Semantic priming supports infants' ability to represent and name unseen objects

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Abstract

Human language permits us to call to mind objects, events, and ideas that we cannot witness directly. This capacity requires that one links words not only to their referents, but to mental representations of those referents. Together with the recognition that words are used intentionally for communication, this link constitutes *'verbal reference.'* Although the development of verbal reference is a pivotal achievement, questions concerning its origins remain. To address this gap, we investigate infants' ability to establish a representation of an object that is hidden from view based on language input and to learn its name.

Keywords: verbal reference, word learning, language acquisition

Language is among our most powerful tools for learning and communication. It permits us to learn information that does not, or cannot, manifest perceptually at the time of learning (Deacon, 1997), such as historic facts, hypothetical scenarios, or scientific constructs. From one learning about a friend's weekend plans to physicists conversing about gravity, the communicative power of language enables us to transmit information, without needing perceptual access to it (see Clark & Marshall, 1981; Miller, 1990; Waxman & Gelman, 2009). This uniquely human power is enabled by *verbal reference – a recognition that words are used intentionally for communication and are linked to both real-word referents and mental representations of those referents* (Figure 1). When and how do infants develop this recognition?

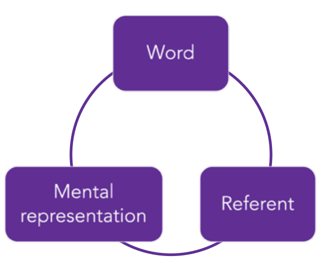

Figure 1. A referential link between words, referents, and mental representations of those referents that enables verbal reference.

Evidence documenting infants' comprehension of *'absent'* reference[1] suggests that the first signs of this recognition emerge by 12 months of age. Twelve-month-olds can represent absent objects and interpret pointing gestures in the direction of non-present objects as referential (Gliga & Csibra, 2009; Novack & Waxman, 2020). Twelve-month-olds begin to produce such behaviors in response to verbal requests for hidden objects (Gallerani et al., 2009; Osina et al., 2013, 2014; Saylor & Baldwin, 2004). By 14 months, infants move beyond accessing their representations of objects via words and begin to use words to retrieve memories of past events (Bauer et al., 2000) and look for absent caregivers (Saylor & Baldwin, 2004). At this age infants also incorporate social information into their interpretation of absent reference (Saylor & Ganea, 2007).

Although compelling, evidence from the absent reference studies leaves room for several interpretations. On the one hand, is possible that infants' behavior reflected a genuinely referential link between words, referents, and mental representations of those referents. On the other hand, because infants were asked to locate an object whose name they learned when the object was visible, they may have accessed a perceptual representation of a recently displaced object upon hearing a word associated with it. Moreover, infants' success in retrieving representations of hidden objects required visual 'anchors'– reminders that scaffold their representation of the now-absent referent (Ganea, 2005). Thus, it is unclear whether 12-to-14-month-olds have established a truly referential link between words and mental representations required for comprehension of verbal reference.

[1]A common challenge among the studies of infants' language comprehension is that words and their referents are co-present during both learning and test. However, testing whether infants linked a word to a mental representation requires that the word and its referent are not co-present either during learning or during test. The majority of studies that attempted to evaluate this link used an 'absent reference' design. In this design, infants' word comprehension is tested in the absence of the word's referent. Infants' looking, pointing, and search behaviors in response to a verbal prompt containing the target word ("Where is the modi?") are measured. Behaviors directed at the former location of the object or its plausible current location are interpreted as evidence of infants' comprehension of the experimenter's verbal prompts.

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Research with older infants, however, suggests that a referential link between words and mental representations may be place by 15-16 months. At this age infants move beyond accessing representations with the help of perceptual anchors and begin to update representations of object locations based on language input alone (Ganea et al., 2016). Sixteen-month-olds also look longer to the images of objects that were mentioned in the absence of any images, suggesting that they comprehend reference to non-present objects without perceptual anchors (Luchkina et al., 2020).

By 19 months, infants' reach a new milestone in their comprehension of verbal reference. These infants are not only able to *access and update representations*, but also *establish new representations of objects* they have never seen based on language input. For example, Ferguson et al. (2014) showed that 19-month-olds successfully identify the referent of a novel word even if that referent is not available when the name is introduced. Fifteen- and 19-month-olds were presented with novel nouns that were arguments of known verbs, either animacy-selecting ("The dax is crying") or animacy-neutral predicates ("The dax is right there"). When the novel word was presented in phrases that specified animate arguments, 19-month-olds, but not 15-month-olds, successfully mapped the novel word to an animate object when it later became visible.

