different Color Condition failed to use the color differences between two objects (balls/bottles/cups) to establish a representation of two distinct objects behind the screen. Similarly, in the Same Color Condition, infants also failed to use the sameness in color (indeed, sameness in all properties) to establish a representation of a single object. In neither condition did the infants have a clear expectation of one or two objects; their preferences on the test trials were not different from those on the baseline trials.

To ensure that our methods provide a sensitive measure of object individuation, and that infants this age *can* override a baseline preference for two objects on test trials under these conditions, a Spatiotemporal Condition was included. After seeing both objects simultaneously for a few seconds at the beginning and end of the encoding trials, the infants did look longer, relative to their baseline preferences, at the one-object, unexpected outcome. This result replicated those from the Spatiotemporal Conditions in Xu and Carey (1996). Thus the infants' failure to use color differences for object individuation in Experiment 1 was not due to the insensitivity of the method.

Equally important, the encoding trials showed that the infants' failure to use color differences as a basis for object individuation was not due to a failure to encode the colors of these objects. Infants habituated faster in the Same Color Condition than in the Different Color Condition. Furthermore, by the end of the encoding trials, the infants in the two conditions had habituated to the same extent, suggesting that the failure in the Different Color Condition could not have been attributed to the infants' not having fully encoded the objects. In the next experiment we investigated whether size difference alone was sufficient for object individuation.

3. Experiment 2

Experiment 2 used the same procedure as that of Experiment 1. After four baseline trials, infants were shown an object (e.g., a small red ball) emerging from behind the screen and returning, followed by a second object (e.g., a large red ball) emerging from behind the screen and returning. Pilot testing suggested that six encoding trials were not enough to allow the infants to fully encode the objects (i.e., looking times declined very little after six encoding trials). Therefore, we used nine encoding trials in Experiment 2. Three conditions were included: Different Size Condition, Same Size Condition, and Spatiotemporal Condition. As in Experiment 1, the comparison of the encoding trials in the Different Size and Same Size Conditions informed us whether the infants perceived the size differences.

3.1. Methods

3.1.1. Participants

Forty-five full-term 12-month-old infants (22 girls and 23 boys) participated in the study (mean age was 12;14, ranging from 12;3 to 13;2). Roughly equal numbers of boys and girls were randomly assigned to each of the three conditions (mean ages were 12;13 for the Different Size Condition, 12;14 for the Same Size Condition, and 12;14 for the Spatiotemporal Condition). All infants were recruited by the same methods as in Experiment 1. Nine additional infants were excluded due to fussiness (5) or parental interference (4).

3.1.2. Materials

Three pairs of objects were used in the experiment: Two balls, two boxes, and two bottles. The balls were painted bright red and covered with glitter. The small ball measured 4 cm in diameter and the large ball measured 9 cm in diameter. The boxes were painted bright reddish orange with a blue star and blue glitter on the front. The small box was a 7 cm cube and the large box was an 11.5 cm cube. The bottles were painted green and decorated with purple dots and thin stripes of silver material. The small bottle was 9.5 cm tall and 3.5 cm at its widest and the large bottle was 19 cm tall and 5 cm at its widest. The same four foam core screens as in Experiment 1 were used.

3.1.3. Apparatus and procedure

The apparatus and procedure were identical to those of the Different Color and the Same Color Conditions of Experiment 1, except for the change in stimuli and the increase of encoding trials from six to nine.

3.2. Results

The findings of Experiment 2 are shown in Fig. 3. An α level of 0.05 was used for all statistical analyses. Preliminary analyses found no effects of sex, order of outcome, and stimulus pair. Subsequent analyses collapsed over these variables.

To anticipate the main results of Experiment 2: although infants encoded the size differences of the objects, they failed to use this information to establish that there were two numerically distinct objects behind the screen.

3.2.1. Encoding trials: Different Size vs. Same Size Conditions

In order to establish that infants had encoded the size differences between the objects, an ANOVA examined the effect of condition (Different Size vs. Same Size) and of trial block (first vs. second; because there were a total of nine encoding trials, they were divided into the first, second, and third triplets). There was a main effect of block, $F(1, 28) = 34.189$, $p < .0001$. Infants looked longer in the first block of encoding trials ($M = 18.5$ s, $SD = 7.6$) than the second block ($M = 11.6$ s, $SD = 5.8$). More importantly, there was an interaction between the two variables, $F(1, 28) = 4.662$, $p < .05$. In the Different Size Condition, the average looking times for the first and second blocks of encoding trials did not differ from each other (18.3 s vs.

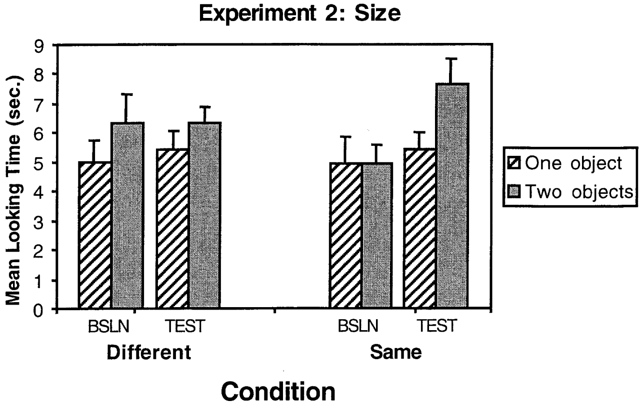

Fig. 3. Mean looking times of Experiment 2.

13.2 s), whereas in the Same Size Condition, the two blocks of encoding trials differed from each other (18.7 s vs. 10.0 s). The infants in the Different Size Condition encoded the distinct sizes of the objects.

To see if the infants had habituated to the same extent by the end of the encoding trials, an ANOVA examined the effect of condition (Different Size vs. Same Size) and the effect of trial block (first vs. third) on looking times during the encoding trials. There was a main effect of block, $F(1,28) = 23.980$, $p < .001$. Infants looked longer in the first block of encoding trials ($M = 18.5$ s, $SD = 7.6$) than the third block ($M = 11.2$ s, $SD = 4.8$). More importantly, there was no interaction between the two variables, $F(1,28) = 0.729$, $p = .4$. By the end of the encoding trials, the infants in the two conditions habituated to the same extent.

3.2.2. Baseline trials and test trials

An ANOVA examined the effects of condition (Different Size vs. Same Size vs. Spatiotemporal), trial type (Baseline vs. Test) and outcome number (1 vs. 2 objects) on looking time (Fig. 3). There was a main effect of outcome number, $F(1,42) = 8.720$, $p < .005$. There was an interaction between condition and outcome number, $F(2,42) = 7.633$, $p < .01$. This interaction was best understood in light of the three-way interaction between condition, trial type, and outcome number, $F(2,42) = 7.978$, $p < .001$.

Three planned comparisons examined the three conditions separately and enabled us to understand the three-way interaction.

3.2.3. Different Size Condition

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome number (1 vs. 2 objects) on looking times. There was no main effect of trial type; there was a main effect of outcome number, $F(1,14) = 5.077$, $p < .05$. Overall infants looked longer at two objects ($M = 6.3$ s, $SD = 2.9$) than one object ($M = 5.2$ s, $SD = 2.7$). There was no interaction between the two variables, $F(1,14) = .563$, $p = .465$. The average looking times on the baseline trials were 6.4 s for two objects and 5.0 s for one object;

the average looking times on the test trials were 6.4 s for two objects and 5.4 s for one object. That is, infants' preference for two objects did not change on the test trials compared to the baseline trials. Ten of the 15 infants had a smaller preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -.840$, $p = .4$).

