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Research Report

Word comprehension facilitates object individuation in 10- and 11-month-old infants

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ABSTRACT

The present study investigated the role that comprehending words for objects plays in 10- and 11-month-old infants' ability to individuate those objects in a spatiotemporally ambiguous event. To do this, we employed an object individuation task in which infants were familiarized to two objects coming in and out from behind a screen in alternation, and then the screen was removed to reveal either both or only one of the objects. Results show that only when 10- and 11-month-olds comprehend words for *both* objects seen do they exhibit looking behavior that is consistent with object individuation (i.e., looking longer when one of the objects is surreptitiously removed). Neither level of object permanence reasoning nor overall receptive vocabulary had an effect on performance in the object individuation task, indicating that the effect was specific to the immediate parameters of the situation, and not a function of overall precocity on the part of the succeeding infants. These results suggest that comprehending the words for occluded/disoccluded objects provides a kind of "glue" which allows infants to bind the mental index of an object with its perceptual features (thus precipitating the formation of two mental indexes, rather than one). They further suggest that a shift from object indexing driven by the *where* (dorsal) system to one which is driven by integration of the ventral and dorsal neural systems, usually not observed until 12 months of age, can be facilitated by word comprehension in 10- and 11-month-old infants.

1. Introduction

This special issue examines the comprehension of the meanings of words in real-life contexts. The present study approaches this question from the standpoint of very early language development. Specifically, it asks: how does the comprehension of the meanings of words act to change an infant's perception and cognition about the world? To explore this, we use a well-known paradigm in infant research which evaluates infants' abilities to individuate objects. Object individuation involves determining the discrete number of objects involved in an event. This is a task that infants are continuously faced with in their lives. Consider the following scene: A baby sees her mother retrieve a baby bottle from the diaper bag. The mother re-considers, places the bottle back into the diaper bag, and her hand comes back out, instead,

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with a sippy cup. Does the infant understand that this is not the same object she briefly saw a few seconds ago? Does she expect that a second object remains in the diaper bag? Does she further expect that the object in the diaper bag is a *bottle*, rather than a sippy cup (and would she be surprised, if she looked inside, to find another sippy cup there?) Thanks to years of clever experimentation on the part of developmental psychologists, we have strong predictions about what infants' behaviors will be in these types of situations depending on their age, the properties of the objects they see disappear, whether or not the objects disappear into the same or into two spatially distinct locations, and so on. We first review what is already known about this ability, what insights we have from neuroscience research about the underpinnings of this ability, and about how labeling objects plays a role in this knowledge. We then present two experiments that probe, in a given infant, the relationship between knowing the words for objects and his or her ability to represent those objects numerically when they go out of sight.

1.1. What properties do infants rely on in individuating objects, and at what ages?

It is well established that spatiotemporal information (information about spatial location and motion) is a robust cue to object individuation in infants. A number of studies have converged on the finding that unambiguous spatiotemporal information enables infants to succeed in individuation at an age much younger than they are able without such information. One example comes from complex, single-screen *event-mapping* tasks. In these tasks, infants are first familiarized to two objects emerging and returning behind a single screen, and then the screen is removed to reveal either the *expected* outcome of two objects or the 'unexpected' outcome of only one object. If the infant forms two distinct object representations (and thus succeeds in individuating the objects), then he/she should show surprise when only one of the objects is revealed behind the screen, as evidenced by longer looking at the *unexpected* outcome vs. the *expected* outcome. While it is not until 12 months of age that infants have been found to succeed in individuating objects based on kind-differences alone (i.e., objects that belong to different categories, such as a duck and a ball), 10-month-old infants are able to succeed in doing so when provided spatiotemporal information (i.e., when objects were shown simultaneously during familiarization) (Krojgaard, 2003; Xu and Carey, 1996). Similarly, while 12-month-olds are unable to establish a representation of two distinct objects that differ only in color, size, texture, or shape, they are able to do so when the objects are shown simultaneously during familiarization (Xu et al., 2004).

There is also evidence that spatiotemporal discontinuity leads to a representation of two distinct objects, and spatiotemporal continuity leads to a representation of a single, persisting object in infants as young as 4.5 months of age (Spelke et al., 1995). Similarly, 10-month-olds who were shown two identical objects (e.g., two rubber ducks) coming in and out from behind two spatially distinct screens expected to see two objects when the screens were removed (as long as they never saw a duck move through the space between the two screens) (Xu and Carey, 1996).

Finally, *event-monitoring* tasks, which present infants with one continuous event and ask the infant to judge whether the successive portions of the event are consistent, offer additional evidence of the primacy of spatiotemporal information in infants' object representation system. In these tasks, infants watch two objects emerge and return behind either a wide screen (one that is sufficient in width to fit both objects) or a narrow screen (one that is too narrow to fit both objects). Findings have revealed that infants in the narrow screen conditions look significantly longer at the event than infants in the wide screen conditions. Infants are said to succeed at individuating objects which differ in size alone and in shape alone at 4.5 months of age; which differ in object/kind (i.e., green spotted ball and red felt box) and in pattern, at 7.5 months of age; and which differ in color at 11.5 months of age (Wilcox and Baillargeon, 1998). Various explanations have been offered as to why infants look longer at the narrow versus wide screen events and whether or not infants are successfully individuating the objects in these events (Krojgaard, 2004; Wilcox, 2003; Xu, 2003). Nonetheless, the physical nature of this kind of display does appear to offer enough unambiguous spatiotemporal information so as to enable infants to detect the spatiotemporal violation within the narrow screen event, and thereby expect only one object to be involved.

In summary, when infants are provided with unambiguous spatiotemporal information that two objects (two-screen task) or one object (narrow-screen task) is involved in the event, they are able to detect the spatiotemporal and number violation that occurs within the event at significantly younger ages than when this spatiotemporal information is withheld (as in the one-screen, event-mapping tasks).