But why did 15-month-olds fail, despite possessing the command of verbal reference that allows them to update mental representations of object locations based on language? *One possibility* is that these infants' link between words and representations is not yet referential – they can access mental representations via words but do not yet recognize the referential status of word, which precludes them from realizing that words can carry entirely new information. *Another possibility* is that the referential link between words and mental representations is in place, but 15-month-olds' sparse lexical knowledge (on average, infants in Ferguson et al. comprehended 4.3 verbs from the MacArthur Level II Short Form) prevents them from leveraging linguistic cues in forming a novel representation. Infants' verb knowledge at 15 months may have been too sparse to support the acquisition of novel noun arguments.

To (1) distinguish between these possibilities and (2) provide a more stringent test of infants' comprehension of verbal reference, we introduce a new paradigm. This paradigm that taps into infants' capacity for abstract reference, but relies instead on (a) the nouns they know (on average, 15-month-olds comprehend 71 nouns; Frank et al., 2017) and (b) their sensitivity to semantic neighborhoods (Bergelson & Aslin, 2017; Delle Luche et al., 2014).

We ask whether priming a semantic neighborhood supports infants' ability to establish a representation for the referent of a novel noun, even when the referent cannot be seen, and recruit this representation later to identify a referent of the novel word when it becomes visible.

We focused on infants aged 15 months because although there is ample evidence that they comprehend absent reference for known words (Ferguson et al., 2014; Hendrickson & Sundara, 2017; Luchkina et al., 2020; Saylor, 2004; Saylor & Ganea, 2007), there is no evidence that they learn novel word meanings without a referent being present during learning.

Method

Participants

Eighty-four 15-month-olds (M_{age}=14.8 months) were recruited from an online database on Lookit (Scott & Schulz, 2017). Parents completed a MacArthur Short Form Vocabulary Checklist: Level II, augmented with words used in the experiment. They also completed a demographic questionnaire about their education, employment, gender, and race.

Stimuli

Infants viewed a series of four video-taped vignettes, each featuring a new novel word-object pairing. The order of vignettes was counterbalanced using a Latin square design (Bradley, 1958). Each video began with the Priming phase, in which an actor pointed to three familiar objects and named each with its familiar basic-level noun. Next the actor looked toward an object entirely hidden behind her back, naming it with a novel word (Figure 2). During Test two novel objects were presented side by side (the side on which the target object appeared was counterbalanced among trials). Infants heard the actor's voice prompting them to look to the object, using the novel name provided during Priming.

Stimulus Selection and Design

We used vocabulary norms (Dale & Fenson, 1996) to select the visual and linguistic materials. For the familiar objects presented in the Priming phase, we selected objects whose names are understood by at least 60% of 15-month-olds (nouns: apple, banana, orange, jacket, sock, hat, truck, car, bus, cat, dog, horse). For the novel objects presented during Test, we (a) selected objects whose names infants do not understand (e.g., rare tropical fruits), and (b) chose pairs of objects from distinct semantic neighborhoods (e.g., dragon fruit vs. chandelier).

Procedure

All infants participated in 4 trials, each including a Priming phase and a Test phase (Figure 2). Each trial included one novel object-novel word pairing. Infants were assigned randomly to one of three conditions. In the Semantic Priming and Switch Word conditions, familiar objects presented during Priming were members of the same semantic neighborhood (e.g., animals, food, clothing); in the No Priming condition, they were drawn from different semantic neighborhoods. We selected a between-subject design to avoid potential carry-over effects, which would dilute the predicted advantage of semantic priming. In all conditions we provided infants with rich communicative and referential cues to support their interpretation of Trial 4 of the Priming phase (in which the object is hidden) as a labeling episode as well.