3.2.4. Same Size Condition

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome number (1 vs. 2 objects) on looking times. There was a main effect of trial type, $F(1, 14) = 8.944$, $p = .01$. Infants looked longer overall on the test trials ($M = 6.5$ s, $SD = 3.0$) than on the baseline trials ($M = 4.9$ s, $SD = 3.0$). There was also a main effect of outcome number, $F(1, 14) = 5.347$, $p < .05$. Infants looked overall longer at two objects ($M = 6.2$ s, $SD = 3.1$) than one object ($M = 5.1$ s, $SD = 3.0$). Finally, there was a marginally significant interaction between the two variables, $F(1, 14) = 3.895$, $p = .07$. This trend reflected the lack of a clear preference for one vs. two objects on the baseline trials (M one-object = 4.9 s, $SD = 3.5$; M two-object = 4.9 s, $SD = 2.4$) in the face of a preference for two objects on the test trials (M one-object = 5.4 s, $SD = 2.4$; M two-object = 7.6 s, $SD = 3.2$). Ten of the 15 infants had a larger preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -1.817$, $p = .07$). Infants may have used the sameness in all properties, including size, to establish representation of a single object.

3.2.5. Spatiotemporal Condition

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome number (1 vs. 2 objects) on looking times. There was a main effect of trial type, $F(1, 14) = 7.649$, $p < .02$. Infants looked longer overall on the baseline trials ($M = 9.7$ s, $SD = 4.5$) than on the test trials ($M = 6.9$ s, $SD = 2.1$). More importantly, there was an interaction between the two variables, $F(1, 14) = 7.805$, $p < .02$. On the baseline trials, the mean looking times for the one-object and the two-object displays were 8.5 s ($SD = 3.1$) and 11.0s ($SD = 5.4$), respectively. On the test trials, the mean looking times for the one-object and the two-object displays were 7.7 s ($SD = 2.2$) and 6.1 s ($SD = 1.6$), respectively. Twelve of the 15 infants had a larger preference for one object on the test trials than on the baseline trials (Wilcoxin $z = -2.379$, $p < .05$). When infants were given clear spatiotemporal evidence that there were two distinct objects, they reversed their pattern of looking on the test trials compared to the baseline trials.

3.3. Discussion

Just as the infants in Experiment 1 failed to use color differences between two objects seen one at a time to establish representations of two objects behind the screen, so too the infants in Experiment 2 failed to use size differences as a basis for individuating objects. The analyses of the encoding data revealed that infants did encode the size difference between the objects, as evidenced by the slower habituation rate in the Different Size Condition than the Same Size Condition between the first three and middle three encoding trials. Furthermore, by the end of the encoding trials, the infants in the two conditions had habituated to the same extent, as evidenced by the equal declines in looking times between the first three and the last three encoding trials. The failure in the Different Condition could not have been attributed to the infants' not having fully encoded the objects.

The results of Experiment 2 differed from those of Experiment 1 in two respects, both concerning the Same Conditions. First, there was some indication that infants in the Same Size Condition infants may have used the sameness in all properties to establish a representation of a single object. There was a trend for relatively longer looking at the two-object outcome on the test trials of the Same Size Condition, relative to the baseline trials. Second, infants in the Same Size Condition, unlike any other condition in all the experiments reported here, looked longer during the test trials than during the baseline trials. There was no hint of either of these effects in Experiment 1, in spite of the fact that the objects in the Same Color Condition were also physically identical to each other. Although we have no interpretation of these discrepancies between the two experiments, we note that the results of the Same Size Condition of Experiment 2 could be due to a simple novelty effect, as well as to the use of sameness of properties to establish a representation of a single object. Infants were familiarized to nine exposures to a single object, and thus the longer looking times to the two-object outcome could simply be a dishabituation to two objects. This overall dishabituation may also account for the longer looking times during the test trials than during the baseline trials. The results of Experiments 1 and 2 taken together show that there is not a robust tendency for 12-month-old infants to use sameness of properties to establish representations of a single object emerging from both sides of a screen.

More relevant to the question at hand, 12-month-old infants failed to use color or size difference alone to establish a representation of two distinct objects in the Different Conditions of Experiments 1 and 2. These failures contrast with the successes in Xu and Carey (1996), in which infants of this age robustly used the differences between a duck and a car, a bottle and a book, to individuate objects under exactly the same circumstances. There are two differences between the Xu and Carey (1996) stimuli and those of Experiments 1 and 2. In the Xu and Carey (1996) experiments, the stimuli differed in kind as well as in properties, and they differed in many properties, rather than in just one. For example, the duck and the car differed in size, color, pattern, texture, material, and shape. Experiment 3 explored whether presenting infants with objects varying in multiple properties (color, size, and surface pattern) would lead to successful individuation at 12 months.

4. Experiment 3

4.1. Methods

4.1.1. Participants

Fifteen full-term 12-month-old infants (7 girls and 8 boys) participated in the study (mean age 12;15, ranging from 12;2 to 12; 26). The infants were recruited using the same methods as in Experiment 1. Three additional infants were excluded because of fussiness.

4.1.2. Materials

Three pairs of objects were used in the experiment: two balls, two cups, and two ducks. The small ball was a soccer ball (5 cm in diameter) decorated with orange, green, and white hexagons. The large ball (9 cm in diameter) was bright red covered with glitters. The small cup measured 6.5 cm wide and 6.5 cm tall. It was painted bright yellow with green and red vertical stripes and had an orange handle on one side. The large cup measured 7 cm wide and 14 cm tall. It was semi-transparent with a bright orange rim and was decorated with red, green, and yellow squares and circles; it had a blue handle on one side. The small duck was light brown with a yellow bill. It measured 6 cm at its widest and 7 cm tall. The large duck was bright yellow with a red bill. It measured 12 cm at its widest and 12 cm tall. Each pair of objects had the same overall shape but differed in color, size, and surface pattern. The same four screens were used as in Experiment 1.

4.1.3. Apparatus and procedure

The same apparatus was used in as in Experiment 1.

Given that infants detected the differences in color and size alone in Experiments 1 and 2, it seemed likely that the infants would detect the perceptual differences in the objects of Experiment 3, because they differed in color, size, and surface pattern. Therefore, we included only one condition in Experiment 3: the Different Properties Condition. The procedure was identical to that of the Different Size Condition in Experiment 2, except for the change in stimuli.

4.2. Results

The data from Experiment 3 are shown in Fig. 4. An α level of 0.05 was used for all statistical analyses. Preliminary analyses found no effects of sex, stimulus pair,

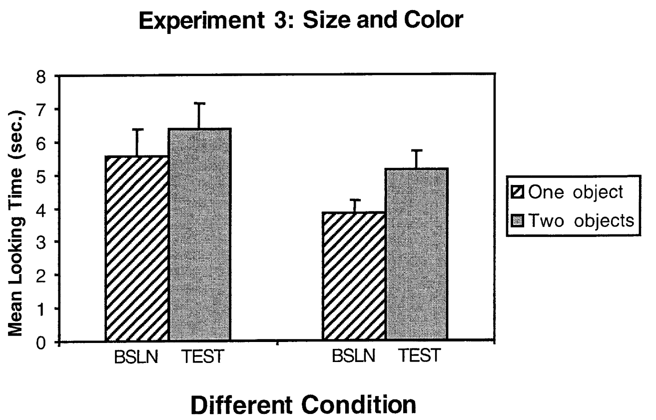

Fig. 4. Mean looking times of Experiment 3.

order of outcome, and which object was the single object. Subsequent analyses collapsed over these variables.

The main result of Experiment 3 was that the infants failed to use the combination of color, size, and surface pattern differences to establish representations of two objects behind the screen.

4.2.1. Encoding trials

As an estimate of whether the infants encoded the differences between the objects in Experiment 3, we compared the encoding trials of the Different Properties Condition with those of the Same Size/Properties Condition of Experiment 2.