A prominent account of the aforementioned data has been offered by *Indexing Theory*, a model whereby infants set up an object representation for individuation (Kaldy and Leslie, 2003; Leslie and Kaldy, 2001; Leslie et al., 1998; Tremoulet et al., 2000; Xu, 1999). According to this model, object *identification* is accomplished only when the infant is able to use certain kinds of information stored in this representation to decide whether an object being encountered now is the same as that which was seen previously. Central to *Indexing Theory* is the concept of an initial *object index*—an abstract mental token that functions as a pointer to an object. According to *Indexing Theory*, an object index does not inherently contain any of the features (e.g., color, shape) possessed by the object it is pointing to. Typically, the assignment of indexes "sticks" to an object, even as it is moved through space and time, and so if the number of indexes in a scene is small enough, this system can be used to individuate objects (as in the two-screen object individuation events, or perhaps the narrow-screen event-monitoring events, reviewed above). In the special case of when the location information is absent, subtle, or ambiguous (as in the one-screen event-mapping procedure described earlier), the only way the index assignment can be accomplished is by assigning property information to the index. According to proponents of an *Indexing Theory*, this strategy may not be available to young infants, and thus the model predicts that infants will accomplish *individuation-by-location* before *individuation-by-feature*.

This notion of the dissociability of location and object feature information fits with the distinction made in the visual attention literature of the *what* and *where* systems of visual processing (Posner and Presti, 1987; Sagi and Julesz, 1985; Van Essen and Maunsell, 1983) as well as a possible *which* system for establishing object tokens (Kanwisher and Driver, 1992; Xu, 1999). If, as suggested by the neuroscience literature, the spatiotemporal properties of objects are stored separately from the featural properties, a unified representation of the object could only be accomplished by a joining of these two sources of information. Accordingly, one suggestion as to why spatiotemporal information is necessary for object tracking and identification in young infants is that, while both *what* and *where* pathways are operative early in development, they start out segregated (Atkinson, 1993; Leslie et al., 1998; Xu, 1999). By this account, early in development, if infants are given clear spatiotemporal information, they may rely on the *what* system to keep track of particular objects as they come and go from sight. In the case where spatiotemporal information is ambiguous, the *where* pathway will become engaged, but properties (e.g., shape) of the individual objects being tracked will not be integrated into that representation. Towards the end of the first year of life, these two pathways become integrated, allowing the infant to keep track of both the properties of objects and their location in space, in the service of individuating those objects. While this proposal is at this point speculative, there is behavioral evidence that supports it. First, 4-month-old infants have been shown to respond (showing significant looking time difference relative to baseline) to changes in either surface feature (faces and asterisks—ventral processing) or location information (toys which had or had not been manipulated by the child—dorsal processing) independently, but not to changes in the conjunction of the two (binding trails) (Mareschal and Johnson, 2003). In contrast, by 12 months of age, infants have been found to be sensitive to changes in the conjunction of surface feature (shape) and location information (Tremoulet et al., 2000).

The question we now turn to is: What is the glue that facilitates the binding of features to objects at about the end of the first year of life when clear spatiotemporal information is not available (such as in the case of distinct objects emerging one a time from a single occluder)? Can word comprehension serve this purpose for the infant? More specifically, can knowing the words for the objects being indexed "bootstrap" an infant younger than 12 months into assigning two object indexes in a situation where they would normally assign only one?

1.2. The role of language in representing objects

For years, developmental psychologists have explored the hypothesis that knowing words for objects can facilitate infants' representations of those objects. The majority of these studies involve *labeling* objects for infants and then testing their perceptions and inferences of the objects being named. For example, labels (both novel nouns and adjectives) have been found to facilitate 12-month-olds' establishment of categories at the superordinate level (Waxman and Markow, 1995). In addition, pairing spoken words with pictures during a familiarization phase facilitates subsequent object categorization in 9-month-olds (Balaban and Waxman, 1997; Graham et al., 2004; Welder and Graham, 2001).

Similarly, naming objects as they are brought in and out from behind a screen in an event-mapping paradigm (e.g., saying "ball" as a ball is revealed and "duck" as a duck is revealed) helps 9-month-old infants succeed at this task. Infants who hear the two items labeled uniquely look longer at the unexpected outcome relative to a baseline looking pattern. This has also been replicated with unfamiliar objects labeled with nonsense words (e.g., "a fendle" and "a toma"). In contrast, when both objects are labeled "toy," infants look equally as long at expected and unexpected outcomes (Xu, 2002b). Infants also fail at object individuation when emergences of objects are accompanied by distinct tones/sounds or emotional expressions, suggesting that these facilitation effects are language specific. This effect of language facilitation has also been replicated using a manual search, rather than a preferential looking method (Xu et al., 2005).

The aforementioned studies all involve providing a label for young infants, thereby giving them the information needed to map the object representations in real time. Impressive facilitative effects are observed when this is done; allowing infants to succeed on object representation tasks earlier than they would normally (approximately 3 months earlier, in one case (Xu, 2002b)). It can be argued, however, that an even more difficult scenario for the infant is that which he is faced with everyday, i.e., mapping representations in the absence of simultaneously heard labels. Let us return to the hypothetical infant mentioned at the beginning of this article. Her mother is not, in real time, narrating the event for the infant as she takes out a bottle, returns it to the diaper bag, and in turn pulls out a sippy cup. Whatever cognition the infant, herself, brings to bear on the situation is of utmost importance to her success in individuating and/or identifying those objects. Would a 10-month-old infant who comprehends the meanings of the words *bottle* and *cup* be more likely to know that a second object still exists in the diaper bag? What if the infant knew the word for only one of those objects, and not both?

An exploratory analysis from one of the earliest object individuation papers offers some tantalizing insights to this question. When data were collected on parent ratings of infants' familiarity with and probable comprehension of labels for the everyday objects they were being shown in the experiment, it was found that 10-month-old infants whose parents judged them to comprehend nouns for 2 or 3 of the four highly familiar objects used in the test trials were more likely to overcome their baseline preference to look at 2 objects than infants who comprehended nouns for zero or 1 of those objects (Xu and Carey, 1996). Since the study was not designed to explore this relationship, however, the authors emphasized the finding as preliminary in nature.

In the following set of experiments, we directly investigate the role that comprehending labels for objects being seen plays in individuating those objects in a group of 10- to 11-month-old infants. To do this, we employ an adapted version of a standard event-mapping object individuation task (Xu and Carey, 1996). In addition, we explore the relationship between object individuation and infants' general knowledge about objects (as assessed by standard object permanence tasks) and the size of their overall receptive vocabulary (as assessed by the MacArthur Child Development Inventory).