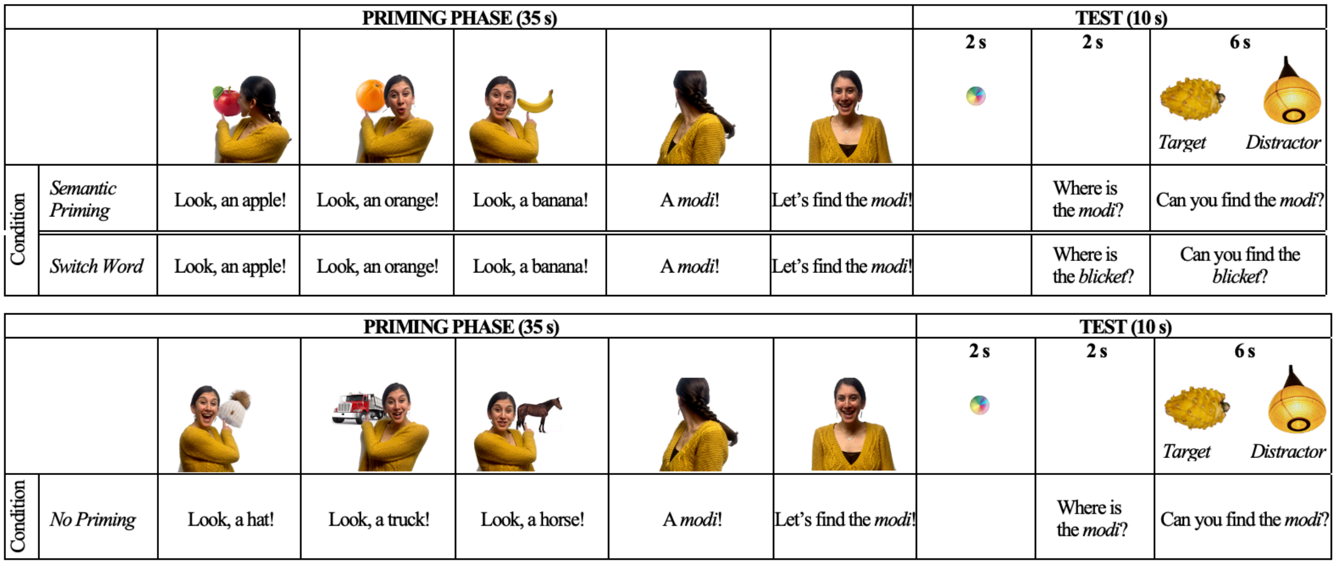

Figure 2. A representative example of visual and linguistic information presented in each phase in the Semantic Priming (top panel), Switch Word (top panel), and No Priming (bottom panel) conditions.

Semantic Priming condition (*N*=28) During Priming (35 s) an actor pointed to and named three familiar objects, all from the same semantic neighborhood (either fruits, clothing, vehicles, or animals). The objects appeared one at a time, behind the actor; the actor turned to point to and name them, using their familiar basic-level nouns (e.g., "Look! An apple! Do you see the apple?"). A fourth object, seemingly unintentionally occluded by the actor's body, was labeled with a novel noun (e.g., "Look, a modi!"), so that during naming, no referent object was visible. The actor alternated between looking to the object and to the camera to indicate that the referent object was located behind her. We presented infants with familiar word-object pairs during the Priming phase to access their resident semantic knowledge (Arias-Trejo & Plunkett, 2009; Delle Luche et al., 2014; Mani & Plunkett, 2010; Wojcik, 2018). During Test (10 s), infants first saw an attention getter (2 s), followed by a blank white screen (2 s), during which they heard the first prompt to look to the object corresponding to the novel label, e.g., "Now look! Where is the modi?". Immediately after, two objects appeared side-by-side—one was a member of the same semantic neighborhood as the familiar objects presented during the Priming phase (e.g., a novel fruit) and the other was a semantically distant, but perceptually similar, item. With these objects visible, infants heard a verbal prompt, e.g., "Can you find the modi?".

No Priming condition (*N*=30) The procedure was identical to the Semantic Priming condition, except that during Priming, infants were presented with familiar word-object pairs, drawn from different semantic neighborhoods (e.g., a hat, truck, and horse). Thus, no particular semantic neighborhood was primed. Neither of the three familiar word-object pairs belonged to the same semantic neighborhood as either of the test objects.

Switch Word condition (*N*=26) The Switch Word condition was identical to the Semantic Priming condition with one exception: during Test, infants heard a novel word that differed from that presented on Trial 4 during Priming. This condition was designed to explore the possibility that infants' looking behavior in the Semantic Priming condition was driven by their expectation about the fourth object and not related to hearing the name of the object. If infants formed an expectation about the fourth object solely based on the category membership of the three familiar objects, then their performance in the Switch Word condition should not differ from that in the Semantic Priming condition. Conversely, if infants' performance in the Semantic Priming condition was driven by a newly established link between the representation of the hidden object and its name, then performance in the Switch Word condition should not differ from the No Priming condition.

