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Conceptually Rich, Perceptually Sparse: Object Representations in 6-Month-Old Infants' Working Memory

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Abstract
Six-month-old infants can store representations of multiple objects in working memory but do not always remember the objects' features (e.g., shape). Here, we asked whether infants' object representations (a) may contain conceptual content and (b) may contain this content even if perceptual features are forgotten. We hid two conceptually distinct objects (a humanlike doll and a nonhuman ball) one at a time in two separate locations and then tested infants' memory for the first-hidden object by revealing either the original hidden object or an unexpected other object. Using looking time, we found that infants remembered the categorical identity of the hidden object but failed to remember its perceptual identity. Our results suggest that young infants may encode conceptual category in a representation of an occluded object, even when perceptual features are lost.

Keywords
object representation, binding, cognitive development, working memory

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What information is encoded in an object representation stored in working memory? Maintaining the surface features (such as color, shape, or orientation) of items in working memory is known to be costly: As the number of to-be-remembered items increases, fewer features are retained (Kibbe & Feigenson, 2016; Kibbe & Leslie, 2013; Pylyshyn, 2004; Zosh & Feigenson, 2012; for a review, see Kibbe, 2015). For example, 6-month-olds who observe two featurally distinct objects hidden sequentially in two separate locations will remember the featural identity of only the last object they saw hidden (e.g., Káldy & Leslie, 2005; Kibbe & Leslie, 2016). However, infants are surprised when the forgotten first-hidden object is revealed to have vanished completely, which suggests that they remembered its existence (Kibbe & Leslie, 2011).

Evidence from older infants suggests that they may use categorical information about objects to individuate those objects. Xu and Carey (1996) found that, before 12 months, infants were unable to decide, for example, that a duck pulled from behind a screen and placed back again was distinct from a truck that is subsequently pulled from behind the same screen, even though the objects were featurally distinct. However, by 12 months, infants could use their knowledge of the objects' categories to individuate the objects themselves (Xu, Carey, & Quint, 2004; Xu, Carey, & Welch, 1999). Testing 10-month-olds, Bonatti and colleagues found that if one of the two objects was a doll's head, infants individuated the objects, but if the objects consisted of two featurally distinct dolls' heads, infants failed (Bonatti, Frot, Zangl, & Mehler, 2002; see also Bonatti, Frot, & Mehler, 2005). Surian and Caldi (2010) found that when one of two featurally distinct objects was animate and the other was inanimate, 10-month-olds individuated the objects; however, infants failed when both objects were animate. Together, these studies suggest that the categories *human* and *animate* may be used for individuation by younger infants when surface features are not (for

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evidence of a privileged face category in adults, see Liu, Harris, & Kanwisher, 2010; Peelen & Caramazza, 2012; Stein, Sterzer, & Peelen, 2012).

The above studies, however, examined only individuation. Leslie, Xu, Tremoulet, and Scholl (1998; Scholl & Leslie, 1999) drew a distinction between individuation and object identification, arguing that information that creates an object representation may not necessarily be bound to that representation. Infants may then know how many objects there are in a scene but have limited or no expectations regarding what properties each has.

Given that category information, when available, is more readily used to individuate objects than objects' surface features, perhaps category information also may be more readily encoded in an object representation than surface features. Indeed, Baillargeon and her colleagues have suggested that categorical information may hold a privileged position in infants' representations of objects in physical events, including occlusion and containment (Baillargeon, Li, Ng, & Yuan, 2009; Baillargeon et al., 2012). However, no work to date has examined whether categories that are used to individuate objects may also be encoded in an object representation or whether an object's category may be encoded even when its surface features are not.

Here, we directly tested the hypothesis that the conceptual content of an object representation in working memory may be richer than the perceptual content. By *conceptual content*, we mean the representation of a category, already stored in long-term memory, which is accessed and applied in a top-down manner. By *perceptual content*, we mean features—for example, shape, surface reflectance (color), spatial frequency—that are currently available in a bottom-up manner (Kanwisher, 2000). We used a two-object, two-location hiding method, which can measure both individuation and identification in 6-month-olds (Káldy & Leslie, 2005; Kibbe & Leslie, 2011, 2016). We tested 6-month-olds in particular because they can remember the existence, but not the featural identity, of the first hidden of the two objects (Kibbe & Leslie, 2011), allowing us to explicitly test whether conceptual content may be encoded where featural content typically is not.

In Experiment 1, we hid objects belonging to two categories that 6-month-olds are known to discriminate—*human object* and *nonhuman object* (e.g., Southgate, Csibra, Kaufman, & Johnson, 2008)—and probed infants' memory for the first-hidden object by revealing either the original hidden object (control condition) or the unexpected other object (swap condition; between-subjects design). We reasoned that if conceptual information is encoded more readily than perceptual information in the object representation, infants should remember the categorical identity of the probed object. In Experiment 2, we ruled out the alternative perceptual-featural explanation for infants' performance in Experiment 1. Experiment 3 replicated key conditions. Finally, in Experiment 4, we asked whether the categorical distinction between the objects improved infants' memory for the featural identity of the probed object.

Experiment 1: Human Versus Object, Between-Category Change

Method

Participants. Twenty-four healthy, full-term infants participated (13 girls; age: M = 6 months, 2 days, range = 5 months, 18 days, to 7 months, 0 days). Each infant was randomly assigned to either the control condition (n = 12) or the swap condition (n = 12). Sample size (n = 12 infants per condition) was determined prior to data collection on the basis of the observed effect size (d = 1.13) in our previous study (Kibbe & Leslie, 2011), which used the same method as in the present study to compare infants' looking times to structural changes to the first-hidden object with infants' looking times to no changes to the first-hidden object ($1 - \beta > 0.8$; $\alpha = .05$). An additional 7 infants were tested but excluded from analysis because of fussiness (n = 5) or equipment malfunction (n = 2).

Materials. Stimuli consisted of two objects: (a) a yellow and red striped ball (~ 9 cm in diameter) glued onto a 4.5 × 4.5 black foam-core platform and (b) a doll's head with brown skin and eyes (~ 9 cm in diameter). A circular rigid blue fabric "bib" (11.5 cm in diameter) was glued around the doll's neck (see Fig. 1). Two black foam-core occluders (28.5 × 17.75 cm) were used during the test trials. Stimuli were presented on a black wooden stage (130 × 43 × 50 cm). A curtain hid the stage area between trials. The experimenter wore long white gloves throughout the experiment and jingle bells around her right wrist.

Procedure. Infants were seated on a caregiver's lap about 70 cm from the stage. At the beginning of the experiment, the experimenter lowered the curtain, revealing the empty stage. She then drew infants' attention to the front and back right, left, and center and to the middle of the stage by jingling the bells that she wore around her wrist, so that an observer who was watching each infant on a monitor could get a sense of the infant's eye positions relative to the stage. The experimenter then raised the curtain, hiding the stage area.