2. Results

2.1. Object individuation task—words known or unknown

Preference for looking at two objects versus one in the baseline phase was analyzed using a 2×2×2×2 ANOVA with number of objects (one vs. two) as within subjects factor and age, gender, and group (*Known* vs. *Unknown*) as between subjects factors. This analysis revealed no significant effects or interactions. No significant preference for two was established, although the mean looking time was slightly higher for two objects ($M=9.72$) than for one ($M=8.93$).

In order to assess infants' looking behavior in the object individuation task, a looking time difference score was derived for each infant by subtracting the mean looking time to one object from the mean looking time to two objects (from here on, referred to as LTP2). Thus, infants with a *positive* LTP2 score looked longer, overall, at two objects (the expected outcome), while infants with a *negative* LTP2 score looked longer, overall, at one object (the unexpected outcome).

Preliminary analyses showed no effects involving age (10-month-olds vs. 11-month-olds), gender, or order (i.e., one object presented first vs. two objects presented first); therefore, these factors are excluded from the following analyses.

We examined the difference between infants' LTP2 in the baseline trials vs. the test trials, across the two groups, using a 2×2 mixed model analysis of variance with group (*Known* vs. *Unknown*) as the between subjects factor and trial phase (baseline vs. test) as the within subjects factor. A significant interaction between trial phase and group emerged, $F(1,77)=4.924$, $p=0.03$ (Fig. 1). Simple effects analysis revealed that infants in the *Known* group had a significantly higher ($t(39)=2.09$, $p<0.05$) LTP2 in the baseline phase (M LTP2=1.46 s, SD=4.88) than in the test phase (M LTP2=−0.18 s, SD=3.15). More critically, in the test phase, infants in the *Known* group overcame their baseline preference for two and showed a preference for the (unexpected) one object outcome. The *Unknown* group, on the other hand, showed no significant differences ($t(38)=-1.09$, $p=0.28$) in their LTP2 between the baseline (M LTP2=0.11 s, SD=4.33) and test phases (M LTP2=1.05 s, SD=3.13).

We also examined the data from a Word Comprehension Questionnaire (WCQ). This instrument assessed infants' familiarity with the objects they were seeing by asking the parents both to rank a list of objects from least to most familiar to the child and to estimate (on a scale of 1 to 5) how frequently their child came into contact with each type of object. Overall, infants who were shown objects for which they knew the label (*Known* condition) were more familiar with those objects than infants who were shown objects for which they did not know the label (*Unknown* condition) ($t(77)=9.37$, $p<0.0001$). For the purpose of analysis, we took a median split of the combined familiarity (rank and frequency of contact) and assigned each infant a familiarity score of *high* or *low*. We again examined the difference between infants' LTP2 in the baseline trials vs. the test trials across the two groups, this time using a 2×2×2 mixed model analysis of variance with group (*Known* vs. *Unknown*) and familiarity (high vs. low) as between subjects factors and trial phase (baseline vs. test) as the within subjects factor. A significant interaction between trial phase and group again emerged, $F(1,75)=4.80$, $p=0.03$. Critically, no 3-way interaction between trial phase, group, and familiarity emerged. Thus, the observed difference between the two groups in familiarity with the items seen did not significantly influence the group effect described above.

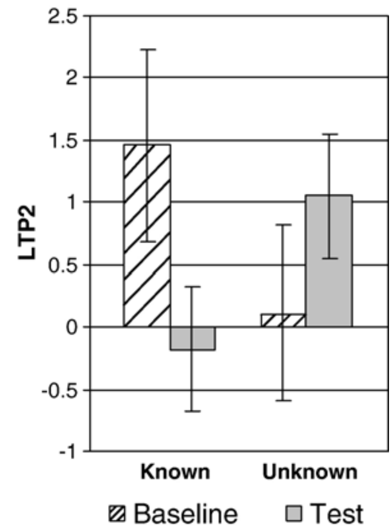

Fig. 1 – Looking time preference for two objects (LPT2) in baseline and test trials for the *Known* and *Unknown* groups for Experiment 1.

2.2. Object permanence—Words known or unknown

Infants were given a score (zero through four) corresponding to the highest object permanence sequence passed. Three infants received a score of zero, indicating that they did not pass any of the sequences. The majority of infants (41 out of 76) received a score of 1, indicating that they passed only the first sequence (one invisible displacement with one hiding box). Twenty-four infants received a score of two, indicating that they passed both the first and the second sequences. Three infants passed the third sequence, and five passed the fourth. For the purposes of statistical analysis, the infants who received an object permanence score of zero or one ($n=44$) were assigned a score of one, and those infants who received a score higher than one were assigned a score of two ($n=32$), resulting in two categories of object permanence.

t-tests were performed between factors of age (10-month-old vs. 11-month-old), group (*Known* vs. *Unknown*), and gender (males vs. females) on the object permanence scores (1 vs. 2). No significant differences emerged, indicating no significant difference between the level of object permanence passed by the 10-month-olds and the 11-month-olds, by males and females, nor by the *Known* and *Unknown* groups (Table 1).

A comparison was made between the infants' object permanence level (1 or 2) and their looking behavior in the object individuation task. Preliminary analyses showed no effects involving age (10- vs. 11-month-olds) or gender, therefore these factors are excluded from the following analyses. LTP2 was analyzed using a 2×2×2 mixed model

Table 1 – Descriptive statistics for object permanence and receptive vocabulary scores across groups in Experiment 1

	Object permanence level 1 (*n*=44)	Object permanence level 2 (*n*=32)	Receptive vocabulary level 1 (*n*=39)	Receptive vocabulary level 2 (*n*=27)	Mean receptive vocabulary
Age					
10 month-olds	21	12	16	14	66.27
11-month-olds	23	20	23	13	61.08
Gender					
Males	22	18	24	10	55.88
Females	22	14	15	17	71.47
Group					
Known	20	19	19	14	66.58
Unknown	24	13	20	13	60.30

analysis of variance with group (*Known* vs. *Unknown*) and object permanence score (1 or 2) as the between subjects factors and trial phase (baseline vs. test) as the within subjects factor. This analysis revealed only a significant interaction between trial phase and object permanence score $F(1,72)=5.96$, $p=0.02$. Examination of the means revealed that, in the baseline phase, there was a significant difference in LTP2 ($t(74)=2.09$, $p<0.05$) between infants with an object permanence score of one (M LTP2=1.62s, SD=5.22) and infants with an object permanence score of two (*M* LTP2=−0.59s, SD=3.41). In the test trials, however, no significant difference between the two groups' LTP2 was found ($t(74)=-0.37$, $p=0.71$). No other effects or interactions involving the object permanence score emerged.