Data preparation

We analyzed infants' looking behavior from the onset of the image presentation through the end of the trial (6 s). Trials on which the total looking to the screen is less than 1 s were excluded from analyses (see Ferguson et al., 2014, for reference on trial duration and exclusion criteria).

We collected data on Lookit (Scott & Schulz, 2017); infants' looking behavior was recorded by the web-cameras attached to (or built into) computers at their homes. Trained research assistants watched the video-recordings and determined whether infants were looking to the left or to the right side of the screen during each frame of the recording. Left and right looks were subsequently converted to 'target' or 'distractor' codes by a computer algorithm blind to the hypothesis.

Analyses

One dependent variable was infants' Net[2] proportion of looking time **(NetLT)** to the target object: the average looking preference for the target from the verbal prompt onset (2000-6000 ms) minus the average looking preference for the target before the target word onset (0-2000 ms).

$$NetLT = \frac{LT_{target\ 2000-6000\,ms}}{LT_{target\ 2000-6000\,ms} + LT_{distractor\ 2000-6000\,ms}} - \frac{LT_{target\ 0-2000\,ms}}{LT_{target\ 0-2000\,ms} + LT_{distractor\ 0-2000\,ms}}$$

NetLT was calculated for each trial of each infant. This yielded up to 4 data points for each infant (one per each of 4 trials). We used 200-ms bins to calculate the proportion of infants' looking to the target.

The other dependent variable was **the timecourse of the NetLT** for each 200-ms bin in the 2000-6000 ms window. We used **Condition** as the main independent variable.

The effects of demographic factors, vocabulary scores, knowledge of the words used in Priming, loss of visual attention to the screen during priming, and trial order were tested in a preliminary analysis of NetLT, implemented by fitting a Generalized Linear Model (GLM). Trial order was included to test whether infants' NetLT changes over the duration of the procedure, as they might lose interest or exhibit a learning effect as the experiment progresses.

In the main analyses of NetLT, we used a Generalized Linear Mixed Model (GLMM) with Condition as a fixed factor and Test Item as a random factor (potentially affecting the intercept and the slope of Condition).

We included the Test Item variable, which stands for the category membership of the target object used at Test (e.g., dragon fruit belongs to 'fruits'), to account for the potential effects of infants' knowledge in different domains–fruits, vehicles, clothing, and animals. In analyzing the timecourse, we used cluster-based permutation analysis (Dink & Ferguson, 2015) to identify significant divergences between the conditions that corresponded to the mentions of the target word.

[2] We originally planned to use the raw proportion LT to the target over the duration of the image display (6000 ms). However, preliminary analyses indicated a sharp increase in LT to the target at the onset of image display (within the first 200 ms, suggesting that it was not related to the first verbal prompt; for reference times ranges see, e.g., Zettersten et al., 2022), which reverted to chance at the onset of the second verbal prompt, in all conditions. We chose the target images to be from familiar to infants categories (fruits, clothing, vehicles, animals) while distractor images were from less familiar categories (home décor, kitchen utensils, coffee makers, handy tools). The initial sharp increase in infants' LT to the target likely reflects their category familiarity preference. To correct for this baseline preference, we subtracted the average proportion of LT to the target during the first 2000 ms from the proportion of LT to the target during the rest of the image display.

Predictions

NetLT Semantic Priming condition We predicted a significant effect of Condition, with NetLT to the target significantly higher in the Semantic Priming than in the No Priming and Switch Word conditions. We also predicted that if infants successfully infer the meaning of the novel word and form a representation of its referent in the Semantic Priming condition, their NetLT to the target should be significantly above zero (i.e., significantly different from the baseline preference).

NetLT No Priming condition Infants in this condition were presented with three semantically distant word-object pairs, distant from either of the test objects. Because no particular semantic neighborhood was primed, their NetLT to both objects should be equivalent and should not deviate significantly from zero. If NetLT is significantly above zero, it is likely that intrinsic preferences for particular objects guide their looking behavior. This outcome would imply that the looking pattern in the Semantic Priming condition cannot be interpreted as evidence of verbal reference comprehension.

NetLT Switch Word condition If infants' looking preference in the Semantic Priming condition was the result of an inference about hidden object's category membership, without learning its name, then their performance in the Switch Word condition should not differ from the Semantic Priming condition. Conversely, if infants' looking in the Semantic Priming condition reflected their inferences about the novel word meaning, then NetLT in the Switch Word condition should not significantly deviate from zero.