In order to establish that infants had encoded the property differences between the objects, an ANOVA examined the effect of condition (Different Properties vs. Same Properties from Experiment 2) and of trial block (first vs. second; because there were a total of nine encoding trials, they were divided into the first, second, and third triplets). There was a main effect of block, $F(1,28) = 33.322$, $p < .0001$. Infants looked longer in the first block of encoding trials ($M = 18.3$ s, $SD = 4.5$) than the second block ($M = 11.8$ s, $SD = 5.8$). More importantly, there was an interaction between the two variables, $F(1,28) = 4.230$, $p < .05$. In the Different Properties Condition, the average looking times for the first and second blocks of encoding trials did not differ from each other (17.9 s vs. 13.7 s), whereas in the Same Size/Properties Condition, the two blocks of encoding trials differed from each other (18.7 s vs. 10.0 s). The infants in the Different Properties Condition encoded the distinct properties of the objects.

To see if the infants had habituated to the same extent by the end of the encoding trials, an ANOVA examined the effect of condition (Different Properties vs. Same Size/Properties) and the effect of trial block (first vs. third) on looking times during the encoding trials. There was a main effect of block, $F(1,28) = 48.334$, $p < .0001$. Infants looked longer in the first block of encoding trials ($M = 18.3$ s, $SD = 4.5$) than the third block ($M = 9.7$ s, $SD = 4.1$). More importantly, there was no interaction between the two variables, $F(1,28) = 0.000$, $p = .983$. By the end of the encoding trials, the infants in the two conditions habituated to the same extent.

4.2.2. Baseline trials and test trials

An ANOVA examined the effects of trial type (Baseline vs. Test) and outcome number (1 vs. 2 objects). There was a main effect of trial type, $F(1,14) = 6.750$, $p < .05$. Overall the infants looked longer on the baseline trials ($M = 5.9$ s, $SD = 2.9$) than on the test trials ($M = 4.4$ s, $SD = 2.0$), presumably because the baseline trials were at the beginning and the objects were novel, whereas the objects shown on the test trials had been shown repeatedly during encoding trials. There was a marginally significant main effect of outcome number, $F(1,14) = 3.775$, $p = .07$. Infants looked overall longer at two objects ($M = 5.8$ s, $SD = 2.6$) than at one object ($M = 4.7$s, $SD = 2.5$). More importantly, there was no interaction between trial type and outcome number, $F(1,14) = 0.170$, $p = .686$. The mean looking times were 5.6 s ($SD = 3.0$) for one object and 6.4 s ($SD = 2.8$) for two objects on the baseline trials; the mean looking times were 3.8 s ($SD = 1.5$) for one object and 5.1 s ($SD = 2.2$) for two objects on the test trials. Seven of the 15 infants had a smaller preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -.170$, $p = .86$).

4.3. Discussion

In spite of the multiple property differences between the objects emerging alternately from opposite sides of a screen, such as between a small, multi-colored, hexagon-covered ball and a large, red, glittery ball, 12-month-olds failed to establish representations of two distinct objects behind the screen. This suggests that the success of 12-month-olds in the Xu and Carey (1996) property/kind conditions was not due to differences in color, texture, and surface pattern. However, the objects in Experiment 3 differed from those in Xu and Carey (1996) in two final respects. In Experiment 3, the objects were both of the same kind and shared a single shape, whereas the objects in Xu and Carey (1996) differed in both shape and kind, both at the basic and global levels (e.g., a duck vs. a car, or a bottle vs. a book.)

In Experiment 4, we asked whether shape difference alone can support object individuation at 12 months of age. Suppose two objects were of the same color, size, and surface pattern, but differed in overall shape, would 12-month-old infants establish a representation of two objects? We contrasted two types of shape differences based on adults' conceptual representations, cross-basic-level-kind shape difference (e.g., a cup vs. a ball) and within-basic-level-kind shape difference (e.g., a sippy cup with a top and two handles vs. a regular cup with one handle). Would any detectable shape difference be sufficient, by itself, to lead infants to individuate the objects? Alternatively, by 12 months of age, perhaps infants have learned that only certain salient shape differences support object individuation.

5. Experiment 4

5.1. Methods

5.1.1. Participants

Thirty full-term 12-month-old infants participated in the study (14 girls and 16 boys). Their mean age was 12;13, ranging from 12;0 to 13;2. Equal numbers of boys and girls were randomly assigned to one of the two conditions (mean ages were 12;10 for the Within-kind Condition and 12;16 days for the Cross-kind Condition). Seven additional infants were excluded due to fussiness (5) or parental interference (2).

5.1.2. Materials

Six pairs of objects were used in the study. Three pairs were used in the Within-kind Condition: two cups, two bottles, and two toy ducks. Each pair of objects was very similar in overall size with the same colors and surface patterns. However, the overall shape of each object was different. The two cups were 9.5 cm at their widest and 8 cm tall, painted fuchsia with blue vertical stripes. One cup was a sippy cup with a top and two handles and the other was a regular cup with no top and only one handle. The two bottles were 5 cm in diameter and 19 cm tall. Both bottles were transparent with a green lid and decorated with pink, blue, green, and yellow squares. One bottle was a regular baby bottle and the other one had a bent neck (the infants were shown the side views of the bottles so the bent neck was easily noticeable). The two toy ducks were rubber ducks with two different poses (one side view and one front view were presented to the infants), which made the overall shape rather different. One duck was 8 cm tall and 6 cm at its widest, the other duck was 6.5 cm tall and 8 cm at its widest. Both ducks were primarily yellow with bright red bills.

Three pairs of objects were used in the Cross-kind Condition: a cup and a ball, a bottle and a box, and a toy duck and a toy seal. Each pair of objects was very similar in overall size with the same colors and surface patterns, but the overall shape of the objects was different. The cup was 8 cm tall and 9 cm at its widest; the ball was 8.5 cm in diameter. The cup was a sippy cup with two handles. Both the cup and the ball were painted with pink and yellow stripes. The box was a 7.5 cm cube and the bottle was 13.5 cm tall and 5.5 cm at its widest. Both the box and the bottle were painted bright orange and decorated with purple and blue squares evenly distributed across the front surface. The toy duck was 8 cm at its widest and 7 cm tall and the toy seal was 10 cm at its widest and 6 cm tall. Both the duck and the seal had black eyes and were painted bright yellow. The same four screens were used as in the previous experiments.

5.1.3. Apparatus and procedure

The same apparatus was used as in the previous experiments.

The procedure was identical to that of Experiment 3, except for the change in stimuli. In addition, pilot testing indicated that infants lost interest in these objects over nine encoding trials, so the number of encoding trials was reduced from nine to six.

5.2. Results

Preliminary analyses found no effects of sex and order of outcome. Subsequent analyses collapsed over these variables.

The main results of Experiment 4 were that although there were no statistical differences between the encoding trials of the two conditions, the infants in the Cross-kind Condition succeeded in using the shape differences to determine that there were two objects behind the screen whereas the infants in the Within-kind Condition failed to do so (Fig. 5).

5.2.1. Encoding trials

In order to compare the infants' encoding of the two types of shape differences, an ANOVA examined the effect of condition (Cross-kind vs. Within-kind) and of trial block (first vs. second). There was a main effect of block, $F(1,28) = 6.011$, $p < .05$. Infants looked longer in the first block of encoding trials ($M = 16.0$ s, $SD = 9.9$) than the second block ($M = 11.6$ s, $SD = 8.5$). More importantly, there was no interaction between the two variables, $F(1,28) = 1.888$, $p = .180$.