Familiarization trials. At the beginning of each familiarization trial, the experimenter placed the doll and the ball sequentially on the center of the empty stage, 7 cm

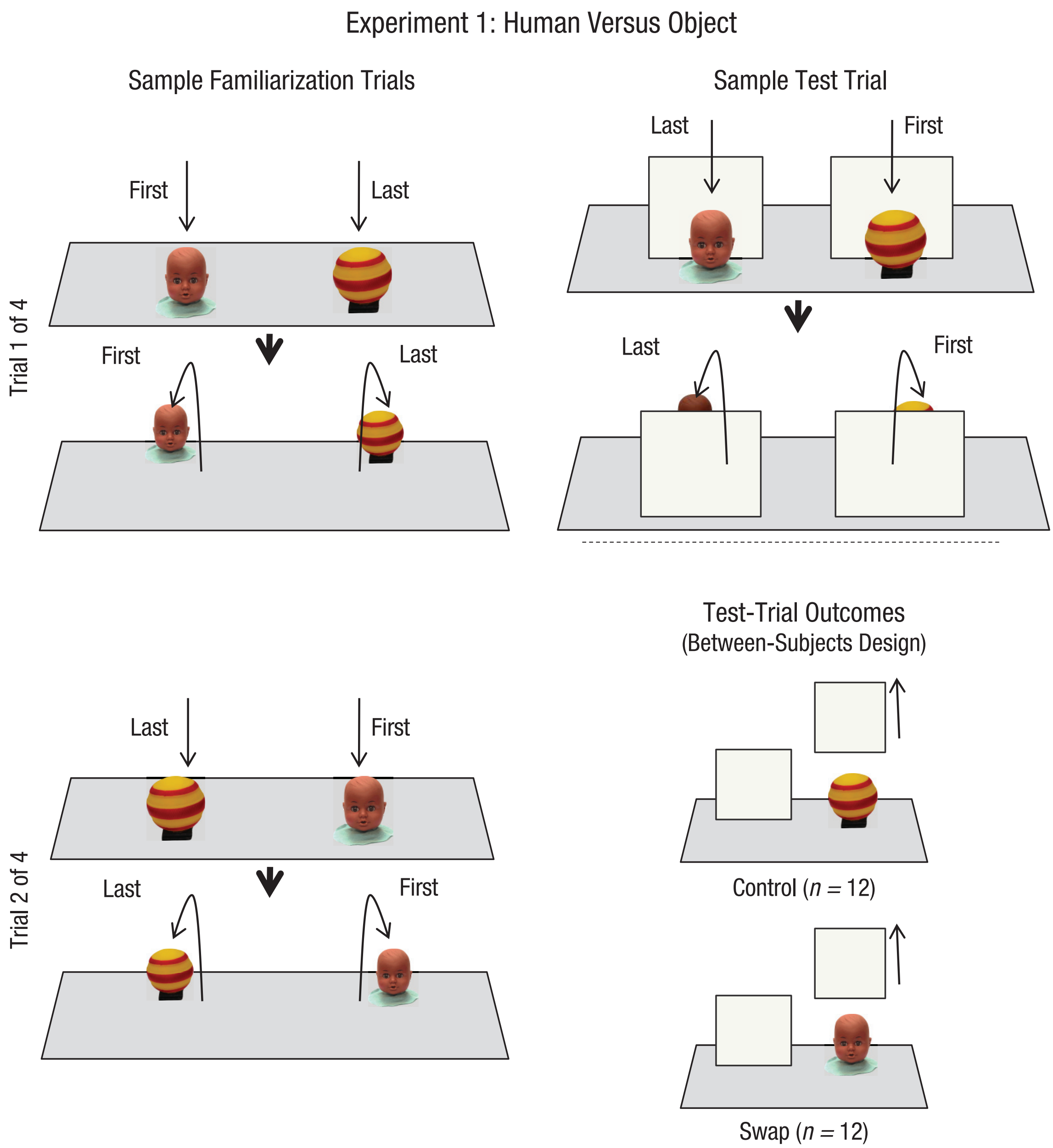

Fig. 1. Sample familiarization trials (left) and test trial (right) for Experiment 1. During familiarization trials, infants observed objects that were placed one at a time on the stage and then moved to the back of the stage. During test trials, infants observed the objects placed on the stage and then hidden alternately behind occluders. The occluder hiding the first-hidden object was then removed to reveal either the object that had been hidden in that location originally (control condition) or the other object (swap condition). Order of presentation and alternating side of placement of objects were counterbalanced across trials during both familiarization and test.

apart. After 4 s, the experimenter moved the objects sequentially to the back of the stage, 55 cm apart, in the same order in which they were originally presented. After 8 s, the experimenter raised the curtain, hiding the stage.

The experimenter repeated this procedure three more times for a total of four familiarization trials. The order and side of placement of the objects were counterbalanced across trials so that infants could not form any long-term associations between particular objects and locations. Order and side of placement of the objects on each trial were also counterbalanced across infants. The left panel of Figure 1 shows two sample familiarization trials (for another example of a familiarization trial, see Video S1 in the Supplemental Material available online). There was no occlusion of objects during familiarization trials.

Test trials. At the beginning of each test trial, the experimenter placed the two occluders on the empty stage, 48 cm apart. The experimenter then placed the ball and the doll sequentially on the center of the stage, 7 cm apart, as in the familiarization trials. After 4 s, she then moved the objects behind the occluders in the order in which they were originally presented. After hiding the second object, the experimenter lifted the occluder hiding the first-hidden (more-difficult-to-remember) object to reveal one of two possible outcomes: Infants in the control condition saw the object that had been hidden there originally (e.g., ball hidden, ball revealed vs. doll hidden, doll revealed); infants in the swap condition saw that the object had been surreptitiously swapped for the other object (e.g., ball hidden, doll revealed vs. doll hidden, ball revealed).

Infants saw three more test trials, for a total of four. The order of placement of the objects and their locations relative to each other across trials was the same as in the familiarization trials. Thus, on half the trials, the ball was hidden first, and on the other half, the doll was hidden first. As in the familiarization trials, the order and side of placement of the objects on each trial were also counterbalanced across infants. The right panel of Figure 1 shows a sample test trial for Experiment 1 (for examples of control and swap test trials, see Videos S2 and S3, respectively, in the Supplemental Material).

An observer who was naive to condition and who was unable to see what infants were seeing measured infants' looking duration following the test outcomes. When infants looked away from the stage for 2 s, the observer signaled the experimenter to terminate the trial. The experimenter then raised the curtain, hiding the stage. Infants' looking times were later recoded off-line, frame by frame, by an observer who was naive to condition, using Preferential Looking Coder software (Libertus, 2011), and these looking times were analyzed. A second naive observer also coded data from a random 50% of infants. Interobserver agreement was high (mean $r = .98$).

Results

All raw looking times were log transformed to correct for right skew, which is common for looking-time data, and analyses were conducted on the log-transformed data (see Csibra, Hernik, Mascaro, Tatone, & Lengyel, 2015; Hays, 1994). For the following planned analyses, we used traditional null-hypothesis significance testing as well as Bayes factor (BF) analysis using the Jeffrey-Zellner-Siow (JZS) prior (Gallistel, 2009; Rouder, Speckman, Sun, Morey, & Iverson, 2009) to quantify the evidence for or against the null hypothesis that infants were unable to remember the first-hidden object.