2.3. *Receptive vocabulary—Words known or unknown*

For the purposes of this investigation, we were interested only in infants' receptive, and not productive vocabulary. Therefore, using the MacArthur checklist, a total receptive vocabulary score was obtained for each of the infants. The mean vocabulary score for the 66 subjects for which these data were available was 63.44 words, SD=40.99. The minimum receptive vocabulary reported was 3 words, the maximum was 175 words.

t-tests were performed between factors of age (10-month-old vs. 11-month-old), group (*Known* vs. *Unknown*), and gender on the receptive vocabulary scores. No significant main effects or interactions emerged. There was no significant difference in number of words comprehended by the 10-month-olds (*M*=66.27, SD=41.77) and number of words comprehended by the 11-month-olds (*M*=61.08, SD=40.76); nor was there a significant difference in number of words comprehended by infants in the *Unknown* group (*M*=60.30, SD=38.29) and infants in the *Known* group (*M*=66.58, SD=43.89). There was a slight difference between the number of words comprehended by females (*M*=71.47, SD=43.06) and males (*M*=55.88, SD=38.03), but this difference did not reach statistical significance ($F(1,65)=3.42$, $p=0.07$).

For the purposes of performing further statistical analysis, the receptive vocabulary scores of each infant were grouped into two categories. Infants who received a receptive vocabulary score lower than the mean (63.44 words) were assigned a score of 1 (*n*=39); infants who received a receptive vocabulary score above the mean (*n*=27) were assigned a score of 2 (Table 1).

Preliminary analysis showed no effect of age or gender; therefore these factors are eliminated from the following analysis. LTP2 was analyzed using a 2×2×2 mixed model analysis of variance with group (*Known* vs. *Unknown*) and receptive vocabulary score (1 or 2) as between subjects factors and trial phase (baseline vs. test trials) as the within subjects factor. No main effects or interactions involving the variable of receptive vocabulary score were found.

2.4. *Object individuation task—One word known, one unknown*

Preference for looking at two objects versus one in the baseline phase was analyzed using a 2×2×2 ANOVA with object (looking time to one vs. two objects) as within subjects factor and age and gender as between subjects factors. This analysis revealed no significant effects or interactions, ($F(1,47)=0.63$, $p=0.43$). (No significant LTP2 was established.)

Preliminary analyses showed no effects involving age (10-month-olds vs. 11-month-olds) or order (i.e., one object presented first vs. two objects presented first); therefore, these factors are excluded from the following analyses. LTP2 was analyzed using a 2×2 mixed model analysis of variance with gender as the between subjects factor and trial phase (baseline vs. test) as the within subjects factor. Only a significant main effect of gender emerged ($F(1,47)=4.40$, $p<0.05$). Overall, females showed a larger LTP2 across both baseline and test phases (*M* LTP2=0.77 s, SD=1.73) than did males (*M* LTP2=−0.38 s, SD=2.07). No other significant effects or interactions were found. Critically, there was no significant difference ($F(1,49)=1.87$, $p=0.18$) between infants' LTP2 during the baseline phase (*M* LTP2=−0.33 s, SD=3.43) and their LTP2 during the test phase (*M* LTP2=0.56 s, SD=2.60).

As in Experiment 1, we factored the data from the WCQ (which assessed infants' familiarity with the objects) into the analysis. The mean familiarity score for the *Known* object was significantly higher than for the unknown object ($t(51)=6.84$, $p<0.0001$). We computed the mean familiarity score (combining rank and frequency of contact) for the two objects seen, and again took a median split and assigned each infant a familiarity score of *high* or *low*. When this factor was added to the analysis, creating a 2×2 mixed model analysis of variance with familiarity (high vs. low) as the between subjects factor and trial phase (baseline vs. test) as the within subjects factor, no significant main effects or interactions emerged.

Critically, no trial phase × familiarity effect was observed ($F(1,49) = 0.364$ $p = 0.55$).

2.5. Object permanence—one word known, one unknown

As described in Experiment 1, infants were given a score (zero through four) corresponding to the highest task passed. Eight infants of the forty-six received a score of 0; 18 infants received a score of 1; 12 infants received a score of 2; 3 infants received a score of 3; and 4 received a score of 4. There were no statistically significant differences between the object permanence scores of males and females nor between the scores of 10-month-olds and 11-month-olds. As in Experiment 1, for the purpose of statistical analysis, the infants who received an object permanence score of zero or one ($n = 26$) were assigned a score of one, and those infants who received a score higher than one were assigned a score of two ($n = 20$), resulting in two categories of object permanence.

Preliminary analyses showed no effects involving age (10-month-olds vs. 11-month-olds); therefore, this factor is excluded from the following analyses. A comparison was made between the infants' object permanence level (1 or 2) and their looking behavior in the object individuation task. LTP2 was analyzed using a 2 × 2 × 2 mixed model analysis of variance with gender and object permanence level (1 or 2) as the between subjects factor and trial phase (baseline vs. test) as the within subjects factor. This analysis revealed no significant effects or interactions involving the variable of object permanence score.

2.6. Receptive vocabulary—One word known, one unknown

The mean receptive vocabulary score ($n = 47$) was 55.17 words, SD 46.52. The minimum receptive vocabulary reported was 3 words, the maximum was 251 words. Examination of data revealed one outlier (a score of 251) that was more than two standard deviations above the mean. With this score filtered from the data, the new mean became 50.91 words, SD 36.62. The minimum receptive vocabulary score remained at 3 words, but the maximum became 145.

t-tests revealed no significant difference between the number of words comprehended by the 10-month-olds ($M = 56.60$ SD = 45.03) and the number of words comprehended by the 11-month-olds ($M = 46.54$, SD = 28.54). There was also no significant difference in the number of words comprehended by male infants ($M = 44.85$, SD = 35.22) and female infants ($M = 59.53$, SD = 37.78).

For the purposes of performing further statistical analysis, the receptive vocabulary scores of each infant (minus the one outlier with a score of 251) were grouped into two categories. Infants who received a receptive vocabulary score lower than the adjusted mean (50.91 words) were assigned a score of 1 ($n = 28$); infants who received a receptive vocabulary score above the mean ($n = 18$) were assigned a score of 2.