To see if the infants had habituated to the same extent by the end of the encoding trials, an ANOVA examined the effect of condition (Cross-kind vs. Within-kind) and

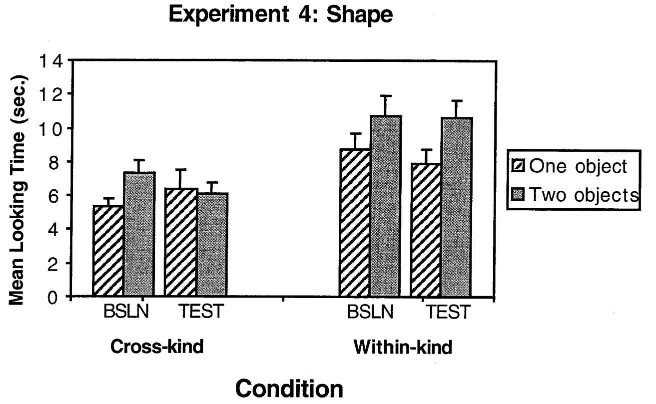

Fig. 5. Mean looking times of Experiment 4.

the effect of trial block (1st vs. 3rd) on looking times during the encoding trials. There was a main effect of block, $F(1,28) = 17.268, p < .0001$. Infants looked longer in the first block of encoding trials ($M = 16.0$ s, $SD = 9.9$) than the third block ($M = 9.0$ s, $SD = 4.5$). More importantly, there was no interaction between the two variables, $F(1,28) = 0.092$, $p = .764$. By the end of the encoding trials, the infants in the two conditions habituated to the same extent.

5.2.2. Baseline trials and test trials

An ANOVA examined the effects on looking times of condition (Cross-kind vs. Within-kind), trial type (Baseline vs. Test) and outcome number (1 object vs. 2 objects). There was a main effect of condition. Overall infants looked longer in the Within-kind Condition ($M = 9.4$ s, $SD = 4.0$) than in the Cross-kind Condition ($M = 6.3$ s, $SD = 3.1$), $F(1,28) = 14.404, p < .001$. There was also a main effect of outcome number. Overall infants looked longer at two objects ($M = 8.6$ s, $SD = 4.0$) than one object ($M = 7.0$ s, $SD = 3.6$), $F(1,28) = 7.451, p < .05$. There was no main effect of trial type. There was a marginally significant three-way interaction, $F(1,28) = 2.409$, $p = .1$.

Two planned ANOVAs examined the effects on looking times of trial type (Baseline vs. Test) and outcome number (1 object vs. 2 objects) for the Within-kind and the Cross-kind Conditions.

For the Within-kind Condition, there was no main effect of trial type. There was a main effect of outcome number, $F(1,14) = 7.346$, $p < .05$. That is, infants looked overall longer at two objects ($M = 10.6$ s, $SD = 4.2$) than one object ($M = 8.2$ s, $SD = 3.4$). There was no interaction between trial type and outcome number, $F(1,14) = 0.198, p = .663$. Infants looked longer at two objects on the baseline trials (M two-object = 10.7 s, $SD = 4.6$; M one-object = 8.7 s, $SD = 3.7$) as well as the test trials (M two-object = 10.6 s, $SD = 4.0$; M one-object = 7.8 s, $SD = 3.3$). Seven of the 15 infants had a smaller preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -.426$, $p = .67$).

For the Cross-kind Condition, there was no effect of trial type or outcome number. There was an interaction of the two variables, $F(1,14) = 4.775, p < .05$. Infants looked longer at the two objects on the baseline trials (*M* two-object = 7.3 s, *SD* = 2.8; *M* one-object = 5.3 s, *SD* = 2.1) but reversed that preference on the test trials (*M* two-object = 6.1 s, *SD* = 2.6, *M* one-object = 7.4 s, *SD* = 4.4). Twelve of the 15 infants showed a smaller preference for two objects on the test trials than on the baseline trials (Wilcoxin $z = -2.329$, $p < .05$).

5.3. Discussion

The effects of two types of shape differences on infant object individuation were contrasted in Experiment 4. Only when the shape difference was (what for adults) a cross-basic-level-kind difference did the infants succeed on the task. In the Cross-Kind Condition, infants used the contrasts between a seal and a duck, a bottle and a box, a cup and a ball, to establish representations of two distinct objects behind the screen. Of all the experiments in this series of studies, except for the Spatiotemporal Conditions of Experiments 1 and 2, it was only in the Cross-Kind Condition that infants reversed their baseline preference during the test trials, looking longer at the unexpected, one-object outcome. In contrast, when the shape difference was (what for adults) a within-basic-level-kind difference (either a subordinate level distinction as in the sippy-cup/regular cup case or the bent bottle/regular bottle case, or a different individual distinction as in the duck/duck case), the infants failed to use the shape difference to establish two distinct objects and they did not look longer at the unexpected, one-object outcome relative to their baseline preference.

It was important to ensure that the two types of shape differences were equally salient and noticeable. To this end, we compared the encoding data between the two conditions. There were no statistical differences between how interested the infants were in the objects (as measured by overall looking time) or how fast they habituated to the objects in the Cross-kind and the Within-kind Conditions. If we take looking time and habituation rates as rough measures of perceptual salience, the two types of shape differences were approximately equivalent for 12-month-old infants.

Perhaps the infants failed to encode the shape differences in either condition. This possibility is mitigated against by the fact that in the Cross-kind condition, infants *succeeded* in individuating the objects, so they must have noticed the shape differences. Furthermore, the overall degree of habituation between the first pair and last pair of encoding trials (about 45% in each condition), was comparable to that in the other experiments in this series. This suggests that infants encoded the properties of these objects.

Thus, although the infants had encoded the shape differences in both conditions, and found them comparably salient, they failed to use Within-kind shape differences as a basis for object individuation.

6. General discussion

Four experiments investigated whether 12-month-old infants were able to use color alone, size alone, the combination of color, size, and surface pattern, and shape information for object individuation in the complex task of Xu and Carey (1996) and Xu (2002). As in Xu and Carey (1996) and Van de Walle et al. (2000), the infants *succeeded* in using spatiotemporal information to establish a representation of two distinct objects, both in Experiments 1 and 2. However, in Experiments 1–3, they *failed* to establish a representation of two objects given perceptual property differences such as color alone, size alone, and a combination of color, size, and pattern, although they perceived the property differences in each case. In Experiment 4, they also *failed* when within-basic-level-kind shape differences were shown (e.g., a regular cup with one handle vs. a sippy cup with two handles). In contrast, when cross-basic-level-kind shape differences (e.g., a cup and a bottle of the same size, color, and surface pattern) were presented, infants *succeeded* on the task.[2]

The failures of the infants in Experiments 1–3 were not due to lack of sensitivity of the method because it required the infant to overcome a baseline preference for two