A repeated measures analysis of variance (ANOVA) with trial (first, second, third, or fourth) as a within-subjects factor and condition (control or swap) as a between-subjects factor revealed no main effect of trial, $F(3, 66) < 1$, $p = .76$, $\eta_p^2 = .018$, and no Trial × Condition interaction, $F(3, 66) < 1$, $p = .46$, $\eta_p^2 = .038$. We observed a significant main effect of condition, $F(1, 22) = 5.39$, $p = .03$, $\eta_p^2 = .20$, although BF analysis suggested anecdotal support for the alternative hypothesis that infants who saw the swap outcome looked longer than infants who saw the control outcome (JZS $BF_{10} = 2.32$). Figure 2 shows the mean raw and log looking time from Experiment 1. In Figure 3, we plot the cumulative probability of the individual mean log looking time from each infant in Experiment 1, providing a visualization of the degree of overlap of the distributions of the data from each condition. Greater overlap suggests that the data from each condition were generated by the same process, suggesting support for the null hypothesis, whereas less overlap suggests that the data from each condition were generated by different processes, suggesting support for the alternative hypothesis (a relationship that is quantified by BF analysis).

Whereas we did not observe a significant interaction between trial and condition, authors of previous studies using violation of expectation typically observed the largest effects on the first test trial (for an example using a similar method, see Kibbe & Leslie, 2011; for trial-by-trial data, see Fig. S1 in the Supplemental Material; for additional information, see the Supplemental Material). Analysis of infants' log looking times on the first trial showed only that infants looked significantly longer at the swap outcome than at the control outcome, $t(22) = 3.08$, $p = .006$, with BF analysis suggesting moderate support for the alternative hypothesis (JZS BF_{10} = 8.039).

Finally, because infants have shown a preference to look at faces over nonfaces (e.g., Farroni et al., 2005; Goren, Sarty, & Wu, 1975), we asked whether the main effect of condition may have been driven by a preference to look at dolls versus balls. We first averaged infants' log looking times across test trials in which the ball was revealed and test trials in which the doll was revealed. We then conducted a repeated measures ANOVA with object revealed (ball or doll) as a within-subjects factor and condition (control or swap) as a between-subjects factor. There was a significant main effect of object revealed, $F(1, 22) = 4.67$, $p = .04$, $\eta_p^2 = .18$; infants looked slightly longer overall at the doll (control: raw $M = 5.65$ s; swap: raw $M = 7.95$ s) than at the ball (control: raw $M = 4.08$ s; swap: raw $M = 6.11$ s), with BF analysis suggesting anecdotal evidence for the alternative hypothesis (JZS $BF_{10} = 1.61$). Critically, there was no Object Revealed × Condition interaction, $F(1, 22) < 1$, $p = .67$, $\eta_p^2 = .008$, which suggests that infants'

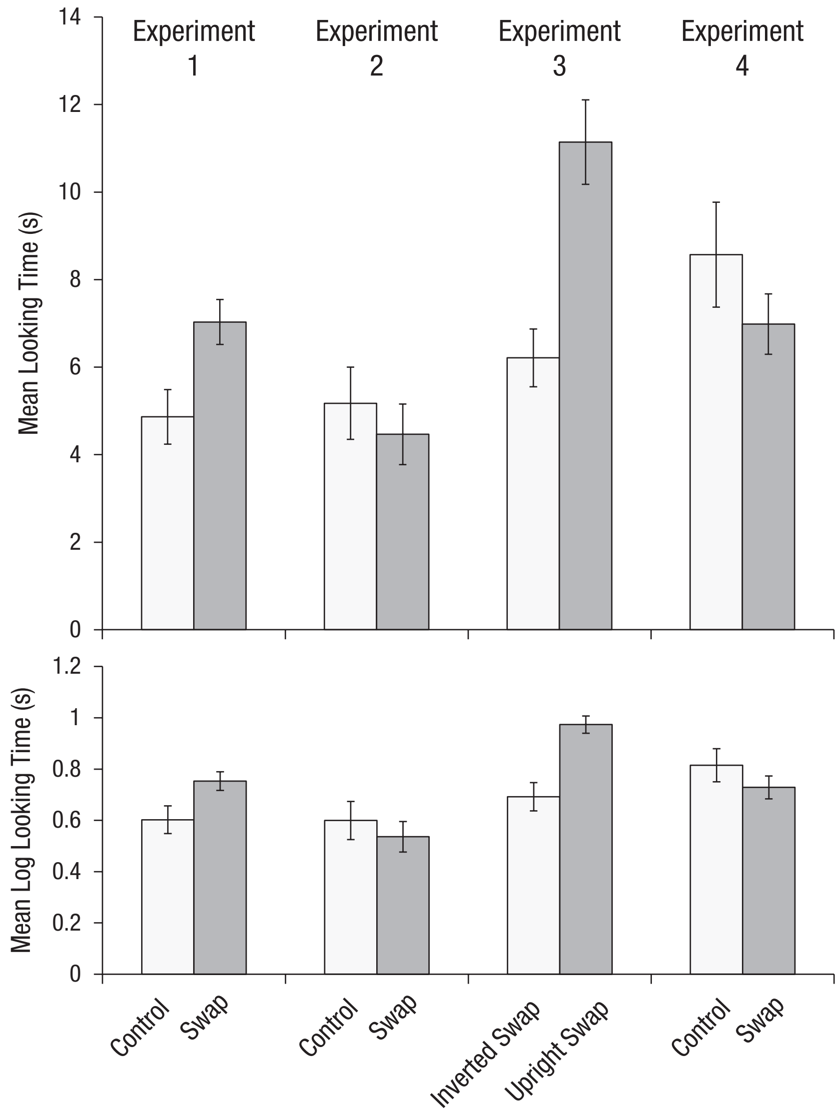

Fig. 2. Mean looking time (top) and mean log looking time (bottom) in each of the two conditions in Experiments 1 to 4. Error bars show ±1 *SEM*.

pattern of longer looking at the doll was not different across conditions.

Discussion

Previous work has shown that infants consistently fail to remember the identity of the first hidden of two objects that contrast in featural identity (e.g., triangle and disk; Káldy & Leslie, 2005; Kibbe & Leslie, 2011, 2016). By contrast, infants in Experiment 1 looked longer at the swap outcome when the two objects contrasted in categorical identity, which suggests that they remembered the first-hidden object's identity. However, it is important to rule out perceptual explanations for our results. The doll and the ball, although categorically distinct, were also highly distinct perceptually. Infants in Experiment 1 may have looked longer not because they encoded categorical information about the objects but because they detected a change to one or more of the many featural differences in the stimuli.