A preliminary analysis also showed no effect of age, therefore this factor is eliminated from the following analysis. LTP2 was analyzed using a 2 × 2 × 2 mixed model analysis of variance with gender and receptive vocabulary score (1 or 2) as between subjects factors and trial phase (baseline vs. test) as the within subjects factor. No significant main effects or interactions involving the variable of receptive vocabulary score were found.

3. Discussion

3.1. The effect of comprehending words on object individuation

A number of previous studies have shown that, before the age of 12 months, infants who are faced with individuating two distinct objects under conditions of ambiguous spatiotemporal information (such as when those objects emerge one at a time from a single screen) do not show evidence of having an appreciation that there are two distinct objects present behind the screen (Bonatti et al., 2002; Krojgaard, 2000; Xu and Baker, 2005, Xu and Carey, 1996, Xu et al., 2004). It has also been shown that when infants are provided with distinct verbal labels as they see the objects emerge, they can succeed as early as 9 months of age (Xu, 2002b). In the present study, we present two experiments that investigate the effect of the child's *own* possession of verbal labels for the objects they are seeing in the single-screen object individuation task. The results of Experiment 1 both replicate and extend those of previous researchers (Xu and Carey, 1996). Ten and 11-month-old infants who comprehended words for the objects they were seeing in an event-mapping object individuation task did not show a looking time preference for two objects (LTP2) during the test trials, while infants who did not comprehend words for those objects did. In other words, when repeatedly shown two different objects (e.g., *cup* and *ball*) coming in and out, one at a time, from behind a single screen, infants who knew the words for those objects looked longer on test trials where one of them had been surreptitiously removed; as if to say, "where did the other one go?" (Fig. 2). This indicates that even in an event where no overt labeling is being done for the child to assist in forming their object representations (as has been done in other studies (Xu, 2002b; Xu et al., 2005)) infants can use their *own* knowledge of word meanings to aid in the object individuation process.

To couch this result in terms of the *Indexing Theory*, infants who comprehended words for the objects they were seeing seemed to be able to assign two indexes to the event, thereby individuating the objects without the aid of spatiotemporal information. If the word for the object is providing the glue which is allowing the infants in the *Known* condition of this experiment to bind the object index with its perceptual features, then a further prediction would be that, in the case where an infant comprehends a word for only one of the two objects being seen, only one object index will be assigned, and infants will fail as did the infants in the *Unknown* condition. Experiment 2 was designed to test this hypothesis.

The results of Experiment 2 indicate that 10- and 11-month-old infants who comprehended words for only one of the objects they were seeing in an event-mapping object individuation task did not show a looking pattern consistent with individuating objects. When repeatedly shown two different objects coming in and out, one at a time, from behind a single occluder, these infants demonstrated longer looking to two objects than to one when the occluder was

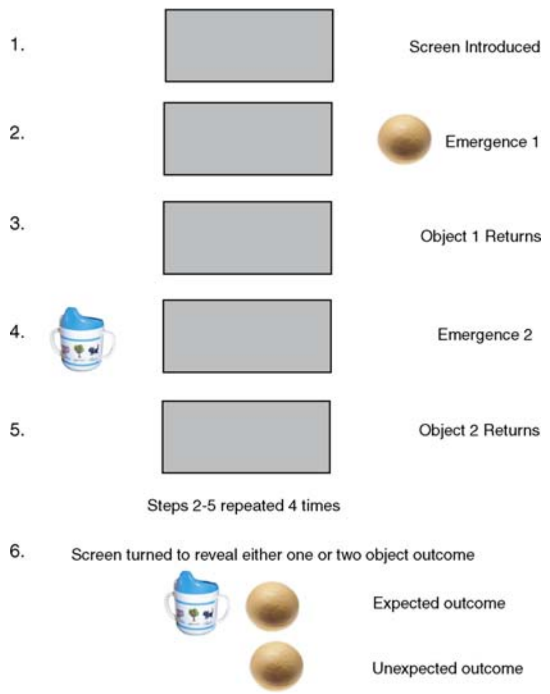

Fig. 2.

removed, suggesting that they did not find the result of a missing object surprising. This result also suggests that infants who comprehend the word for only one of the objects seen assign one, not two indexes to the event.

We also used other measures of cognitive development in our participants to determine what effect they would have on infants' object individuation behavior. Specifically, we assessed their level of object permanence reasoning as well as their overall receptive vocabulary. We wanted to know if it is the case, for example, that an infant who comprehends many words, overall, has a higher probability of successful object individuation in a single-screen paradigm, regardless of whether or not they know the *particular* words for the objects they were seeing in front of them. Likewise for object permanence reasoning, we wanted to know whether an infant who is very good at finding hidden objects and is performing at a level that Piaget (1954) would have called "stage 4 object permanence" has a higher likelihood of success on a single-screen object individuation task. It turns out that the answer to each of these questions is no. Overall, receptive vocabulary had no effect on performance in the object individuation task, indicating that the effect was specific to the immediate parameters of the situation, and not a function of overall precocity on the part of the infants who were succeeding. The only case in which an interaction was found involving infants' object permanence reasoning level was in Experiment 1, where infants with an object permanence reasoning level of 1 showed a larger LTP2 in the *baseline trials* than did infants with an object permanence reasoning level of 2. No effects involving this factor were found in the critical test trials; thus, overall level of object permanence reasoning similarly had no effect on object individuation in this task.

We did attempt to control for the possible role of object familiarity in infants' object individuation by selecting objects, for both groups, that were rated by the infants' parents as being low on familiarity to the child. Nevertheless, we could not escape the fact that infants are more likely to learn the labels of objects with which they are familiar. Infants in the *Known* condition did have a significantly higher familiarity rating for the objects they were shown than did infants in the *Unknown* condition. Critically, however, this difference between the groups did not appear to have an effect on individuation, per se, since no 3-way interaction between group, trail phase, and familiarity emerged when this was factored into the data analysis of Experiment 1. Thus, while young infants' familiarity with objects is surely related to the propensity to learn labels for them, this familiarity, alone, does not seem to be enough to allow object individuation. Indeed, this is consistent with other studies which have shown no differences in infants' ability to individuate familiar versus novel objects (Krojgaard, 2000; Xu, 2002b).