Timecourse We expected that the timecourse data would show significant divergences between the conditions after the verbal prompt. We envisioned that infants in the Semantic Priming condition would exhibit increased NetLT to the target, which we predicted to be above zero (i.e., different from the baseline preference).

In the Switch Word condition, we expected infants' looking behavior to not be significantly affected by the verbal prompt because according to our hypothesis, infants had no particular expectations about the meaning of the novel word. It is, however, also possible that infants would exhibit a weak preference for the target object (the object that is target in the Semantic Priming condition) based on their expectations about the next item shown given the relatedness of the three demonstrated objects.

In the No Priming condition, the Priming phase provided no basis to form any expectation about the object or the meaning of its label. For this reason, we expected that infants' looking behavior would not be affected by the verbal prompts and remain close to the chance level for the duration of the test trial.

Results and Discussion

Preliminary analyses of NetLT resulted in significant effects of Age in days and the Loss of visual attention to the screen during Priming ("TrackLoss": the percentage of the total duration of Priming when the infant looked away), β=-0.001, *SE*=0.001, *t*-value=-2.08, *p*-value=.038 for Age and β=.577, *SE*=.242, *t*-value=2.38, *p*-value=.018 for TrackLoss. No other predictor used in preliminary analyses produced a significant effect at α=.05. Fitting one-predictor models to test the effect of each predictor did not change the direction or the magnitude of the effects. Thus, we included Age and TrackLoss in our main analyses, using the following formula entered into the *lmer* function:

NetLT~Age+Condition+TrackLoss +
[1+Condition| Test_Item].

Consistent with our predictions, the results of these analyses showed a significant effect of Condition (No Priming), β=0.096, *SE*=.041, *t*-value=2.32, *p*-value=.027. That is, the NetLT to the target in the Semantic Priming condition was significantly different (higher) than NetLT in the No Priming condition. Contrary to our predictions, the NetLT to the target in the Switch Word condition was not significantly different from the Semantic Priming condition (Figure 3).

The analysis also revealed a significant effect of TrackLoss, β=0.608, *SE*=.24, *t*-value=2.53, *p*-value=.012. A closer look at this rather surprising positive effect revealed that it was driven by three outliers, who exhibited high NetLT while missing 50-60% of Priming (the mean value of TrackLoss was 2.3%). Re-running the analyses without these outliers eliminated the significant effect of TrackLoss without substantially affecting other effects.

The GLMM also revealed a nearly significant effect of Age in days, β=-0.001, *SE*=.001, *t*-value=-1.92, *p*-value=.054. Following this nearly significant effect of Age, we further explored NetLT within the younger (M_{age}=14.1 months) and the older (M_{age}=15.5 months) age groups, using a median split (see Figure 4).

Finally, the variances of the intercept and the slope of Condition attributable to Test Item were equal to zero. Thus, we collapsed the data across test items in further analyses.

Individual models fitted to the NetLT in the older and in the younger age groups, showed a significant difference between the Semantic Priming and No Priming conditions in the older age group, β=0.165, *SE*=.061, *t*-value=2.69, p-value=.008. No such difference was observed for the younger age group. The comparison of these results with the analysis of the entire sample suggest that the overall effect of Condition was mainly driven by the older age group (15.5 months). Neither age group exhibited NetLT significantly different from zero in any condition.

In sum, the analyses of the average NetLT across 2000-6000 ms suggests that infants (mainly the older group) have a significantly greater net looking preference for the target object in the Semantic Priming than in the No Priming condition. The lack of a significant difference between the Semantic Priming and the Switch Word conditions suggests that infants' NetLT in the Semantic Priming condition was in part driven by their expectations about the category membership of the hidden object.

The analyses of the Timecourse are consistent with this interpretation and with our predictions (see Figure 5).