To test this possibility, in Experiment 2, we kept the features of the objects constant while removing the categorical distinctions between the objects. Infants again were shown the ball and the doll, but this time the doll was inverted. Inversion is known to disrupt face processing in both infants (Farroni et al., 2005; Southgate et al., 2008) and adults (Stein et al., 2012), and infants regard inverted faces as categorically

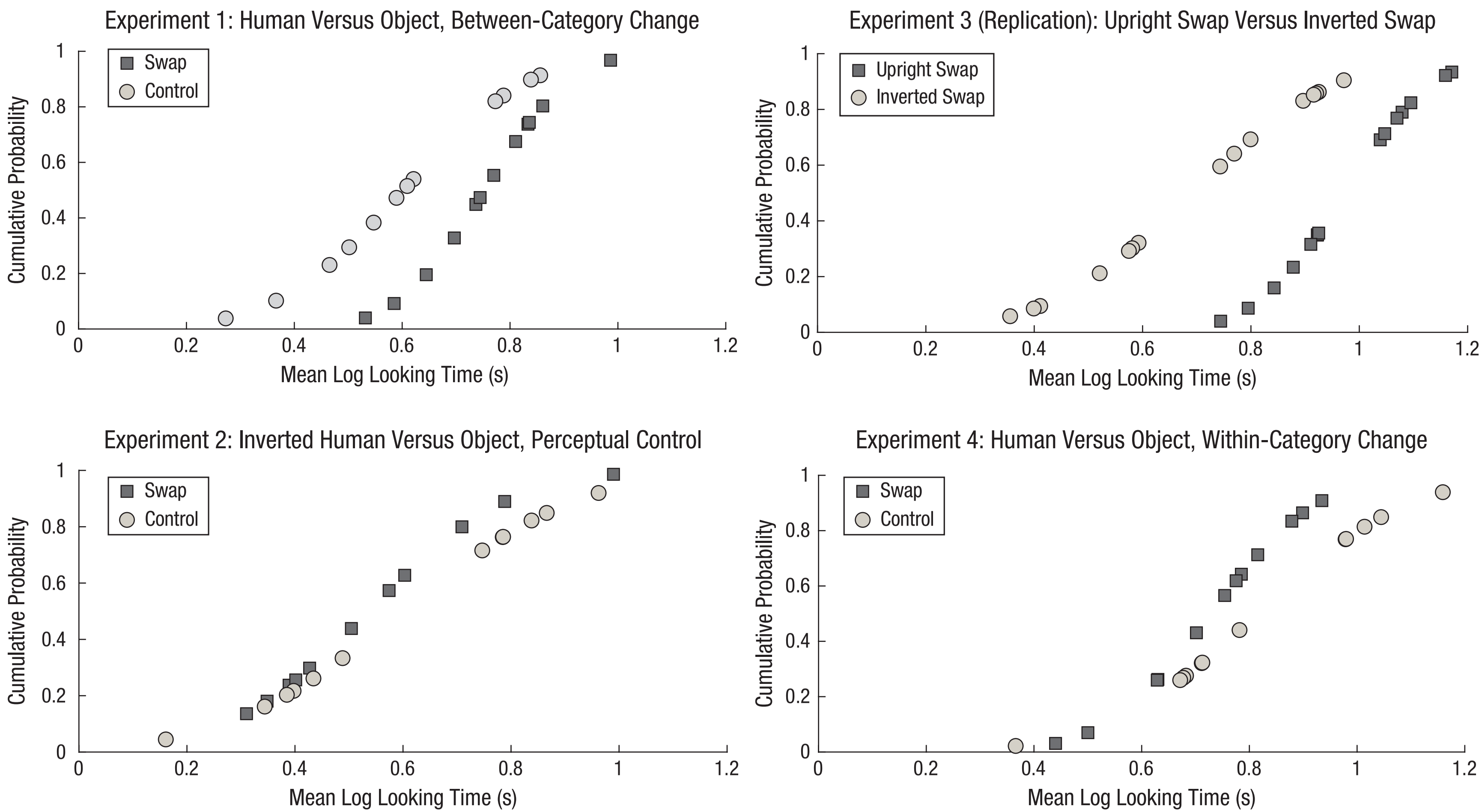

Fig. 3. Cumulative probability of log-scaled mean looking time in each of the two conditions in Experiments 1 to 4.

distinct from upright faces (e.g., Bonatti et al., 2005; Bonatti et al., 2002). If infants succeeded in Experiment 1 because of perceptual differences in the objects, they should succeed again in Experiment 2. However, if infants in Experiment 1 succeeded because they were processing the objects as categorically distinct, infants should fail in Experiment 2. Experiment 2 also addressed the alternative possibility that infants may have succeeded because they remembered the identity of the last-hidden object and noticed that it unexpectedly appeared in the first-hidden location (although previous work suggests that this is unlikely; Kibbe & Leslie, 2013).

Experiment 2: Inverted Human Versus Object, Perceptual Control

Method

Participants. A separate group of 24 healthy, full-term infants participated (13 girls; age: M = 6 months, 14 days, range = 5 months, 15 days, to 7 months, 0 days). Each infant was randomly assigned to either the control condition (n = 12) or the swap condition (n = 12). An additional 2 infants were tested but excluded from analysis because of fussiness.

Materials and procedure. Stimuli and procedure were identical to those in Experiment 1, except that the doll's head was inverted throughout the experiment. Figure 4 shows two sample familiarization trials (left) and an example test trial (right). For another example familiarization trial, see Video S4 in the Supplemental Material, and for example control and swap test trials, see Videos S5 and S6, respectively, in the Supplemental Material.

A naive observer, who was unable to see what infants were seeing, measured looking time during test trials. Infants' looking times were later recoded off-line by an observer who was naive to condition, and these looking times were analyzed. A second naive observer also coded a random 50% of infants. Interobserver agreement was high (mean r = .96).

Results

As in Experiment 1, data were log-transformed to correct for right skew. A repeated measures ANOVA with trial (first, second, third, or fourth) as a within-subjects factor and condition (control or swap) as a between-subjects factor revealed no main effect of trial, $F(3, 66) < 1$, p = .60, η_p^2 = .03, and no Trial × Condition interaction, $F(3, 66) < 1$, p = .81, η_p^2 = .01. There was also no main effect of condition, $F(1, 22) < 1$, p = .52, η_p^2 = .020, which suggests that infants looked equally at control and swap outcomes, although BF analysis suggested anecdotal support for the null hypothesis (BF_{01} = 2.79; see Figs. 2 and 3). Analysis of infants' looking times on the first trial revealed a similar pattern, $t(22) = -0.689$, p = .498; BF_{01} = 2.25 (see Fig. S2 in the Supplemental Material).

As in Experiment 1, we asked whether infants' looking may have been driven by a preference for one object over the other. We predicted that, unlike in Experiment 1, in which infants looked longer at the face than the ball across conditions, infants would not show a preference for the inverted doll in Experiment 2. We averaged infants' log looking times across test trials in which the ball was revealed and test trials in which the inverted doll was revealed and then conducted a repeated measures ANOVA with object revealed (ball or inverted doll) as a within-subjects factor and condition (control or swap) as a between-subjects factor. We found no main effect of object revealed, $F(1, 22) < 1$, p = .98, $\eta_p^2 < .001$, which suggests that infants had no overall preference for the inverted doll (control: raw M = 5.66 s; swap: raw M = 4.14 s) over the ball (control: raw M = 4.69 s; swap: raw M = 4.80 s). BF analysis yielded moderate support for the null hypothesis (JZS BF_{01} = 4.66). Critically, we also observed no Object Revealed × Condition interaction, $F(1, 22) = 1.74$, p = .20, η_p^2 = .073, which suggests that infants' pattern of looking did not vary across conditions.