[2] Studies by Tremoulet, Leslie, and Hall (2000) suggest that 12-month-old infants individuate objects of the basis of color, although they do not re-identify previously individuated objects on the basis of color. How do we reconcile these results with those of Experiment 1? That infants of this age do not reidentify objects on the basis of color is shown by an elegant experiment. Infants were familiarized with a red disk and a green disk emerging alternatively, one at a time, from behind a screen and returning. After this familiarization, the screen was removed, revealing either a red and green disk, or two red disks. Infants looked equally at the two outcomes, suggesting that they had not bound color to their object representations. That is, they did not reidentify objects on the basis of color. What about individuation on the basis of color? In another experiment, Tremoulet et al. compared three other conditions with a control condition in which a red and a green disk was shown one at a time and the outcome was a red and a green disk (Group 1). In the individuation-by-color condition (Group 2), the infants were shown a red disk twice, and the outcome was two red disks. In the identification-by-color condition (Group 3), the infants were shown a red then a green disk, and the outcome was two identical red disks. Lastly, in the identification-and-individuation-by-color condition (Group 4), the infants were shown a red disk twice, and the outcome was a red disk and a green disk. Tremoulet et al. reasoned that longer looking to outcomes of Groups 2 and 4 (number change, since the infants only saw one red disk during familiarization) compared to Groups 1 and 3 (no number change) would provide evidence for individuation on the basis of color. This result was obtained. However, the result was carried by one condition, namely the longer looking time of Group 4. But the longer looking in this condition could be due to a simple novelty effect of introducing a new color on the test trials. If the infants had looked longer in Group 2 (an outcome of two red disks after they had been familiarized with a single red disk) than in Group 3 (an outcome of two red disks after they had been familiarized with a red and a green disk), Tremoulet et al. would have had clear evidence for individuation based on color. However, this comparison was not statistically reliable. We conclude, contrary to Tremoulet et al., that there is no clear evidence for individuation on the basis of color in their experiments with 12-month-old infants, just as there was none in Experiment 1. A related issue is whether infants would use the sameness in properties to establish a representation of a single object before they can use differences in properties to establish a representation of two distinct objects. Like Tremoulet et al., we explored this possibility in Experiments 1 and 2. We habituated infants to a single object and then showed them outcomes of either one object or two identical objects. If infants at 12 months can use the sameness in properties to establish a firm representation of a single object, they should look longer at the two-object outcome. This result was found in Experiment 2, but not in Experiment 1. The failure is perhaps more telling, for there is an alternative explanation for success—infants have been habituated to displays of a single object, so the two-object outcome is simply more novel. We conclude that infants at this age use neither sameness in properties as a basis for establishing a single object representation nor differences in properties as a basis for establishing two distinct object representations, at least not in the present experimental paradigm.

objects. When provided cross-basic-level-kind contrasts, in Experiment 4, 12-month-olds succeeded robustly, as they did in all the previous studies of Xu and Carey (1996) and Van de Walle et al. (2000). Similarly, as in earlier studies, infants also succeeded when provided with spatiotemporal evidence for two distinct objects.

These data suggest that although information-processing demands clearly play a role in when infants succeed on various individuation tasks (Needham & Baillargeon, 2000; Wilcox & Baillargeon, 1998a; Xu & Baker, 2003), it is not the whole story. If information processing demands were the sole factor responsible for the discrepancies found by different laboratories, one would have predicted success on all four of the present experiments—12-month-old infants clearly can process complex objects and complex experimental procedures, as was evidenced by their successes in the experiments of Xu and Carey (1996) and Van de Walle et al. (2000). However, even though the objects used in Experiments 1 and 2 were simpler than those of earlier studies (i.e., they only contrasted on a single dimension, e.g., color or size), the infants failed in each case. They also failed in Experiment 3 in which the objects differed in color, size, and surface pattern. More strikingly, they only succeeded in establishing a representation of two distinct objects when the shape differences were (what for adults) cross-basic-level-kind differences and failed to do so when the shape differences were (what for adults) within-basic-level-kind differences. Thus *the complexity alone hypothesis* would not be able to account for these data, nor for the results of Bonatti et al. (2002; success at 10 months with complex objects, human/doll head vs. dog head, but failure with simple objects, blue cylinder vs. red disc) or Xu (2002; success at 9 months when provided contrasting labels but failure when provided with distinct sounds or emotional expressions).

How do we think about the success and failure with cross-kind and within-kind shape differences, respectively? The data presented here are consistent with at least two interpretations. First, salient shape differences enter into computations of numerical distinctness of objects before other perceptual property differences. Second, by 12 months infants begin to represent some basic-level kinds and it is kind distinctions that support computations of numerical distinctness under conditions of high information processing demands. On the first interpretation, the cross-basic-level-kind shape differences are more salient than the within-basic-level-kind differences. Although analyses of the encoding data in Experiment 4 did not reveal a statistically reliable difference between the Cross-kind and the Within-kind Conditions, a trend in the data suggests that cross-kind shape contrasts might be more salient for the infants (see Table 1). Still, both groups of infants had habituated to the same extent by the end of the encoding trials, confirming that the cross-basic-level-kind shape differences were not greatly more attention grabbing than the within-basic-level-kind shape differences. Furthermore, a potential problem with the salience hypothesis lies in how we think about *salient shape differences*. The more salient shape differences may be the perceptually larger ones, in which magnitude of shape difference is given in terms of some kind-neutral similarity metric, e.g., number and arrangement of geons (e.g., Biederman, 1987). Perhaps our cross-basic-level-kind shape differences are greater than our within-basic-level-kind shape differences on such metric. Second, some shape differences may be *psychologically* more salient precisely because they

Table 1
Looking times (in seconds) of familiarization trials for Experiments 1–4

	1	2	3	4	5	6			
Experiment 1. Color									
Different Condition	7.9	7.6	7.0	6.7	4.7	5.2			
Same Condition	10.1	7.6	4.8	4.6	5.5	3.4			
Spatiotemporal Condition	8.5	9.3	5.6	7.0	4.5	5.0			
	1	2	3	4	5	6	7	8	9
Experiment 2. Size									
Different Condition	7.8	6.2	4.2	3.7	4.3	5.0	3.4	4.1	4.7
Same Condition	7.4	6.6	4.6	3.6	3.3	2.9	3.5	3.6	3.0
Spatiotemporal Condition	7.7	10.2	5.6	7.5	5.6	5.2	5.3	4.6	3.9
	1	2	3	4	5	6	7	8	9
Experiment 3. Color, size, and pattern									
Different Condition	7.4	5.9	4.7	4.7	4.1	4.8	3.2	3.0	3.0
	1	2	3	4	5	6			
Experiment 4. Shape									
Cross-kind Condition	7.8	6.6	6.1	6.4	4.0	3.8			
Within-kind Condition	9.4	8.2	5.2	5.5	5.3	4.8			

entail a difference in object kind. Because we used relatively familiar kinds (e.g., bottle, cup, ball, duck) it is possible that insofar as infants perceived some shape differences as more salient than others, it was because they recognized the differences in object kind. On this interpretation, the shape saliency account collapses to the second interpretation of our data, namely the emergence of kind representations.

We tentatively suggest that the current results provide indirect evidence for *the emergence of kind representations hypothesis*. That is, by 12 months of age, infants' representational system begins to distinguish kinds from properties, and that kind representations have a privileged role in object individuation, relative to property representations. On this interpretation, 12-month-olds succeeded on the Xu and Carey (1996) and Van de Walle et al. (2000) object individuation tasks based on object kind representations as opposed to representations of object properties. That is, they succeed on the basis of contrasts such as *duck* vs. *ball* rather than yellow, rubber, duck-shaped vs. red and spherical.

Three other lines of research are consistent with this suggestion. Using the same complex object individuation task, Bonatti et al. (2002) showed that 10-month-old infants succeeded in using a cross-kind contrast (i.e., the contrast between a human/doll head and a toy dog's head) for object individuation but not a within-kind contrast (i.e., a male vs. a female doll head). Using an inductive inference task, Mandler and colleagues have found that representations of global kinds become robust at around 12 months (e.g., Mandler & McDonough, 1996; McDonough & Mandler, 1998).

Results from Waxman's laboratory are also consistent with our suggestion that by about 12 or 13 months of age, infants begin to distinguish between kind and property representations. Waxman and Markow (1995) and Waxman (1999) showed that by

12–13 months, infants have mapped the distinction between kind and property onto the linguistic distinction between count nouns and adjectives. Upon hearing a series of objects described by a count noun ("Look, it's a blicket."), infants extracted kind similarity (at both the basic and superordinate levels); whereas upon hearing an adjective ("Look, it's a blickish one"), they extracted property similarity (texture or color). That the result was obtained at the superordinate level, where objects do not share shape, suggests that infants of this age distinguish kind representations, rather than shape representations, from property representations such as texture and color.