3.2. *What specific role do words play?*

Our findings are in line with another study reporting that if two (but not one) overt linguistic labels are provided for infants at the time that they see two distinct objects emerge from behind a single-screen, 9-month-olds show success at object individuation (Xu, 2002b). An infant's own ability to comprehend the words for objects they are seeing, however, might have a qualitatively different effect than having labels for the object provided for them. For example, experiments that present repeated auditory presentations of object labels across the familiarization trials might be providing overt auditory markers onto which infants could map their object representations. This suggestion is tempered by the fact that this facilitative effect is only present when *linguistic* labels were provided for the infants, and not when the auditory accompaniment was distinct keyboard tones (Xu, 2002b). There is ample reason to believe, however, that infants treat speech sounds preferentially by this age, and thus the presence of two different words may in fact signal that two distinct *individuate-able* objects (so-called *sortals*) are present. In fact, this idea is at the core of the proposal that words serve as *essence placeholders* which lead infants to expect that words for objects map onto distinct kinds in their environment (Xu, 2002a,b). Nevertheless, the fact that we found converging results under conditions in which infants are not provided with any of this outside scaffolding, but are relying on their own internal process of word comprehension, underscores the power of word comprehension in building object representations.

One alternative explanation that we must address is that the "power" of knowing words for objects lies in enhancing *memory* for those objects. By this account, *what* and *where* pathways might already be integrated in infants at this age, but poor memory for objects which are disappearing and reappearing in alternation leads infants to forget the objects that are involved in the event, and having distinct labels for each object helps infants overcome this lack of memory. When examined in light of the collection of data on this paradigm, however, this explanation to us seems unlikely. There are two circumstances under which infants before the age of 12 months succeed on the one-screen task: (1) when they are provided unambiguous spatiotemporal information (i.e., the opportunity to briefly see the two objects at the same time before the emergences begin) (Xu and Carey 1996); and (2) when they comprehend (as in Experiment 1) or are provided with (Xu, 2002b; Xu et al., 2005) distinct verbal labels for the objects that move in and out of sight. Both of these are consistent with the object indexing account we have outlined here. If success were only a matter of memory enhancement, one would have to make the unlikely conjecture that, in the first instance, the very brief (3 s) simultaneous presentation of the two objects at the beginning of the trial was enough to sustain infants' memory of those two objects across the duration of the familiarization emergences (approximately 16 s). For the second instance, one would have to conjecture that verbal labels are somehow providing the memory enhancement. If this were true, however, it is difficult to explain why, in Experiment 2, having only the word for one of the emerging objects would not be enough to induce a surprise reaction to one-object trials. (For example, if knowing the word for an object helps an infant remember it, an infant who knows only the word "ball" might at least be expected to be surprised on trials when the ball is missing.) A strict memory hypothesis would also have a hard time explaining findings that only object labels, and not other types of auditory pairings such as distinct tones or emotional expressions (Xu, 2002b) lead to object individuation in the one-screen task.

3.3. *A case for the* Indexing Theory

Two findings in this study suggest that there is strong specificity for the effect of word comprehension on object individuation. First, in order to succeed in individuating objects in a spatiotemporally ambiguous event, it was not enough for infants to have a large receptive vocabulary overall. Rather, they needed to comprehend the *particular words* for the objects they were seeing in front of them. Second, comprehending a word for only one of the objects being seen was not enough to induce object individuation in 10- to 11-month-olds. It seems that infants must comprehend a label for both objects in order for them to be able to assign two object indexes, instead of one, in the single-screen scenario. Thus, the current study provides some evidence that word comprehension can serve as a *bootstrapping* mechanism by which infants, at an age younger than they are normally able, can individuate two distinct objects on the basis of their surface features (i.e., in the absence of spatiotemporal information.) Put another way, word comprehension may serve to precipitate a shift, in 10- and 11-month-old infants, from a process of object indexing driven by the *where* (dorsal) system to one which is driven by integration of the ventral and dorsal neural systems, as is apparently in place in 12-month-olds (Tremoulet et al., 2000).

3.4. *Conclusions*

In summary, the present study investigated the relationship between the ability of infants to individuate objects in a spatiotemporally ambiguous event-mapping task and comprehending words for the objects seen. Results show that only when 10- and 11-month-old infants comprehend words for *both* objects seen do they exhibit looking behavior that is consistent with object individuation (looking longer on trials where one of the objects is surreptitiously removed). These results suggest that comprehending the words for occluded/disoccluded objects provides a kind of glue which allows infants to bind the mental index of an object with its perceptual features (thus precipitating the formation of two mental indexes, rather than one). They further suggest that a shift from object indexing driven by the *where* (dorsal) system to one which is driven by integration of the ventral and dorsal neural systems, usually not observed until 12 months of age, can be facilitated by word comprehension in 10- and 11-month-old infants.

4. Experimental procedures

4.1. *Participants*

In Experiment 1, participants were 79 full-term infants, 36 10-month-olds (22 male, 14 female), and 43 11-month-olds (21 male, 22 female). The infants in the 10-month-old age group ranged in age from 9 months, 29 days to 10 months, and 30 days (mean age 10 months, 16 days). The infants in the 11-month-old age group ranged in age from 11 months, 0 days to 12 months, and 2 days (mean age 11 months, 19 days). Forty infants (19 10-month-olds and 21 11-month-olds) were assigned to the *Known* group, and 39 infants (17 10-month-olds and 22 11-month-olds) were assigned to the *Unknown* group. Another nineteen infants were excluded from the experiment: seven due to fussiness during the experimental session; four due to experimenter error; two due to procedural error on the part of the mother; two because the infants were too large for the apparatus; one because between the time the infant was scheduled and brought in for testing, she had learned all of the words on the list and thus did not qualify for inclusion in the experiment; and three because their looking data contained trials that were three or more standard deviations from the mean of *z* scores.

In Experiment 2, participants were 51 full-term infants, 23 10-month-olds (14 male, 9 female), and 28 11-month-olds (15 male, 13 female). The infants in the 10-month-old age group ranged in age from 10 months, 0 days to 10 months, and 27 days (mean age 10 months, 12 days). The infants in the 11-month-old age group ranged in age from 11 months, 0 days to 11 months, and 30 days (mean age 11 months, 15 days). Nine additional infants were excluded from the experiment: eight due to fussiness during the experimental session, and one due to procedural error on the part of the mother. All infants were from northern California. Parents were contacted first by letter and then by telephone; they were not compensated for their participation.