Finally, we compared infants' mean log looking time in the control and swap conditions across Experiments 1 and 2, using a repeated measures ANOVA with trial (first, second, third, or fourth) as a within-subjects factor and condition (control or swap) and experiment (1 or 2) as between-subjects factors. We found no main effect of trial, $F(3, 132) < 1$, p = .94, η_p^2 = .003, and no Trial × Condition interaction, $F(3, 132) < 1$, p = .84, η_p^2 = .006, or Trial × Experiment interaction, $F(3, 132) < 1$, p = .46, η_p^2 = .02. There was also no main effect of condition, $F(1, 44) < 1$, p = .45, η_p^2 = .013, and no main effect of experiment, $F(1, 44) = 3.63$, p = .06, η_p^2 = .076. Of critical interest is the Condition × Experiment interaction, which was weak over all four test trials, $F(1, 44) = 3.44$, p = .07, η_p^2 = .072. However, inspection of trial-by-trial plots (see Figs. S1 and S2) shows that all trials, with the exception of Trial 4, displayed evidence of an interaction, but effects were largest on looking times for first test trials and diminished on later trials, as is typical in infant looking-time studies with multiple test trials. An ANOVA conducted on log looking times for first test trials showed no main effect of condition ($F < 1$) but did show a main effect of experiment, $F(1, 44) = 4.95$, p = .031, η_p^2 = .101, subsumed under a significant Condition × Experiment interaction, $F(1, 44) = 4.74$, p = .035, η_p^2 = .097. No other significant effects were found on later trials.

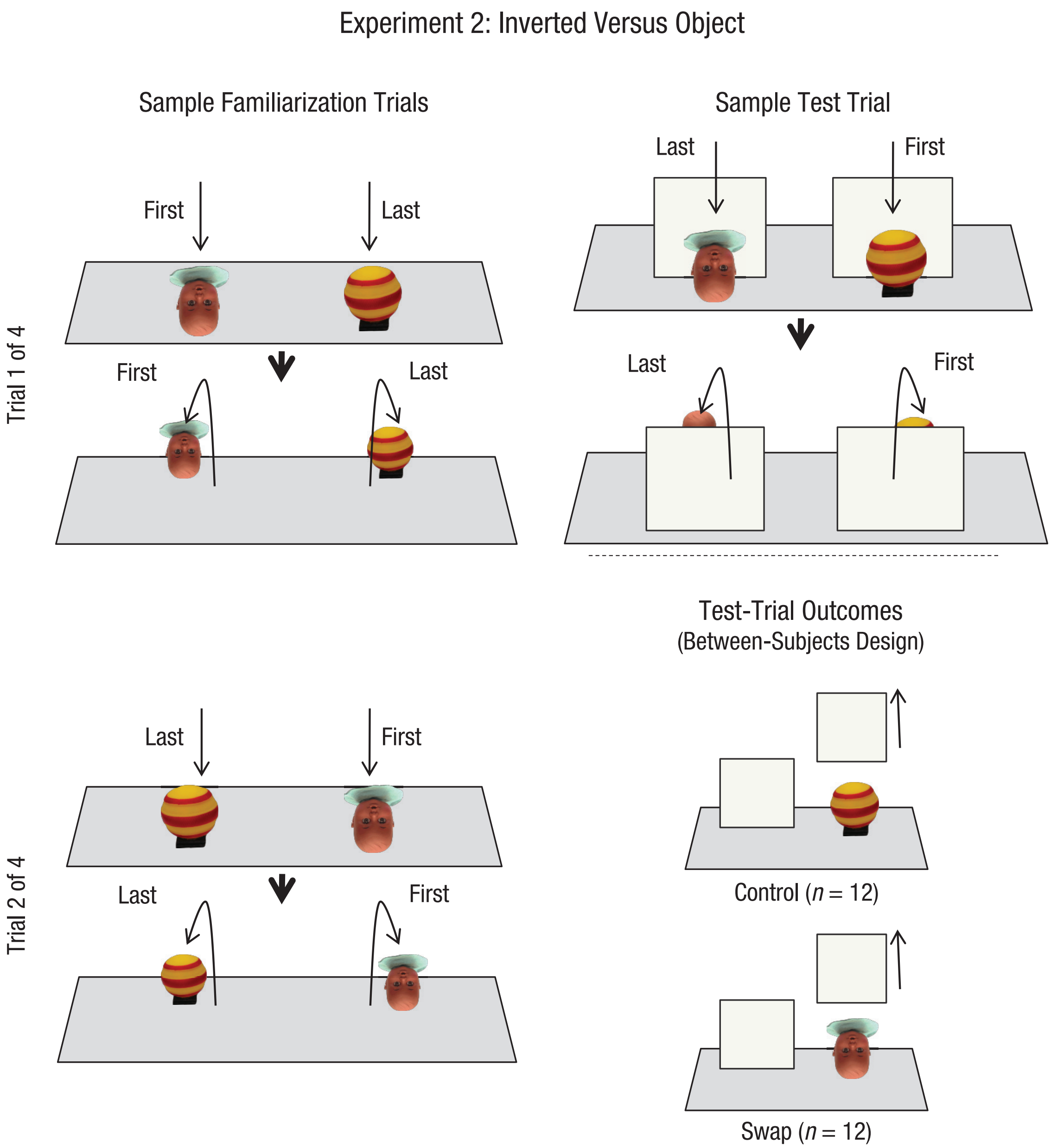

Fig. 4. Sample familiarization trials (left panel) and test trial (right panel) from Experiment 2. Experiment 2 proceeded as in Experiment 1, except that the doll's head was inverted throughout. Order of presentation and side of placement of objects were counterbalanced across trials during both familiarization and test.

We followed these analyses with planned comparisons (Hays, 1994; Chapter 11), using independent-samples *t* tests and BF analysis on infants' log looking times averaged across all test trials. We found that infants looked significantly longer in the swap condition of Experiment 1 than in the swap condition of Experiment 2, $t(22) = 2.84$, $p = .01$, 95% confidence interval (CI) for the mean difference = [0.053, 0.338]; $BF_{10} = 5.339$, and looked roughly equally in the control conditions of the two experiments, $t(22) = 0.033$, $p = .97$, 95% CI for the mean difference = [−0.186, 0.194]; $BF_{01} = 2.68$. We then collapsed the data from the two control conditions and compared the resulting three groups (upright swap vs. inverted swap vs. control) using Dunnett's *t* test for multiple comparisons against a single control with predicted direction, finding a significant difference between the upright-swap and control conditions ($p = .032$) but not the inverted-swap and control conditions ($p = .89$).

Discussion

Unlike infants in Experiment 1, infants in Experiment 2 did not look longer at the swap outcome, which suggests that they failed to notice when the first-hidden object changed. The only systematic difference between Experiments 1 and 2 was that the doll's head was inverted. Together, these results suggest that when objects contrast in categorical identity, infants may successfully encode these identities. However, BF analyses suggested only weak to moderate effects. To confirm the observed pattern of results, in Experiment 3 we conducted a critical replication of the two primary conditions of interest from Experiments 1 and 2—upright swap and inverted swap—using a larger sample of infants.

