Developmental Psychology
2013, Vol. 49, No. 7, 1325–1329

0012-1649/13/$12.00 DOI: 10.1037/a0029746

Fourteen-Month-Old Infants Infer the Continuous Identity of Objects on the Basis of Nonvisible Causal Properties

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Research on object cognition in infancy suggests that children from (at latest) 1 year of age are capable of individuating objects according to property/kind information. It remains unclear from previous work, however, whether infants in such studies truly apply sortal (kind) concepts or whether they merely track objects on the basis of superficial surface features. To clarify this question, we examined infants' flexibility in tracking property changes. In particular, we investigated which property changes infants see as diagnostic for kind changes and whether they can dynamically adapt this view as a function of prior knowledge. Fourteen-month-old infants were presented with a salient property transformation indicating a category change (i.e., a rabbit was placed in a box but a carrot was retrieved from it). Prior to the test, half of the infants saw how a stuffed animal could be transformed into another object by a simple mechanism. The other infants were unaware of this transformation. Only infants of the naive group interpreted the property change observed in the subsequent test as diagnostic for a change in identity and thus expected two objects to be present in the box. The results are discussed in the light of psychological essentialism, which can explain why infants treat some classes of property changes but not others as diagnostic for changes in identity.

Keywords: object individuation, essentialism, infancy

One basic precondition for perceiving and reasoning about the world is the capacity to segment the world into discrete objects and keep track of them over time—so-called *object individuation*. Object individuation allows people to see the world as made up of discrete, countable objects and to answer questions about the numerical identity of objects over time ("Is this car the same car I saw driving over there a moment ago?").

Processes of object individuation make use of three types of information: spatiotemporal information, property (featural) information, and kind (sortal) information (Xu, 2007; Xu, Carey, & Quint, 2004). Spatiotemporal information appears to be the dominant source of information in adults' object tracking (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Pylyshyn, 2001) and the first information infants rely on in ontogenetic development. From 2 months of age, for example, infants infer two numerically distinct objects in an event in which no continuous spatiotemporal path connects them (Aguiar & Baillargeon, 1999; Spelke, Kestenbaum, Simons, & Wein, 1995; Wynn, 1992; Xu & Carey, 1996). The use of property and/or sortal information for object individuation, in contrast, emerges only much later: From around 12 months of age, infants individuate objects in the absence of any definite spatiotemporal information at all. The typical scenario used to test for this ability is the following: Infants see an object of type A with properties ABC emerge from a box and return into the box at Time 1, and then see an object of type X with properties XYZ emerge from the box and return into it at Time 2. In looking time versions of such tasks, infants then see the content of the box that contains either one (unexpected) or two objects (expected). In manual search versions, they search in the box and find one object (with expected or unexpected properties), and it is measured whether they continue searching the original object upon retrieving the unexpected object. Spatiotemporal information alone is of no help for such problems. Spatiotemporally, the situation is ambiguous: It might have been the same object seen at different times, or it might have been different objects. From around one year of age (and potentially earlier when the procedure is simplified; e.g., Wilcox & Baillargeon, 1998a, 1998b), infants show competence in such scenarios and infer that there must be two objects in the box, an inference that must be based on property or kind information (Xu & Baker, 2005; Xu & Carey, 1996; Van de Walle, Carey, & Prevor, 2000). Similar capacities have been found also in nonhuman primates (Mendes, Rakoczy, & Call, 2008, 2011; Phillips & Santos, 2007; Santos, Sulkowski, Spaepen, & Hauser, 2002).

But whether infants (and nonhuman primates) in these studies engaged in truly sortal object individuation (reasoning along the lines of "there was an A, now there's an X, so there must be two objects") or whether they merely individuated objects according to their properties (i.e., looking for the missing properties ABC) is a difficult question. The basic reason is that under normal circum-

This article was published Online First August 20, 2012.

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This research was supported by a grant from the Swiss National Science Foundation to Trix Cacchione. We thank Gabriela van der Steeg, Tanja Sretenovic, and Silvia Colmenero for stimulus design, data collection, and coding.