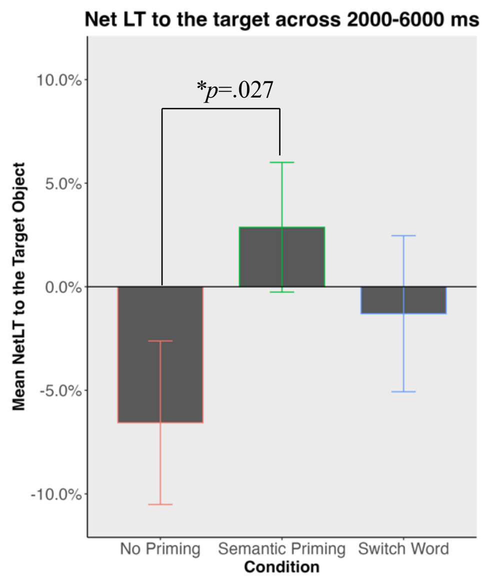

Figure 3. Average NetLT to the target in each condition. The bracket indicates a significant difference between conditions. Error bars represent standard errors.

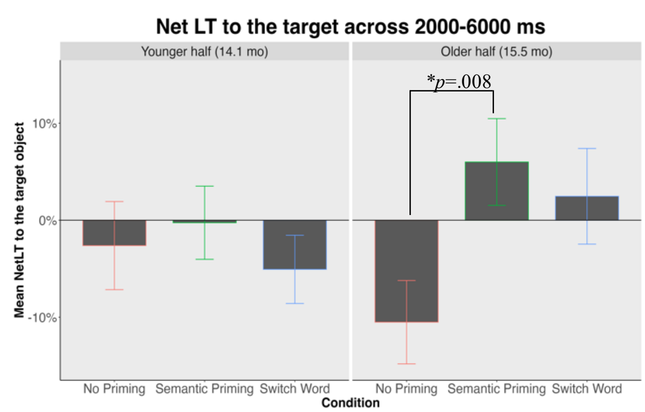

Figure 4. Average NetLT to the target in each condition, split by age. The bracket indicates a significant difference between conditions. Error bars represent standard errors.

Figure 5. Timecourse of NetLT to the target in each condition, split by age group. Shaded areas around solid lines correspond to standard errors. The overlapping light pink and light blue rectangles indicate clusters of divergence.

To evaluate the differences between conditions, we conducted cluster permutation analyses of the timecourse of NetLT within the 2000-6000 ms window. Of particular interest was the *2750-4750 ms window*, corresponding to the 2 s after the onset of the target word. This window corresponds to the window of divergence found in Ferguson et al. (2014) who used a similar procedure, which entailed that infants form a placeholder mental representation of an object they had never seen before. Because of the unique requirements of this type of word learning, we were specifically interested in the pattern of divergencies between the conditions rather than in how infants' looking preferences unfolded over the duration of the trial. We used one-tailed t-tests as the sum-statistic (17.97; cutoff value for individual *t*-values=1.71) that identifies a cluster.

The results of this analyses revealed a significant cluster of divergence between the Semantic Priming and the No Priming conditions in the older group, at 2800 and 4200 ms, p=.001[3] (Figure 5, light pink rectangle). This cluster suggests that older infants in the sample successfully formed a novel representation, linked it to the novel word, and employed the link to identify the target.

There was also a trending (nearly significant) cluster of divergence between the Semantic Priming and the Switch Word conditions in the older group, p=.10 (Figure 5, light blue rectangle). This cluster of divergence suggests that only a small proportion of older infants' looking preference for the target may be explained by their expectation about the category membership of the hidden object.

[3] *P*=.001 represents the probability of observing the same cluster if conditions are assigned to data points randomly. We used 500 samples randomly drawn from these data points to calculate this probability. The non-parametric nature of cluster permutation analysis allows us to choose from a variety of possible test statistics. The validity of this analysis does not depend on the assumptions about data distribution (see Maris & Oostenveld, 2007).

Conclusions

Our goal in this investigation was to fill the gap in our knowledge of the development of verbal reference and create a stringent test of infants' ability to comprehend reference to non-present entities. We evaluated 15-month-olds' ability to use language to form novel object representations when those objects are not visible and learn their names. The results of our model fitting suggest that on average infants succeed on this task by 15.5 months. The results of our time course analyses clarify that their test performance is unlikely to be explained away by the expectation about object category membership alone (albeit these inferences do influence infants' looking preference). Hearing the object's name substantially increases infants looking to the target.

These results present the first evidence of infants' forming a novel object representation and learning the name of the never-seen object based on language input. The success of the older group and the failure of the younger are consistent with the existing literature that shows infants' successful retrieval of existing representations based on language alone.

Our next steps include further exploring the developmental origins of verbal reference by investigating (1) its downstream effects on the ability to learn information from verbal testimony and (2) the mechanisms that facilitate the emergence of verbal reference.

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