Experiment 3 (Replication): Upright Swap Versus Inverted Swap

Method

Participants. A separate group of 30 healthy, full-term infants participated (16 girls; age: *M* = 5 months, 28 days, range = 5 months, 0 days, to 7 months, 4 days). Each infant was randomly assigned to either the upright-swap condition (n = 15) or the inverted-swap condition (n = 15). An additional 2 infants were tested but excluded from analysis because of experimenter error (n = 1) or parental interference (n = 1).

Materials and procedure. Stimuli and procedure were identical to those in the swap trials of Experiments 1 and 2. Infants in the upright-swap condition observed familiarization and test trials consistent with the swap condition of Experiment 1 (see Fig. 1). Infants in the inverted-swap condition observed familiarization and test trials consistent with the swap condition of Experiment 2 (see Fig. 4). A naive observer, who was unable to see what infants were seeing, measured looking time during test trials. Infants' looking times were later recoded offline by two separate observers who were naive to condition. Interobserver agreement was high (mean r = .93).

Results

Data were first log-transformed to correct for right skew. A repeated measures ANOVA with trial (first, second, third, or fourth) as a within-subjects factor and condition (upright swap or inverted swap) as a between-subjects factor revealed no main effect of trial, $F(3, 84) = 1.31$, $p = .28$, $\eta_p^2 = .05$, and no Trial × Condition interaction, $F(3, 84) = 1.04$, $p = .38$, $\eta_p^2 = .04$. We observed a significant main effect of condition, $F(1, 28) = 18.926$, $p < .001$, $\eta_p^2 = .40$; infants looked significantly longer at the upright-swap outcome than the inverted-swap outcome (see Figs. 2 and 3). BF analysis yielded decisive evidence for the alternative hypothesis (JZS $BF_{10} = 138.4$). Analysis of only the first test trial revealed a similar pattern, $t(28) = 2.51$, $p = .02$; JZS $BF_{10} = 3.27$ (see Fig. S3 in the Supplemental Material).

Next, we asked whether the significant main effect of condition could be driven by a preference to look at the upright face in the upright-swap condition, rather than a detection of a change to the object's identity. We computed infants' mean log looking time on test trials in which the ball was hidden and the doll was revealed and on test trials in which the doll was hidden and the ball was revealed. We submitted these to a repeated measures ANOVA with object revealed (ball or doll) as a within-subjects factor and condition (upright swap or inverted swap) as a between-subjects factor. We again observed a main effect of condition, $F(1, 28) = 18.92$, $p < .001$, $\eta_p^2 = .403$, but no main effect of object revealed, $F(1, 28) < 1$, $p = .6$, $\eta_p^2 = .01$; infants looked very slightly, but not significantly, longer at the doll in the upright-swap condition (doll: raw M = 12.77 s; ball: raw M = 9.51 s), $t(14) = -2.09$, $p = .06$; JZS $BF_{10} = 1.29$, and looked roughly equally at the two outcomes in the inverted-swap condition (doll: raw M = 5.81 s; ball: raw M = 6.62 s), $t(14) = 0.80$, $p = .44$; JZS $BF_{01} = 3.85$. We also observed no Object Revealed × Condition interaction, $F(1, 28) = 3.39$, $p = .08$, $\eta_p^2 = .11$, which suggests that the main effect of condition was not driven by mere preference for upright faces in the upright-swap condition.

We then compared infants' log looking times in each condition in Experiment 3 with infants' log looking times in the swap conditions of Experiments 1 and 2. We used a repeated measures ANOVA with trial (first, second, third, or fourth) as a within-subjects factor and condition (upright swap or inverted swap) and experiment type (original or replication) as between-subjects factors. We again found no main effect of trial, $F(3, 150) < 1$, $p = .733$, $\eta_p^2 = .008$, and no Trial × Condition interaction, $F(3, 150) = 1.10$, $p = .35$, $\eta_p^2 = .022$. There was also no Trial × Experiment Type interaction, $F(3, 150) < 1$, $p = .502$, $\eta_p^2 = .016$, and no three-way interaction, $F(3, 150) = 1.378$, $p = .252$, $\eta_p^2 = .027$.

Critically, we observed a significant main effect of condition, $F(1, 50) = 27.22$, $p < .001$, $\eta_p^2 = .353$; infants looked significantly longer at the upright-swap outcome than the inverted-swap outcome, with BF analysis yielding decisive support for the alternative hypothesis (JZS BF_{10} on combined mean log looking time = 721.59; JZS BF_{10} on combined log looking time on Trial 1 only = 45.5; see Fig. 3). There was a significant main effect of experiment type, $F(1, 50) = 15.48$, $p < .001$, $\eta_p^2 = .236$, but no Condition × Experiment Type interaction, $F(1, 50) < 1$, $p = .50$, $\eta_p^2 = .009$; overall, infants looked longer in Experiment 3 (replication) than in the original experimental conditions, but their pattern of looking longer at the upright-swap outcome than the inverted-swap outcome did not differ across experiments.

Finally, to confirm the results of Experiments 1 and 2, we conducted separate BF analyses comparing the combined upright-swap conditions from Experiments 1 and 3 with the combined control conditions from Experiments 1 and 2, as well as the combined inverted-swap conditions from Experiments 2 and 3 with the combined control conditions. Analysis of infants' mean log looking time in the combined upright-swap conditions versus the control conditions yielded a JZS BF_{10} of 2,288.3, with a similar pattern observed on the first trial only (JZS BF_{10} = 1,632.1), decisively favoring the alternative hypothesis. Analysis of infants' mean log looking time in the combined inverted-swap conditions versus the control conditions yielded a JZS BF_{01} of 3.2, with a similar pattern observed on the first trial only (JZS BF_{01} = 3.4), suggesting moderate evidence in favor of the null hypothesis.

Discussion

The results of Experiment 3 replicated the pattern of results observed in Experiments 1 and 2. Together, these results suggest that when objects contrast in categorical identity, infants are able to track their identities into occlusion. One additional possibility should be explored: Presenting infants with objects from two distinct conceptual categories may help infants to better encode the features of each object in addition to, or even instead of, the objects' categorical identities. Infants in Experiments 1 and 3 could have tracked the objects by recalling the features of the objects, the categories of the objects, or both.

To test this possibility, in Experiment 4 we again hid two categorically distinct objects as in Experiment 1. However, on swap trials, the first-hidden object was revealed to have changed to a featurally distinct object from the same category as the hidden object. If the categorical distinctions between the objects prompt infants to encode the features of the objects, infants should successfully detect the large featural change between objects with the same categorical identity. However, if the categorical distinctions between the objects prompt infants to encode the categorical identity but not the featural identity of the probed object, infants should fail.

Experiment 4: Human Versus Object, Within-Category Change

Method

Participants. A separate group of 24 healthy, full-term infants participated (12 girls; age: M = 6 months, 7 days, range = 5 months, 5 days, to 7 months, 13 days). Each infant was randomly assigned to either the control condition (n = 12) or the swap condition (n = 12). An additional 4 infants were tested but excluded from analysis because of fussiness (n = 3) or experimenter error (n = 1).

Materials. Materials were identical to those in Experiment 1, except that two additional objects were used: a green ball with red polka dots (~ 9 cm in diameter) glued onto a 4.5 × 4.5 black foam-core platform and a doll's head with plastic blonde hair, pink skin, blue eyes, and a pink necklace, also glued onto a 4.5 × 4.5 black foam-core platform and roughly the same size as the other objects used. These objects were chosen to be highly featurally dissimilar from their counterparts from the same category (see Fig. 5).