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stances, there is a necessary confound between an object's properties and its kind. One line of indirect evidence, however, suggests that infants do not just track any property difference in object individuation indifferently: 12-month-olds successfully used cross-kind property differences (e.g., in shape) for individuation while at the same time failing to track similar property differences within kind (Xu et al., 2004; see also Feigenson & Carey, 2003; Kingo & Krøjgaard, 2011). Such indirect evidence, however, leaves open the question of why infants ignore certain classes of property differences (e.g., differences in shape between different objects of one kind, say, different cups). The main reason is that the property differences in the cross-kind case were accompanied by more additional property differences than in the within-kind case. Infants thus might have individuated objects not as a function of single property differences but according to clusters of property differences (a round cup and a square cup simply have less overall property difference than a square cup and a round ball).

Our aim in the present study was therefore to investigate early forms of kind-based object individuation more directly by presenting infants with the very same differences in overall properties in different contexts in which they were of varying diagnostic value for kind membership. In particular, we examined whether infants can dynamically adapt their interpretation of a given overall property difference as a function of experience. For this aim, we presented 14-month-old infants (an age where kind/property-based individuation should be well in place) with an event where a toy animal apparently changed into another object kind (e.g., a ball). Prior to the test, half of the infants were shown how the animal could be transformed by a simple causal mechanism. The other half of the infants were unaware of this possibility. The rationale was the following: If infants' object individuation is truly sortal and not just based on property tracking, prior information should lead to different identity judgments in naive versus informed participants. For infants informed about the hidden causal mechanism, this transformation would become explainable and would therefore be merely viewed as a transformation in superficial, accidental properties. By contrast, naive infants would experience this transformation as unexplainable and therefore as diagnostic of an identity change. The infants were tested using a manual search paradigm (Schaub, Bertin, & Cacchione, 2012; Van de Walle et al., 2000; Xu & Baker, 2005). Prior to the test, we showed half of the infants how a stuffed pig could be everted into a ball (see Figure 1). The other half of the infants were unaware of this transformation. In the subsequent test, a stuffed rabbit (that could be everted into a carrot) was hidden inside a box and the infants were encouraged to search for it. In half of the trials, infants found the rabbit (no-switch trials); in the other half of the trials, infants found the carrot (switch trials). In both cases, infants were allowed to search the box again. If children go beyond mere property tracking, the following pattern would be expected: Children who are naive about the animal–object transformation should search longer in switch than in no-switch trials (i.e., expecting two objects to be involved in the event), whereas children who saw this transformation before the testing should search equally long in both cases (i.e., expecting only one object to be involved in the event).

Figure 1. Familiarization (stuffed pig) and test stimuli (rabbit/carrot), and box.

Method

Participants

Participants were twenty-four 14-month-old infants (mean age = 14 months 3 days, *SD* = 6 days). Half of the infants were girls. Eleven additional infants had to be excluded because of parent interference (one), experimenter error (three), failure to complete all test trials (three), and fussiness (four).

Materials

A stuffed pig (familiarization) and a stuffed rabbit (test) that could be everted into a round-shaped object (ball/carrot) and closed with a zip fastener (see Figure 1) served as stimuli. They measured 8 cm (height) × 5 cm (diameter at the largest) before the transformation and 7 cm (height) × 5.5 cm (diameter) after the transformation. The toys were placed inside a 26 cm wide × 34 cm deep × 18 cm high wooden box. An opening in the front wall of the box measuring 15 cm × 9 cm was covered with a pink spandex material with a horizontal slit across its width. An additional wall was mounted at the back end of the box (not visible from the outside).

Design

Infants were randomly assigned to either the pretraining group (and were thus informed about the animal–object transformation) or the no-pretraining group. All infants received four trials, consisting of two switch (sw) trials and two no-switch (nsw) trials in two orders (sw–nsw–sw–nsw/nsw–sw–nsw–sw).

Procedure

Pretraining. Infants of the pretraining group were shown a stuffed pig and were allowed to manipulate it for 60 s. Then the experimenter showed how the pig could be everted inside its cover and transformed into a ball. Again, the infant could manipulate it for 10 s. Then the experimenter transformed it back into a pig. The infants of the no-pretraining group played with other toys (cars, blocks, etc.) for the same amount of time.