The distinction between shape and kind is difficult to draw, thus we put forth the second interpretation as a working hypothesis. The distinction we have in mind is that drawn by Kornblith (1993), Markman (1989), and Gelman (2003), in which kind distinctions are inductively deeper than property distinctions, and by Macnamara (1986), Hirsch (1982), Wiggins (1980), in which certain kind distinctions provide criteria for individuation and numerical identity, and thus are lexicalized as count nouns in languages with a count/mass distinction, whereas property distinctions do not. Our second hypothesis makes sense of all the extant data using the complex object individuation tasks—successes at 12 months only when cross-kind contrasts were presented (and even at 10-months when the kind distinction is person/inanimate object, Bonatti et al., 2002).

Some important issues remain in reconciling all of the extant data on object individuation in infancy. Consider the basis of success by 9- and 10-month-old infants in the single trajectory experiments of Wilcox and Baillargeon (1998a) and the switch experiments of Xu and Baker (2003). When information processing demands are lessened such that the infants need not hold representations of two different objects with differing properties in memory in order to succeed at the task, infants under 12 months of age are able to use property or kind information in the service of object individuation. What is the basis of success, single property, multiple properties, or object kind? Because the studies have used stimuli that differed both in properties (color, shape, texture, size) and kind (duck, shoe, cup, etc.), at present we are unable to answer this question. However, Xu and Baker (2003) manipulated the familiarity of the objects in their studies by including pairs of objects that were highly familiar to 10-month-old infants (e.g., cup vs. shoe) and pairs of objects that were highly unfamiliar (e.g., pear vs. train), and found that infants succeeded across the board. Perhaps the combination of property differences sufficed even when the infants were not familiar with the specific kinds. Further studies along the lines of the present ones, in which the objects are contrasted on single properties alone, are needed to fully answer the question.

The present studies also raise an important developmental question: What changes between 10 and 12 months such that the older, but not the younger, infants can draw on certain shape or kind representations for object individuation in the complex object individuation procedures of Xu and Carey (1996) and Van de Walle et al. (2000)? One possibility is that the kind distinctions required in our studies emerge during these months, as we suggest above. Then the question becomes what drives their development at that time? Perhaps over the course of the first year, by interacting with different objects, infants can gradually learn that certain property differences (in particular certain shape differences) are correlated with systematic differences in causal/functional properties that determine with kind membership. Or perhaps language plays a role in the development of kind distinctions, as suggested by Xu (2002). Infants may expect their first words, such as "doggie" or "cup," to refer to kinds. Consistent with this suggestion, Balaban and Waxman (1997) have shown that hearing common labels facilitates categorization on the basis of kind as early as 9 months. Xu (2002) found that even 9-month-old infants succeeded at using the differences between a duck and a ball to infer two distinct objects when distinct labels were presented (e.g., "Look, a duck" vs. "Look, a ball") but not when two distinct sounds or emotional expressions were presented, thus providing further evidence for this suggestion. These two mechanisms are not mutually exclusive, and both could play a role in the developmental changes we observe between 10 and 12 months of age.

Lastly, the results from the current studies reinforce the distinction between perceiving perceptual property differences and using these differences for other computations, in this case, using them in the service of object individuation. Twelve-month-old infants clearly encoded the color, size, and within-kind shape contrasts, but they failed to use them to establish a mental model of the event that contained two distinct objects. (See Appendix A for a different line of evidence supporting the same distinction.) Thus perceiving salient perceptual differences and using these differences for object individuation are two distinct psychological processes, just as we may encounter a person with glasses and black hair today and a person with no glasses and purple hair tomorrow, once we have noted the salient perceptual differences, a second step needs to be taken in deciding whether it was one person with different appearances or two distinct people.

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Appendix A

One important and extremely interesting series of studies by Wilcox and Baillargeon (the narrow/wide screen studies) yield data that suggest that infants as young as 4 months can use property information as a basis for object individuation under some circumstances. Because of the interest of these elegant studies, and the challenge they pose to the picture of the development of object individuation that emerged from our studies, we studied *adults*' representation of these events.

This appendix describes what we found for the interested reader. The data raised the possibility of two very different representations of the narrow/wide screen events, only one of which depends upon having used property differences as a basis for object individuation.

In Wilcox and Baillargeon's studies (1998a, Experiments 3–6; 1998b), infants watched an event in which a green ball moved behind a screen and a red box emerged from the other side, one at a time. Then the box reversed direction and moved behind the screen, followed by the ball emerging from the other side. This event was repeated until the infants looked away. Wilcox and Baillargeon contrasted two conditions: In the wide-screen condition, the occluding screen was 30 cm wide, wide enough for both objects to simultaneously fit behind, since the sum of the widths of the ball and the box was 22 cm. In the narrow screen condition, however, the screen was only 21 cm wide (and in later studies only 15.5 cm wide, Wilcox, 1999), too narrow for both objects to fit behind. They found that infants as young as 4.5 months of age looked longer at the narrow screen event than the wide screen event. They interpreted the infants' behavior as follows: In the narrow screen event, the infants must have used the property differences between the box and the ball to infer two distinct objects and realized that the two objects could not fit behind the screen simultaneously. We call this interpretation the "object individuation" interpretation. Furthermore, Wilcox (1999) found a progression in the ages at which infants succeeded with different types of property differences (4.5 months: size and shape; 7.5 months: pattern; 11.5 months: color). The data from the narrow screen paradigm are robust and systematic.

As will be seen below, our adult description task suggests another possible interpretation of these results. The narrow/wide screen events are very similar to a phenomenon studied in mid-level vision: the tunnel effect (e.g., Burke, 1952). The basic paradigm is to show adults an object going behind a screen, or into a tunnel, followed by another object emerging from the other side. Under some circumstances (related to the speed of the object, the relative sizes of the objects and the occluder, the shape of the inferred path, etc.), the object is perceived as persisting behind the occluder. This phenomenon is called "amodal completion." It is "amodal" because we do not *see* the object behind the occluder (unlike apparent motion, which is "modal completion," because we *see* the object's *apparent* motion). Nonetheless, in amodal completion, our visual system takes into account the various spatiotemporal parameters and yields a representation of a single object persisting through occlusion. Interestingly, as in apparent motion, the features of the objects play a minimal role in the tunnel effect. If we see a green ball going behind an occluder and a red box emerging from the other side, we perceive it as the same object that has changed properties. Perhaps the conditions of the narrow screen event are those that support amodal completion. The narrow screen event may have provided unambiguous spatiotemporal evidence for a single object, leading the infant to interpret the event as a box turning into a ball (as opposed to two objects that could not fit simultaneously). If infants' default expectation is that objects maintain their properties over time, then seeing an object changing properties may be interesting or anomalous. We call this the "single object with property change" interpretation. The primary goal of the study reported in the appendix was to establish that adults, like infants, spontaneously see the narrow screen events as anomalous. But because we asked adults to describe what was happening, we were able to establish whether the event, when judged anomalous, was represented as a single object undergoing interesting property changes or as two objects too big to fit behind the narrow screen. In other words, perhaps the narrow screen events yield the tunnel effect in adults.

Our study had a second goal. In Wilcox and Baillargeon's original studies, for infants to have made the computations claimed for them, they must compare the sum of widths of two objects never seen together (22 cm) with a screen that is only 1 cm too narrow (21 cm), a rather precise calculation. Wilcox and Baillargeon obtained adults' ratings to show that they were capable of this computation. Adults were shown the wide screen or the narrow screen events in a between-subject design, and asked whether they thought both objects could fit simultaneously behind the screen. Those in the narrow screen conditions said "no" (10 out of 12) and those in the wide screen events said "yes" (10 out of 12). In addition, subjects were asked to indicate how much wider the narrow screen would have to be before the two would fit, or how much narrower the wide screen would have to be before the two would not fit. On average they estimated that the narrow screen would have to be around 26.5 cm for the objects to just fit behind them. Wilcox and Baillargeon appeal to "representational momentum" (Freyd, 1993) to explain why adults overestimate the total size of the screen necessary.