4.2. *Subject selection*

For Experiment 1, each infant was placed into either a *Known* or an *Unknown* group. Those in the *Known* group were to see items in the object individuation task (described below) for which their parents reported they did comprehend a label. Infants in the *Unknown* group were to see items for which their parents reported they did not comprehend a label.

Participating infants were pre-screened for eligibility in the study. This was done by administering a telephone questionnaire to one parent of each potential subject to find out which (if any) of a list of eight items the child comprehended a label. The eight items (ball, book, bottle, car, cat, cup, dog, and shoe) are among those most commonly known by 10- and 11-month-old infants (Fenson et al., 1994).

In order to be eligible for participation in Experiment 1, children had to comprehend a label for at least two, but not more than six of the items on the eight-item list. Thus, any child scheduled for the participation in the study could theoretically be placed in either the *Known* or the *Unknown* group. Each potential subject was assigned to a testing group, *Known* or *Unknown*, before his or her parent was contacted. In this way, a researcher could not make the biasing error of consistently placing children knowing more words into the *Known* group or placing children knowing fewer words into the *Unknown* group. In order to be eligible for Experiment 2, children had to comprehend a label for between one and seven of the items.

When first contacted, the parents were simply told that we were interested in the "amount of word comprehension that infants between 10 and 12 months of age have." The researcher also asked the parent to "keep in mind that we don't expect that any infants this young will be saying many words yet, but we are only curious about what words they can understand." In addition, the parents were told that we were interested in whether their child knew any label for the list of items. Thus, if the child had an idiosyncratic label for any item (e.g., *ba ba* for bottle), or if the child knew the label for an object in a language other than English, those were counted.

4.3. *Word Comprehension Questionnaire*

When each family arrived at the laboratory, prior to the object individuation task, parents were asked to fill out a Word Comprehension Questionnaire (WCQ). This questionnaire was used to assess which words, of the list of eight, a given child comprehended a label for at the time that they arrived for the study. It was also used to assess how familiar that child was with each item as the parent both rank-ordered the items (1 being the least familiar, and 8 being the most) and assigned each a rating (1, *less than once a week*, through 5, *more than two times/day*) corresponding to how often their child came in contact with each item. From this questionnaire, two items to be used in the object individuation task were chosen.

For Experiment 1, if the child was in the *Known* group, we chose among those items for which the parent reported their child did comprehend a label and (if there were more than two such items) picked the two with the lowest combined rank scores for familiarity (1 through 8), and for how often they came into contact with the item (1 to 5). If the child was in the *Unknown* group, we chose among the items for which the parent reported their child did not comprehend a label and (if there were more than two such items) again picked the two with lowest combined scores for familiarity ranking and for how often they come into contact with the item. In this way, we attempted to, as much as possible, parcel out the effect of just being familiar with an object, from the effect of having a label for an object.

For Experiment 2, we proceeded accordingly, but chose from among the objects for which labels were known (if there was more than one such item) the one scored as least familiar, and also from among the objects for which no labels were known (if there was more than one such item) the one scored as least familiar.

4.4. *Materials*

Eight items were used as stimuli in the object individuation task for both experiments: one hot pink *Nerf*™ ball, 10 cm in diameter; one small *Winnie the Pooh*™ cardboard book, 8.75 × 8.75 cm; one clear plastic baby bottle with blue cartoons and blue rim around nipple, 13.73 cm tall; one sedan-style lightweight plastic toy car, 1 blue and 1 red (chose color most dissimilar to other item presented), 17.5 cm long, 7.5 cm wide; one tan and white *Pound Purry*™ toy cat, approximately 12.5 cm long and 10 cm wide; one double-handed, clear sippy cup with *Winnie the Pooh*™ cartoon on front, 7.5 cm tall; one toy *Wishbone*™ dog, 12.5 cm tall, 10 cm long; and one infant girl's navy blue t-strap shoe. The items were concealed using a free-standing foam-board screen (34 × 25 cm).

4.5. *Apparatus*

For both experiments, infants sat in a *Sassy Seat* attached to a low 70 cm × 70 cm table, which served as the floor of the stage for presenting the occlusion events. The parent sat in a child-sized chair to the left and slightly behind the infant. The parents were instructed not to interact with their infant during the experiment and to simply smile and look forward toward the stage if their infant turned to look at them. Approximately 38 cm from the infant, situated near the center of the table, was a wooden bridge-like structure, 62.5 cm wide × 32.5 cm high × 25 cm deep, on the top side of which was mounted a Sony CCD-TR64 video camera, which was focused to the infant. The images from this camera were recorded on a videotape, and also projected on-line to a monitor in an adjacent testing room. Attached to either side of the backside of this bridge (out of view of the infant) were two clip-on lights with 10-watt bulbs that pointed down towards and illuminated the stage. A black curtain hung from the ceiling down to where the bridge was located, and concealed the camera, as well as preventing the infant from seeing above or around the sides of bridge. Attached in a perpendicular fashion to the far side of the table (directly across from where the infant sat) was a 65.63 × 33.33 cm wooden frame with three solid wood sides and a dowel across the top. A black piece of material hung from this dowel and was fastened with Velcro to the bottom of the frame, so that it formed a back wall for the stage. Two slits through which the experimenter could put her hands were cut into this material. In this way, the infant could see only the hands of the experimenter situated behind the apparatus.

One experimenter worked behind the apparatus during the experiment. This experimenter could not see the infant, and the infant and parent could see only her hands. An observer in the adjacent room, blind to experimental group and trials, watched the infant on a monitor and pushed a button when the infant looked at the display at any time during the experiment. A third experimenter stood behind a curtain partitioning in the testing room, operated the computer, and monitored the infant's state during the experiment.

A computer program sent a signal in the form of an LED light to the experimenter behind the apparatus, indicating the start of trials (and thus when to bring down the screen with the object(s) behind it). The computer program also kept track of the infants' looking time via button presses from the on-line observer and sent signals to the LED light to signal the end of the trial (and thus when to turn the screen back and lift it, with the object(s) behind, out of sight).