Familiarization. Infants of both groups were familiarized with the box. The experimenter placed the box containing the familiarization stimulus on the table, out of reach of the infant (46 cm away). The experimenter took out the stuffed pig and placed it in front of the box for 1 s while saying, "Look at this." The pig was then placed at the bottom of the opening in the front wall, and the box was placed in front of the infant. The experimenter encouraged the infant to retrieve the pig, saying, "Now you." After the infant retrieved the toy, he or she was allowed to play with it (for 5 s). This procedure was repeated with the exception that the pig was now placed well into the box (not at the opening). Again, if the infant retrieved the pig, he or she could play with it for 5 s. If infants did not reach inside the box, the same procedure was repeated three times. The familiarization phase ended as soon as the infant had retrieved the pig at least once from the box. The experimenter removed the box and the familiarization stimulus from the infants' view.

Testing. The experimenter placed the box on the table, out of reach of the infant (46 cm away). The box already contained two test stimuli: (a) the rabbit and (b) a second identical rabbit that was already everted into a carrot. The experimenter took out the rabbit and placed it in front of the box while saying, "Look, have you seen" (1 s). Then she put it back inside the box and repeated this procedure.

Switch trials. After the rabbit was replaced in the box, the experimenter hid the rabbit behind the back wall and placed the carrot at the front. Thus, for sake of simplicity, the experimenter did not transform the rabbit in the box, but she moved her arms inside the box in a similar fashion and for an equal duration. Then the box was placed in front of the infant, who was encouraged to search it. Once he or she had retrieved the carrot, the box was removed out of the reach of the infant again. The child was allowed to play with the carrot for 5 s, after which the experimenter took the carrot away.

No-switch trials. The procedure for the no-switch trials was identical with the exception that the rabbit was not replaced with the carrot inside the box and the infants thus retrieved the rabbit when searching the box. To control for stimulus enhancement, the experimenter imitated the motions of the switch trials in type and duration.

Second search phase, After switch and no-switch trials were terminated, the experimenter again placed the box in front of the infant and allowed him or her to search it for 10 s.

Data scoring and analysis. Dependent measures were the duration and the number of reaches in the second search phase (coded from videotapes). Reaching was coded when infants' backmost finger joints were fully inside the front opening of the wall. Twelve randomly chosen participants were reassessed by a second rater (unaware of the experimental condition) to calculate interrater reliability. The average Pearson correlation between the two observers was .99 (reaching time) and 1.00 (number of reaches).

Results and Discussion

Reaching time and number of reaches were analyzed. Preliminary analyses showed no effects of order of test trials or of trial number (first vs. second trial per trial type) when the data were collapsed over the two trials per type (switch trials and no-switch trials), respectively. An analysis of variance (ANOVA) on mean reaching times with trial type (switch or no switch) as a within-subject variable and condition (pretraining or no pretraining) as between-subjects variable revealed a main effect of trial type, $F(1, 22) = 4.87$, $p = .04$, $\eta_p^2 = .18$, with infants searching longer in switch ($M = 2.81$ s, $SD = 2.35$) than in no-switch trials ($M = 1.89$ s, $SD = 2.15$).

Additionally, a significant interaction of Trial Type × Condition was found, $F(1, 22) = 7.58$, $p = .01$, $\eta_p^2 = .26$. Focusing on the performance in each condition revealed that infants that were naive to the animal–object transformation searched longer in switch trials compared with no-switch trials, $t(11) = 2.54$, $p = .03$, but infants in the informed group did not, $t(11) = 1.24$, $p = .24$ (see Figure 2). Nonparametric tests confirmed these findings. In the no-pretraining group, nine out of the 12 infants searched longer in switch trials, Wilcoxon $z = 2.12$, $p = .03$; in the pretraining group, four out of the 12 infants searched longer in switch trials, Wilcoxon $z = 1.33$, $p = .2$.