Importantly, Wilcox and Baillargeon *explicitly* asked their subjects to judge whether the two objects could fit behind the screen, and so did we in the present experiment. However, the infants in Wilcox and Baillargeon's experiments clearly did *not* receive explicit instructions while watching the events. It would be much more analogous to the infants' situation if adults were simply shown the events and their spontaneous responses recorded. That is, would adults be spontaneously surprised by the narrow screen event, noting there must be a trick, and would they describe their surprise as the screen being too narrow to fit the two objects behind simultaneously? Accordingly, before asking adults for their explicit judgments, the present experiment first tried to establish their spontaneous representations of the events.

A.1. Methods

A.1.1. Participants

Participants were 31 college students randomly assigned to the 15 cm narrow screen condition ($n = 15$) or the 21 cm narrow screen condition ($n = 16$). An additional 20 participants also contributed to the rating task. (They had participated in a pilot version of the first part of the task.)

A.1.2. Materials

The stimuli were the same as in Wilcox and Baillargeon (1998a), a green foam ball, with a diameter of 10.25 cm, and a red cubical foam core box with a side length of 11.75 cm. The objects were mounted on wooden dowels protruded through a track in the floor of the stage, so they could be moved from side to side from below, without the experimenter's hands being visible. One of the sides of the box could be pushed up by the ball when the ball made contact with it and fell back into place as the box was moved away from the ball. The opening was never seen by the participants. The box had no bottom, but this was not visible to the participants. Five 20 cm tall blue screens with widths of 15, 18, 21, 24, and 27 cm were used in the study.

A.1.3. Events and procedure

The experiment took place on a violation-of-expectancy looking time stage surrounded by black curtains. Subjects sat on chairs with their eyes roughly at the same height above the stage as are those of the infants in the Wilcox and Baillargeon narrow screen studies. Initially the stage was covered by a curtain. Subjects were told that they would be shown events that we show to infants and we simply wanted them to describe what was happening on the stage as accurately as possible, and that the event would continue until they had given us their description. We then lowered the curtain, revealing a screen centered on the stage and the ball in view, 6 cm to the left edge of the stage. For half of the participants the screen was the very narrow 15 cm screen and for the other half it was the narrow 21 cm screen. The ball then moved behind the screen, followed by the box emerging from the other side continuing the same trajectory (timing of emergence determined by speed of the object and width of the screen). The box continued to move until it was 6 cm to the right edge of the stage. Its trajectory was then immediately reversed and it returned behind the screen, followed by the ball coming out, continuing the same trajectory to its original position on the left side of the stage. The objects moved at a rate of 12 cm/s, as in the Wilcox and Baillargeon experiments. The event was repeated until the adults provided a description of it.

After describing the event (Q1), adults were asked three additional questions, as the event continued: Is there anything unusual about the event (Q2)? What happens to the ball and the box when they were behind the screen (Q3)? Could the ball and the box fit behind the screen without some kind of trick (Q4)? Responses were taped and transcribed.

Finally, adults were shown how the trick was done (that the ball could hide inside the box) and were told that from now on we would always do the trick, so that they did not misconstrue the rating task as guessing whether the trick was done. The experimenter then showed them events with different size screens and asked them to rate each event on a scale from 1 to 5, where 1 = the ball and box definitely *cannot* fit behind the screen side by side and 5 = the ball and the box definitely *can* fit behind the screen side by side. The screen widths were presented in a randomized order, with each adult judging each screen width twice for a total of 10 trials.

Although the rating task followed the spontaneous description task, we present its results first along with adults' answers to the last question on whether the ball and the box could fit behind the screen without a trick (Q4), for it is a conceptual replication of the Wilcox and Baillargeon explicit judgement task.

A.2. Results

A.2.1. Explicit judgment: Will the two objects fit behind the screen?

The last question, before the rating task, was whether the two objects could fit simultaneously, side by side, behind the screen. The results showed that 100% of the participants in the 15 cm condition said "no," whereas only 43.7% of the participants in the 21 cm condition said "no." This latter percentage was different from that obtained by Wilcox and Baillargeon (1998a) in their adult study; they found 83.3% in the 21 cm condition saying "no." It is likely that the participants in the two studies adopted different criteria on the yes–no decision task, perhaps because it was the only question asked in the Wilcox and Baillargeon study but it followed the spontaneous descriptions in the present study. The participants in the Wilcox and Baillargeon task may have taken the question to be whether they were *certain* the two could fit, whereas our participants may have taken the question to be whether it was *possible* that they could fit.

A.2.2. Ratings

That participants were not sure whether the two objects would fit in the 21 cm condition was shown by the rating phase of the study. Participants were certain that the two objects could not fit behind the 15 and 18 cm screens (mean ratings, 1.0 and 1.2, respectively), were not sure about the 21 cm screen (mean rating, 2.6), were fairly certain that they could fit behind the 24 cm screen (mean rating 4.1), and absolutely certain they would fit behind the 27 cm screen (mean rating, 5.0).

These rating results confirm Wilcox and Baillargeon's adult rating data. Their participants judged that the screen would have to be 5.5 cm wider than 21 cm for the objects to fit behind them, and in our study, participants were confident that the objects would fit behind only the 24 and the 27 cm screens. However, our results extend those of Wilcox and Baillargeon by showing that adults are in fact not certain whether or not the two objects could fit behind the 21 cm screen.

A.2.3. Spontaneous descriptions

The participants' spontaneous descriptions of the events were coded as follows. First, did they spontaneously mention that there was anything anomalous when first shown the event? Second, did they consistently describe the anomaly over the four codable responses (the spontaneous description and the three additional questions)? Third, how did they describe the anomaly if they mentioned it?

A.2.4. First description of the events

Each subject's initial description of the event was coded into one of two categories by coders who were blind to the participant's condition (15 cm screen or 21 cm screen): Ordinary or Explicit/Implicit Mention of a Trick. Ordinary responses simply mentioned two objects entering and emerging from behind the screen. For example, "A blue ball went behind a green piece of cardboard and a red cardboard cube came out the other side." (21 cm participant). Explicit/Implicit Mention of a Trick responses either explicitly commented that there must be some trick and speculated as to the mechanism of the trick, or mentioned what seemed impossible. For example, "Yeah, there's probably a trick to it, the screen is rather small, but I'm sure there's a way of doing that" (pointed out trick; 15 cm participant). Or "I think the blue fuzzy ball goes into the red box and then the red box can come out so it looks like it's transforming" (speculated on the mechanism; 15 cm participant). Or the participant thought the event seemed odd, "Well, that when the circle slides to the right it turns into a square. I expect it to just slide to the right and just stay a circle" (21 cm participant). Two coders independently coded the responses with 100% agreement. The modal response of the participants in the 15 cm condition was Explicit/Implicit mention of a trick (73%), whereas the modal response of the participants in the 21 cm condition was Ordinary (62.5%). Still, almost 40% of the participants in the 21 cm condition did spontaneously refer to a trick, either implicitly or explicitly, indicating that they noticed something impossible about the event.

A.2.5. Consistency of describing the impossibility of the event

Next the consistency of mentioning the impossibility of the event over the four qualitative questions (Q1–Q4) was coded. If the participants mentioned the trick 3 or 4 out of the 4 questions, they were coded as "consistent trick." Below is an example of a participant coded "consistent trick" (15 cm condition; coding of each statement in parentheses):

Q 1. The ball goes behind the piece of paper and supposedly turns into a box (trick).