Procedure.

Familiarization trials. The four familiarization trials proceeded similarly to those in Experiments 1 and 2. On each familiarization trial, infants saw one ball and one doll placed on the stage. Across trials, infants saw each object from one category (humanlike dolls) paired with each object from the other category (nonhuman object balls), with order and side of placement counterbalanced across trials and across infants. Thus, whereas infants got less overall exposure to each object than in Experiments 1 and 2, they experienced each object in each potential location, in each potential presentation order, and paired with each object from the other category during familiarization trials. The left panel of Figure 5 shows examples of three of the four familiarization trials. For an example familiarization trial, see Video S7 in the Supplemental Material.

Test trials. The four test trials proceeded similarly to those in Experiments 1 through 3. A ball and a doll were placed one at a time on the stage. After 4 s, the experimenter hid these sequentially behind the occluders. The experimenter then lifted the screen occluding the first-hidden object. Half of the infants saw the object that was hidden there originally (e.g., striped ball hidden, striped ball revealed; control condition). The other half of the infants saw that the object had been swapped for a featurally distinct object of the same category (e.g., striped ball hidden, green ball revealed; swap outcome).

Infants then saw three more test trials, for a total of four test trials. Across test trials, as in familiarization trials, infants always saw one ball and one doll on each trial, with the order and side of placement of the objects counterbalanced across trials and infants. Thus, on half the trials, the ball was hidden first, and on the other half, the doll was hidden first. The right panel of Figure 5 shows

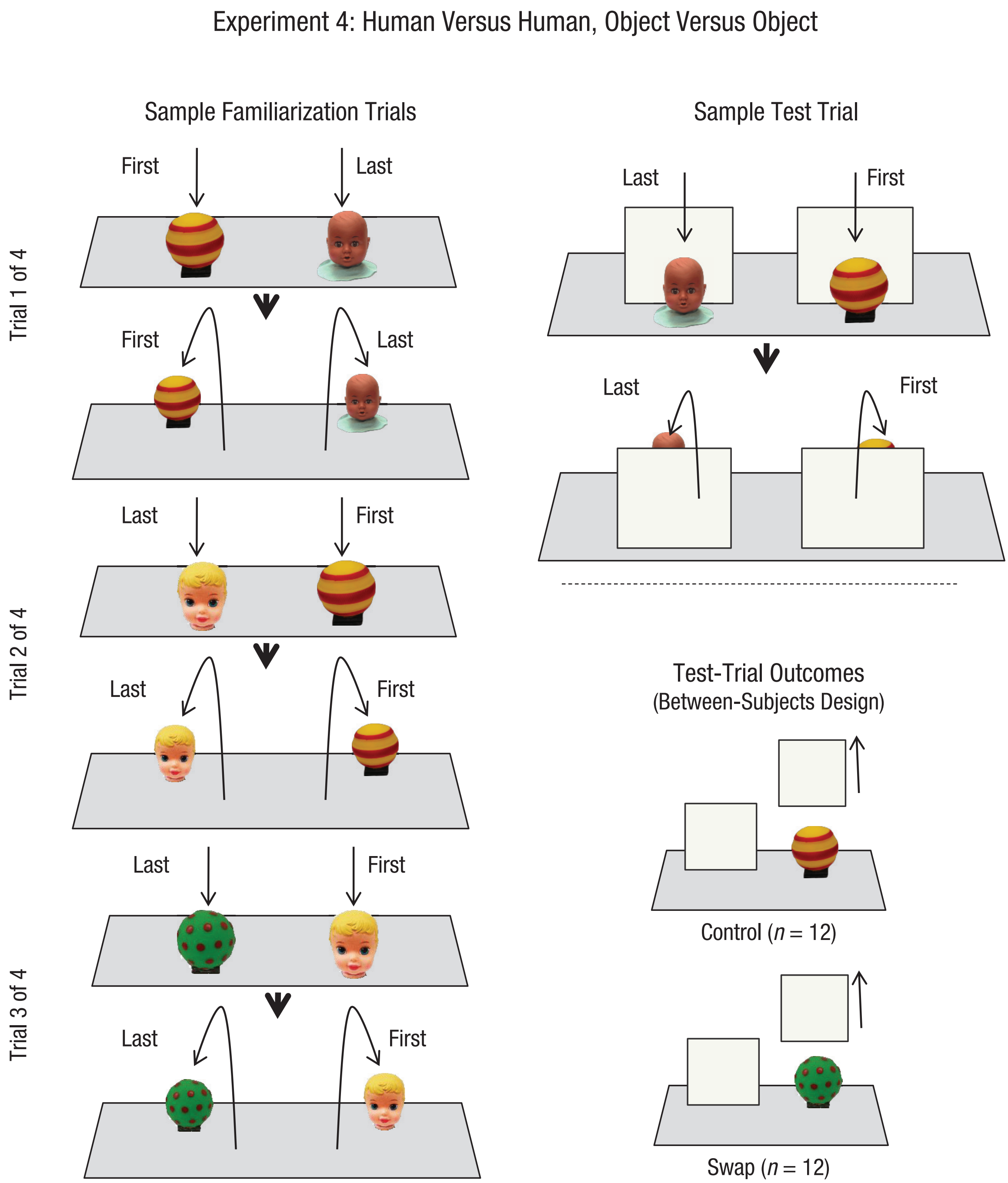

Fig. 5. Sample familiarization trials and test trial from Experiment 4. The left panel shows examples of three of the four familiarization trials for Experiment 4. Infants observed all possible pairings of dolls and balls, with order and side of placement counterbalanced across trials and across infants. The right panel shows an example of one of the four test trials for Experiment 4. Infants observed a doll and a ball hidden alternately behind separate occluders. The occluder hiding the first-hidden object was then removed to reveal either the object that had been hidden in that location originally (control condition) or the object from the same category to which infants had been familiarized but that was not present on that trial (e.g., yellow ball hidden, green ball revealed; swap condition).

a sample test trial for Experiment 4. For example test trials from the control and swap conditions, see Videos S8 and S9, respectively, in the Supplemental Material.

A naive observer who was unable to see what infants were seeing measured looking time during test trials. Infants' looking times were later recoded off-line by an observer who was naive to condition, and these looking times were analyzed. A second naive observer also coded a random 50% of infants. Interobserver agreement was high (r = .98).

Results

As in Experiments 1 to 3, data were log-transformed to correct for right skew. A repeated measures ANOVA with trial (first, second, third, or fourth) as a within-subjects factor and condition (control or swap) as a between-subjects factor revealed no main effect of trial, $F(3, 66) = 1.88$, $p = .14$, $\eta_p^2 = .08$, and no Trial × Condition interaction, $F(3, 66) < 1$, $p = .76$, $\eta_p^2 = .02$. There was also no main effect of condition, $F(3, 66) < 1$, $p = .95$, $\eta_p^2 < .001$, which suggests that infants looked equally at control and swap outcomes, with BF analysis yielding weak evidence for the null hypothesis (JZS $BF_{01} = 2.19$; see Figs. 2 and 3). Analysis of only the first trial revealed a similar pattern, $t(22) = -0.418$, $p = .680$; JZs $BF_{01} = 2.513$ (see Fig. S4 in the Supplemental Material).