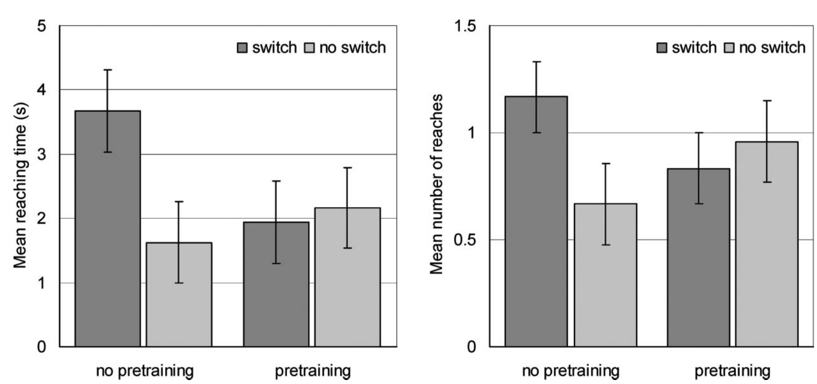

Figure 2. Mean reaching time and mean number of reaches with standard errors (show by error bars) in the switch and no-switch trials for both test conditions (in the pretraining group, the manipulation was known; in the no-pretraining group, the manipulation was unknown).

Further analyses with number of reaches per trial as the dependent variable confirmed these findings. An ANOVA with trial type (switch or no switch) as a within-subject variable and condition (pretraining or no pretraining) as a between-subjects variable revealed no main effects but a significant interaction of Trial Type × Condition, $F(1, 22) = 7.86$, $p = .01$, $\eta_p^2 = .26$. Only naive infants reached more often in switch than in no-switch trials, $t(11) = 3.07$, $p = .01$, but not infants in the informed group, $t(11) = 0.82$, $p = .43$ (see Figure 2). Nonparametric tests confirmed these findings. Eight out of 12 infants searched the box more often in switch trials in the no-pretraining group (Wilcoxon $z = 2.36$, $p = .02$), but only three out of 12 in the pretraining group (Wilcoxon $z = 0.88$, $p = .4$).

Thus, as expected, infants interpreted the observed transformation on the basis of preexisting knowledge. The group of infants who was naive about the animal–object transformation expected a rabbit in the box and searched longer when they retrieved a different kind of object instead (i.e., carrot). In contrast, infants that were informed about the transformation inferred that despite the major surface transformation, the object (the rabbit) was still the same.

Supplementary Control Analyses

However, two alternative explanations must be ruled out. First, there is a very small possibility that the null effect in the pretraining group was a consequence of their prior exposure to the stuffed pig culminating in a general decrease of attention in stuffed animals in the test phase. To rule out this possibility, we tested eight additional 14-month-old naive infants (four girls; mean age = 14 months 5 days, $SD = 9$ days) with exactly the same procedure except that they played with the stuffed pig for 70 s before the test (the duration of the pretraining in the informed group). Mean reaching times of these infants were longer in switch ($M = 4.38$, $SD = 1.79$) than in no-switch trials ($M = 3.44$, $SD = 1.71$), $t(7) = 2.65$, $p = .03$. Six of the eight infants searched the box longer in switch trials, Wilcoxon $z = 1.89$, $p = .06$. Thus, despite prior exposure to the stuffed pig, the uninformed infants searched longer after retrieving an unexpected object in the switch trials.

Second, it is possible that infants of the pretraining condition failed to search for the rabbit in switch trials because their attention was focused on the transformation mechanism itself. In switch trials, informed infants might have been interested in whether the new toy has a transformation mechanism similar to the one they had seen in the pretraining phase. Accordingly, although they might have been surprised by the change in shape, they were even more interested in the toy and its transformation mechanism and therefore might have stopped their search behavior. To address this possibility, we analyzed the amount of time the infants spent manipulating the stimulus after retrieval. An ANOVA on mean manipulation times with trial type (switch or no switch) and test pair (first or second) as within-subject variables and condition (pretraining or no pretraining) as the between-subjects variable revealed no significant main effects or interactions. That is, infants of the informed group did not manipulate the toy longer in switch trials ($M = 4.88$ s, $SD = 0.35$) than in no-switch trials ($M = 4.75$ s, $SD = 0.46$) and did not differ from naive infants in this respect (in the switch trials, $M = 4.85$ s, $SD = 0.32$; in the no-switch trials, $M = 4.86$, $SD = 0.32$ s).