Q 2. The ball seems to change into a box, an I'm not sure where it goes instead (trick).

Q 3. The ball changes into a box and then comes out the other side (trick).

Q 4. Maybe if there was a hole that the ball can descend into (trick).

If the participants mentioned the trick on 1 or 2 of the 4 questions, they were coded as "maybe trick." Below is an example of a "maybe trick" protocol (21 cm condition):

Q 1. A blue ball went behind a green piece of cardboard and a red cardboard cube came out the other side (ordinary).

Q 2. No, I guess it's magic (trick).

Q 3. I don't know, maybe the box gets put around the ball, I'm not really sure (trick).

Q 4. Yeah (ordinary).

Finally, if the participants showed no hint that there was a trick involved over the 4 questions, they were coded "ordinary event, no trick." Below is an example (21 cm condition):

Q 1. The blue ball went behind the green and then out came a red cube on the right side, and then it went back and the blue ball came out and went back in. The box came out and then it went back in and then the blue ball came back out (ordinary).

Q 2. I don't think so (ordinary).

Q 3. They hide behind the green screen (ordinary).

Q 4. Do I think that ... Right, yeah (ordinary).

Responses were coded by two independent coders with 100% agreement. The responses of virtually all (87%) of the participants in the 15 cm condition fell in the "consistent trick" category, whereas the modal response of those in the 21 cm condition (56%) were in the "maybe trick" category, with only 19% falling in the "consistent trick" category.

The responses in the 15 cm condition demonstrated that this method was sensitive; participants spontaneously noted that something impossible was happening in these narrow screen events and they were certain of it. The participants in the 21 cm condition, however, were much less sure. Fully one quarter of the subjects treated these events as ordinary events involving two objects entering behind and emerging from a screen wide enough to fit both of them, even when explicitly probed whether there was anything unusual and asked to describe what was happening behind the screen. Nevertheless, three quarters of the adults in the 21 cm condition fell into the "consistent trick" or "maybe trick" categories; they had some inkling that something was wrong.

Perhaps the most important question is *how* participants perceived and conceptualized the impossibility of the events when they detected it. Did they see a single object magically transforming, as the tunnel effect hypothesis suggests, or did they see two objects, together too wide to fit behind the narrow screen? To address this question, we analyzed every statement concerning the violation that characterized how the event was being perceived. There were 33 such statements in the 15 cm condition and 15 in the 21 cm condition. Of these 48 statements, all but two described the event as if the ball was magically changing into a box behind the screen (see examples above; "... the circle slides to the right and it turns into a square," "... so it looks like it's transforming," or "... supposedly turns into a box.") The two statements (both in the 15 cm condition) that mentioned that the screen was too narrow for the two objects to fit did so very indirectly—commenting only that the screen seemed "rather small" or "too narrow."

A.3. Discussion

There are two important results from this study, which together add to the plausibility of the tunnel effect alternative to Wilcox and Baillargeon's interpretation of their narrow screen experiments. That is, the narrow screen events are represented in terms of an interesting/anomalous property change of a *single* object rather than an anomalous event in which *two* objects too large to fit behind a single screen. First, adults are not sure whether the two objects could fit behind the 21 cm screen. Not all adults even saw this event as impossible, and in their explicit judgments, adults said they were "not sure" whether the two objects would fit. It is highly unlikely that infants' estimates are more precise that those of adults, such that they could reason that the two objects could not fit behind the screen. However, this argument is hardly conclusive. Our adult raters, like those of Wilcox and Baillargeon, were *not* sure that the objects *could* fit behind the screen until the screen was several centimeters wider than the 21 cm narrow screen. The infants' longer looking could reflect object individuation on the basis of property/kind information and attention being drawn to trying to determine whether the two objects could fit.

More importantly, the second result of note was that when adults spontaneously noticed that something impossible was happening, they universally described what they were experiencing in the language of the tunnel effect interpretation. What they said presupposed that they perceived a single object that was magically transforming shape and color. Adults overwhelmingly interpreted the 15 cm narrow screen event this way, and when they detected any anomaly in the 21 cm screen event (as about 40% of them did), they also interpreted it this way.

The parameters of these events do not overlap with any that have been studied in experiments on the tunnel effect. Rather, the spatiotemporal evidence for a single object in these studies is much stronger than in the traditional literature. The fact that the tunnel effect interpretation was stronger in the 15 cm screen events than in the 21 cm screen events is entirely interpretable; the spatiotemporal information in these events *requires* that only one object was involved. On the tunnel effect interpretation of the Wilcox and Baillargeon narrow screen studies, infants looked less at the wide screen (30 cm) events than the narrow screen events (21 or 15 cm) because the wide screen events did not provide unambiguous spatiotemporal evidence for a single object, and thus the property differences were not anomalous.

One further consideration favors property change over the object individuation representation of the anomaly in the narrow screen events. Wilcox and Baillargeon's narrow screen events provide contradictory evidence to the viewer: the property information is more consistent with two objects behind the screen whereas the spatiotemporal information specifies a single object. Wilcox and Baillargeon assume that the property information dominates, and thus the fact that the screen is too narrow is seen as anomalous. The tunnel effect interpretation assumes that the spatiotemporal information dominates property information, and thus the fact that the object is changing properties is seen as interesting or anomalous. In many studies of mid-level object based attention in adults, when spatiotemporal information is in conflict with property/kind information, the spatiotemporal information dominates (see e.g., Nakayama, He, & Shimojo, 1995, for a review). If object representations of young infants are the same as those of mid-level vision (as was argued by Carey & Xu, 2001; Leslie, Xu, Tremoulet, & Scholl, 1998; Scholl & Leslie, 1999; Xu, 1999, 2003), we should expect the same principle to hold: unambiguous spatiotemporal evidence for a single object should dominate property/kind evidence for two.

Wilcox (1999) tested infants on displays in which the objects differed only in a single property and found that 4.5-month-olds looked longer at the anomalous narrow screen events when shape alone or size alone changed, but not pattern or color; 7.5-month-olds detected the pattern change, and it was not until 11.5 months that infants reacted to a change in color alone. On the property change account, these age differences reflect the saliency of these different property changes, rather than developmental changes in the properties that are used as a basis for object individuation.

It would be informative to discover when infants can use color alone, size alone, or a combination of these properties for object individuation in our task. The data from Experiments 1 to 4 of this paper already suggest that we will not find the same developmental trajectory as Wilcox (1999), for the size contrast did not pattern with the shape contrast. Preliminary results from Van de Walle's (p.c.) and Xu's laboratories found that infants *succeeded* in using color differences alone for object individuation at 14 months whereas they *failed* to use size differences alone at the same age in our complex task (Xu, Cote, & Baker, 2003). This pattern is different from that of Wilcox (1999) where success with size precedes color, providing further evidence that the narrow screen studies and the present studies are tapping into different underlying processes.

In sum, while the spontaneous descriptions support the property change interpretation of the anomalous narrow screen events, *for adults*, this does not prove that the same holds for young infants. We offer these data in support of three conceptual points. First, as the studies reported in the body of this paper show, noticing a property difference does not entail being able to use that property difference as a basis of object individuation. Second, to decide whether infants have represented an event as involving a single object or as two objects, it may be necessary to use a dependent measure that explicitly probes for representations of one versus two objects, as do the experiments in the body of this paper and the manual search experiments of Van de Walle et al. (2000) and Xu and Baker (2003). Third, eliciting spontaneous descriptions from adults of the "magic tricks" we show to infants may be a source of hypotheses concerning how events seen as anomalous might be represented.

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