4.6. *Object individuation task procedure*

Infants were presented with four baseline trials (using the same objects as in the test trials) to establish whether or not there was an a priori preference to look at two objects. The interval between baseline trials was 10 s. In these trials, the infant looked initially at an empty stage. An experimenter then lowered a screen, with two objects concealed behind it, onto the stage, and then turned the screen 90° to the side revealing either one or two objects. On trials where only one object was revealed, the other was surreptitiously removed through one of the slits in the back curtain before the screen was turned. There were four experimental orders in all (two numerical outcomes 1, 2, 2, 1 and 2, 1, 1, 2, each varying the position of the single object, left or right) counterbalanced across subjects. On each trial, as soon as the screen was turned and the object(s) behind it became visible to the infant, the second experimenter pressed a key on the computer. This key press signaled the program to begin tabulating looking times from the live observer. A trial ended either when the infant looked away from the display for two consecutive seconds after having looked for at least half a second or when the infant looked for 30 cumulative seconds. If the infant failed to look at the display in a period of 20 s after the screen was turned, the trial would end; however, this actually never occurred in these experiments.

Three pairs of test trials followed the baseline trials. The six test trials were presented in one of two orders: 1, 2, 1, 2, 1, 2 or 2, 1, 2, 1, 2, 1 (each varying the position of the single object, left or right) counterbalanced across subjects. Each test trial consisted of two phases, a familiarization and a test phase (Fig. 2).

Each test trial began with the infant looking at a blank stage. An experimenter then lowered a screen, with two objects concealed behind it, onto the stage, and then proceeded with the object emergence sequence: the first object was brought out to one end of the stage, left there for about 2 s, and then returned behind the screen. The second object was then moved out to the other end of the stage and brought back behind the screen in the same manner. This was repeated until the baby saw the objects emerge from each side (left and right) four times. After the object emergences (the familiarization phase), the screen was grasped and turned 90° to the side of the stage, revealing either one object (unexpected outcome) or two objects (expected outcome). In the case of the unexpected outcome, one of the objects was surreptitiously removed through one of the slits in the curtain behind the screen before the screen was turned. The test phase began when the screen was turned after the familiarization phase. As soon as the object(s) behind the screen became visible to the infant, the second experimenter pressed a key on the computer, and button presses from the live observer then began to be recorded just as described above for the baseline trials. As in the baseline trials, a trial ended either when the infant looked away from the display for two consecutive seconds after having looked for at least half a second or when the infant looked for 30 cumulative seconds. If the infant failed to look at the display in a period of 20 s after the screen was turned, the trial would have ended; however, this actually never occurred in these experiments.

On-line looking time data from infants (particularly necessary since the length of trials was determined by infants' looks to the display) were tabulated by the computer. The looking time data used in the analyses were not derived from these on-line observations, but rather from subsequent coding of the video recordings of each experimental session. The coding of video recordings was done using Noldus Observer™ software. Coders were blind to information about what group infants were assigned to, and the videotape recordings provided no information on the order of objects revealed. Inter-rater reliability was obtained by calculating Pearson correlation coefficients between looking time per trial scored by two independent coders. In Experiment 1, this was done for 29% of infants tested, and overall reliability of $r = 0.93$ was obtained. In Experiment 2, this was done for 84% of the infants tested, and the overall reliability was $r = 0.92$.

4.7. *Object permanence assessment*

In order to assess each child's stage of object permanence reasoning and to be able to relate that level of reasoning to performance on the object individuation task, each child also underwent up to four displacement object permanence search tasks (Uzgiris et al., 1975). Infants sat in an infant seat attached to a low, 70×70 cm table. The experimenter sat at this table directly across from the infant. The parent sat in a child-sized chair to the right and slightly behind the infant. The parents were instructed not to interact with the infant during the assessment, and only to give their infant a reassuring smile if he or she turned to look at them. A video camera on a tripod was positioned behind the experimenter and focused on the infant so that his or her actions during the session could be videotaped. The task consisted of a progression of 4 sequences of trials. The progression began (sequence 1) with one visible displacement (i.e., object placed in a small container and deposited into one hiding box with cover) and ended (sequence 4) with successive invisible displacements (i.e., experimenter placed a small toy fully in the palm of her hand and proceeded to sequentially lift the covers and pass her hand underneath each of the hiding boxes in the direction of the infants' left to right). The hiding objects were various small toys (approximately 5×6.25 cm).

The object permanence task trials were administered consecutively in order until the experimenter ceased to get cooperation and/or successful search behaviors from the infant. Data for this task were successfully collected for seventy-six of the seventy-nine subjects who completed the object individuation task in Experiment 1 and for forty-six of the fifty-one subjects in Experiment 2.

The object permanence assessments were coded from videotape by a second experimenter using a scoring sheet adapted from ordinal scales of infant development (Uzgiris et al., 1975). For each sequence, infants received a score corresponding to their level of success across the trials. For the first sequence, infants received one point for each successful retrieval, and zero points for all other behaviors. For the second sequence, infants received one point for each successful retrieval (i.e., going directly to the correct hiding box to retrieve the object) and zero points for all other behaviors, with one exception: the infants received .5 point if they lifted both cloths simultaneously, but while doing so looked in the correct hiding box. For the third sequence, infants received one point for each successful retrieval (i.e., going directly to the correct hiding box to retrieve the object) and zero points for all other behaviors, with two exceptions: the infants received .33 point if they searched in one incorrect then the correct box and received .5 point if they lifted two cloths simultaneously, one of them the correct one, and while doing so looked in the correct hiding box. For the fourth sequence, infants received one point for each successful retrieval (i.e., either going directly to the last hiding box in the path to retrieve the object or searching under all boxes in the path in the order of hiding). The infants received zero points for all other behaviors with the same two exceptions as mentioned above for the third task. Infants were then assigned a score based on the ratio of successful trials to trials attempted. For all tasks, infants were said to have "passed" if they received a score of .60 or higher (e.g., success on 2/3 trials on the first and second tasks, success on 3/5 trials on the third task, etc.).

4.8. *Receptive vocabulary measure*

In order to obtain a general measure of each child's language comprehension and production abilities, parents of the participating infants were asked to fill out a MacArthur Child Development Inventory: Words and Gestures—a parent-report questionnaire which consists of a checklist of words commonly found in infants' early receptive and productive vocabularies (Fenson et al., 1993). The inventory was sent to each parent at the time of scheduling, with a request to fill it out the evening before coming in to participate. The inventory was collected at the time of the scheduled appointment. This inventory was successfully collected for sixty-six of the subjects in the Experiment 1 and forty-seven of the infants in Experiment 2.

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