General Discussion

Infants in this study interpreted the observed transformation differently as a function of their preexisting knowledge. They viewed one and the same difference in surface properties as diagnostic for object individuation when they were naive and the difference was thus unexplainable to them except as implying the presence of two different objects. The informed infants, in contrast, viewed the differences as explainable and inferred that despite the major surface transformation, the object in question was still the same. Thus, these infants apparently interpreted the observed property/kind differences as related to causal/functional attributes of a specific kind of object that they encountered in the prior training. These results thus confirm previous research that found that at least from 12 months on, infants individuate objects not only spatiotemporally but according to property/kind information (Feigenson & Carey, 2003; Van de Walle et al., 2000; Xu & Carey, 1996). Further, the present study showed that 14-month-old infants not only detected and used property/kind changes to individuate but that they also realized that some property changes can be neglected in kind-based individuation. Again, this confirms previous studies that found indirect evidence that not all property changes are used equally in individuation (Feigenson & Carey, 2003; Xu et al., 2004).

However, although these earlier findings mostly remained ambiguous as to whether individuation was truly sortal or just property related, the present findings strongly suggest that infants based their inferences on kind/sortal information. Indeed, infants in the present study used one and the same set of property changes only if they interpreted it as being diagnostic for a change in kind (when they were naive about the animal–object transformation) but not if they knew that despite the major surface changes, this was most likely still the same object (i.e., when they were informed about the animal–object transformation). The present work is thus the first to show stringent evidence that early object individuation can be truly sortal and is not just based on property tracking.

Questions of why children realize that some property differences can be neglected in kind-based individuation and which property differences cannot be neglected has been the focus of developmental work on psychological essentialism (see Gelman, 2003, 2004, for reviews). Thus more generally, the present findings may be interpreted as being among the first to suggest that rudimentary forms of psychological essentialism may indeed appear very early in infants. Psychological essentialism proposes that children and adults think about objects and kinds in the same way that philosophers have argued natural kind semantics works (Kripke, 1972; Putnam, 1975). In this view, natural kind categories have two distinct but interrelated levels: the surface level of observable properties (clusters of features) and the underlying unobservable level of a "true nature" (essence) that gives an object its identity and that is responsible for the surface features that all members of this category share (Gelman, 2004). Moreover, essentialist reasoning explains how an object may be tracked as the same individual even through major featural changes. Only the deep essential properties make objects what they are (e.g., deep chemical properties, deep biological properties). If you change these properties, you change the object. In contrast to that, you may change the superficial (prototype) features without altering the identity/kind of the object.

Infants' remarkable flexibility in tracking property changes in the present task suggests that they appreciated that the superficial (prototype) properties may be changed without altering the identity or kind of the object. Thus, the infants likely appealed to essentialism to decide when a change in surface properties was diagnostic of a change in identity. First of all, after learning about a simple causal mechanism effectuating an animal–object transformation, infants treated these causal (but nonobvious) features as more important than the noncausal surface features. Thus, they correctly inferred that the object retrieved from the box was still the same individual (the rabbit) despite its fully different surface appearance. This is consistent with the essentialist view that a nonvisible causal essence determines and sustains the properties of an object and confers its identity. Second, what they learned about the hidden causal properties of one animal (pig) during familiarization, they generalized to another animal (rabbit) encountered in the subsequent test. Note that establishing an analogy between the objects and their transformations witnessed in the training and test events was the only information available to the informed infants to assess the rabbit–carrot transformation as possible conditions of one and the same object. Thus, on the basis of nonvisible causal properties, they formed something like a category of "stuffed animals that may be everted into objects" and readily put both animals (pig and rabbit) in this same category despite major differences on a surface level. Again, these category-based inferences are consistent with essentialist reasoning in that (a) children inferred internal properties and nonvisible functions from one category member to another and (b) children inferred category membership on the basis of nonobvious properties when the objects were not perceptually similar (Gelman, 2004). However, on the basis of the present findings, we cannot ultimately decide whether infants truly appealed to essentialism or actually believed in a magic rabbit–carrot transformation. Future research will need to clarify the scopes and limits of such precocious forms of reasoning and their subsequent developments (particularly in tandem with linguistic developments), as well as their phylogenetic distribution and evolutionary history.

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Received October 26, 2011
Revision received July 5, 2012
Accepted July 13, 2012 ■