We also asked whether infants' pattern of looking to the different objects (e.g., a preference for the doll) impacted their looking across conditions. A repeated measures ANOVA with object revealed (ball or doll) as a within-subjects factor and condition (swap or control) as a between-subjects factor revealed that infants tended to look longer at dolls (control: $M = 9.36$ s; swap: $M = 8.58$ s) than at balls (control: $M = 7.78$ s; swap: $M = 5.39$ s), but this difference was not significant, $F(1, 22) = 3.43$, $p = .08$, $\eta_p^2 = .14$. There was also no interaction between object revealed and condition, $F(1, 22) = 1.33$, $p = .26$, $\eta_p^2 = .06$, which suggests that infants' pattern of looking to the two object types did not differ as a function of condition.

Finally, we asked whether infants' looking time to the within-category-swap outcome of Experiment 4 differed significantly from their pattern of looking to the swap outcomes in Experiments 1 to 3. This allowed us to test the critical hypothesis that infants would be able to detect a change to the identity of the first-hidden object only if the following two criteria were met: (a) The hidden objects contrasted in category, and (b) the first-hidden object was revealed to have changed to an object from a different category. If this hypothesis were supported, it would suggest that infants encode the category of the first-hidden object but not necessarily its specific featural identity. We hypothesized that infants would look significantly longer at the upright-swap outcomes of Experiments 1 and 3 than at the inverted-swap outcomes of Experiments 2 and 3 or the within-category-swap outcome of Experiment 4.

We submitted infants' log looking time to the swap outcomes of Experiments 1 through 4 to a repeated measures ANOVA with trial (first, second, third, or fourth) as a within-subjects factor and condition (upright swap, inverted swap, or within-category swap) and experiment type (original or replication) as between-subjects factors. Main effects were examined using planned post hoc tests with Bonferroni correction for multiple pairwise comparisons. We observed no main effect of trial and no interactions between trial and any other variables (all Fs < 1.53, all ps > .05). There was a significant main effect of experiment type, $F(1, 61) = 16.10$, $p < .001$, $\eta_p^2 = .209$, but no Experiment Type × Condition interaction, $F(1, 61) < 1$, $p = .49$, $\eta_p^2 = .008$; infants looked longer overall in the replication than in the original experiments ($p < .001$), regardless of outcome.

Critically, we observed a significant main effect of condition, $F(1, 61) = 15.12$, $p < .001$, $\eta_p^2 = .331$. Post hoc pairwise comparisons with Bonferroni correction revealed that infants looked significantly longer at the upright-swap outcome than at both the inverted-swap outcome ($p < .001$) and the within-category-swap outcome ($p = .05$), with BF analysis yielding decisive (upright swap vs. inverted swap: JZS $BF_{10} = 721.59$) and moderate (upright swap vs. within-category swap: JZS $BF_{10} = 3.80$) support for the alternative hypothesis. Infants' looking times to the inverted-swap and within-category-swap outcomes did not differ significantly ($p = .237$), with BF analysis offering anecdotal support for the null hypothesis (JZS $BF_{10} = 1.44$).

General Discussion

We tested the hypothesis that the conceptual content of object representations may be richer than the perceptual content. We tested 6-month-old infants, who can individuate multiple objects but can remember the featural identity (e.g., shape) of only a single object (Káldy & Leslie, 2005; Kibbe & Leslie, 2011, 2016). We hid two objects from infants and tested their ability to recall the first hidden of the two objects, for which infants typically fail to recall perceptual features. In Experiment 1, we hid two objects from different conceptual categories (human object and nonhuman object) and found that 6-month-olds' pattern of looking suggested that they successfully recalled the categorical identity of the probed object. In Experiment 2, we ruled out lower-level perceptual explanations for infants' pattern of looking in Experiment 1. In Experiment 3, we replicated the critical comparison from Experiments 1 and 2 with a larger sample of infants. Finally, in Experiment 4, we found that presenting infants with categorically distinct objects did not simply improve their working memory for the featural identities of those objects.

Together, our results suggest that categorical identity may be encoded more readily than featural identity in the object representation. This suggests that some conceptual content may be a privileged or essential part of the structure of object representations, as hypothesized by Baillargeon et al. (2012). Our results are consistent with previous work on object individuation that showed that if 10-month-old infants are sensitive to conceptual distinctions between the objects, they will use these distinctions to form representations of distinct individuals (e.g., Bonatti et al., 2002; Futó, Téglás, Csibra, & Gergely, 2010; Needham, Dueker, & Lockhead, 2005; Xu & Carey, 1996). However, in those studies, infants did not need to encode or retain categorical identity in their representations of the objects. Our results show for the first time that such information finds its way into the object representation itself and that this happens by 6 months of age. Yoon, Johnson, and Csibra (2008) argued that a social communication context, such as ostensive pointing, is important for 9-month-olds to remember object type but at the cost of remembering location. Our findings with 6-month-olds show memory both for location and for object type even outside of a communicative context.

What is the structure of infants' representations of occluded objects? Perhaps some conceptual information is essentially represented whenever an object is (e.g., Baillargeon et al., 2012). For 6-month-olds, whose conceptual repertoire is small, essential content may be limited to core-knowledge concepts such as *object* and *agent* (cf. Carey, 2009; Leslie, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992). The conceptual content included automatically in representations of occluded objects may be limited to these core-knowledge concepts across the life span or may be expanded to include conceptual content acquired through specific experience, including kind-based information (Feigenson & Halberda, 2008; Needham et al., 2005; Xu & Carey, 1996) and functional information (e.g., Futó et al., 2010; Stavans & Baillargeon, 2018).

A different possibility is that conceptual information requires binding to object representations, just like perceptual features do. However, concept bindings may be easier to form, cheaper to maintain, or more durable over time, and certain concepts, such as *human*, may be privileged in certain ways (Bonatti et al., 2002; Stein et al., 2012). For example, whereas feature binding may rely on sensory traces in early visual areas (e.g., Harrison & Tong, 2009; Serences, Ester, Vogel, & Awh, 2009)—traces that are inherently noisy and subject to interference as new sensory information comes in—concept binding may rely on more durable long-term representations that are more resilient to interference or decay. In either case, the notion of concept binding is consonant with previous work suggesting that an object representation can be a raw, featureless pointer to an occluded object's location in space, containing no information about the object's identity (conceptual or otherwise; Kibbe & Leslie, 2011; Leslie et al., 1998; Pylyshyn, 1989; Scholl & Leslie, 1999).

Action Editor

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Author Contributions

Both authors developed the study concept and design. M. M. Kibbe collected the data, and both authors analyzed the data. M. M. Kibbe drafted the manuscript, and A. M. Leslie provided critical revisions. Both authors approved the final manuscript for submission.

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Supplemental Material

Additional supporting information can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797618817754

Open Practices

Data for these experiments have not been made publicly available but will be provided on request. Materials consisted of physical objects and therefore cannot be readily shared publicly, but videos of the methods are available in the Supplemental Material available online. The design and analysis plans were not preregistered.

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