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Fast mapping, slow learning: Disambiguation of novel word–object mappings in relation to vocabulary learning at 18, 24, and 30 months

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ABSTRACT

When hearing a novel name, children tend to select a novel object rather than a familiar one, a bias known as disambiguation. Using online processing measures with 18-, 24-, and 30-month-olds, we investigate how the development of this bias relates to word learning. Children's proportion of looking time to a novel object after hearing a novel name related to their success in retention of the novel word, and also to their vocabulary size. However, skill in disambiguation and retention of novel words developed gradually: 18-month-olds did not show a reliable preference for the novel object after labeling; 24-month-olds reliably looked at a novel object on Disambiguation trials but showed no evidence of retention; and 30-month-olds succeeded on Disambiguation trials and showed only fragile evidence of retention. We conclude that the ability to find the referent of a novel word in ambiguous contexts is a skill that improves from 18 to 30 months of age. Word learning is characterized as an incremental process that is related to – but not dependent on – the emergence of disambiguation biases.

1. Introduction

Dozens of experimental studies have shown that when young children are presented with a novel object and one or more familiar objects as they hear a novel name (e.g. *Where's the dax?*), they tend to select the unfamiliar object. This pattern of response has been consistently demonstrated in children 2 years and older (Clark, 1990; Golinkoff, Hirsh-Pasek, Bailey, & Wenger, 1992; Markman, 1991; Markman & Wachtel, 1988; Merriman & Bowman, 1989), with less robust effects beginning to emerge at younger ages (Byers-Heinlein & Werker, 2009; Halberda, 2003; Markman, Wasow, & Hansen, 2003; Mervis & Bertrand, 1994). Although interpretations of this phenomenon are debated, a widespread conjecture is that such skill in referent selection, which we will refer to as *disambiguation*, is fundamental to children's success in early word learning (e.g., de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011; Golinkoff et al., 1992; Markman, 1991). While this conclusion may seem consistent with many of the experimental findings on children's responses in situations of referential ambiguity, it rests on two largely untested assumptions that are evaluated in this study: The first assumption is that successful identification of the appropriate referent in this context constitutes evidence that the novel word has been "learned," with the implication that this new word–object mapping is retained over time. The second and related assumption is that the ability to use this disambiguation strategy plays a critical role in the rapid growth in vocabulary learning that begins for many children in the second year after birth.

1.1. Does success in disambiguation lead to word learning?

In the first study to look at disambiguation in relation to early word learning, Carey and Bartlett (1978) demonstrated that preschoolers could learn something about

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the link between a new color word and an unfamiliar color after only a few indirect learning trials, a phenomenon they called 'fast mapping.' However, even after several months of weekly exposure to this pairing, most children still did not show evidence of a fully accurate mapping. Carey (1978) stressed the gradual nature of word learning, suggesting that the immediate selection of a potential referent for a novel word is just the beginning of a long, slow process, and thus that learning is far from complete after a single encounter with a novel word. The view that fast mapping is only a provisional first step in apprehending the meaning of a new word was central to this influential characterization of early word learning.

Despite an emphasis on the prolonged and incremental nature of word learning in Carey's (1978) initial formulation, much of the research that followed focused on the immediate process of fast mapping, i.e. on referent selection in the moment. However, only a few studies have actually investigated the link between this initial disambiguation and later retention. For example, Golinkoff et al. (1992) replicated the result that 30-month-olds mapped a novel word onto a previously unnamed object, also showing that children extended the newly learned name to another exemplar of the same category immediately following disambiguation. These findings were the first to indicate that 30-month-olds could retain word–object mappings after a minimal delay, with similar results emerging in more recent research with children ranging in age from 30 to 48 months (Spiegel & Halberda, 2012; Wilkinson & Mazzitelli, 2003; Wilkinson, Ross, & Diamond, 2003). Although the children showing lexical retention in these studies were at an age when they already had hundreds of words in their expressive vocabularies, such results have been interpreted as evidence for the importance of disambiguation biases to young children's success in early word learning (e.g., Golinkoff et al., 1992).

The importance of skill in disambiguation to word learning was recently challenged by Horst and Samuelson (2008), who examined both referent selection and retention in four experiments with 2-year-olds. When children were shown a novel object among familiar objects, they selected the unfamiliar object when hearing a novel label, as found in previous studies. But surprisingly, on Retention trials 5 min later, these children showed no evidence of remembering the names of the novel referents they had previously identified. Although children were accurate in referent selection on Disambiguation trials, they did not remember the mappings between the novel words and novel objects – a finding inconsistent with the assumption that success in referent selection leads automatically to word learning and retention.

Subsequent computational work explains these findings by proposing different mechanisms for in-the-moment referent selection and long-term word learning (Horst & Samuelson, 2008; McMurray, Horst, & Samuelson, in press; McMurray, Horst, Toscano, & Samuelson, 2009). Referent selection, implemented with a simple dynamic probabilistic constraint-satisfaction device, explains how children can determine the referent of a word in the moment based on partial input. Simple associative learning mechanisms, implemented with a connectionist statistical learning core, explain how learning can slowly occur over time, while children keep track of the consistent co-occurrence between visual forms and auditory input. Although the referent selection and learning processes are deeply interrelated, they operate on different time scales. Slow learning provides crucial information for referent selection, while in-the-moment problem solving may provide a training signal that contributes to learning, allowing the system to behave as if it knows a word based on limited knowledge and to learn words slowly over time.

1.2. Is skill in disambiguation fundamental to early vocabulary development?

A second common assumption in the developmental literature follows from the first: If success in disambiguation is conflated with word learning, then young children's skill in disambiguation could help explain the acceleration in vocabulary growth over the second year. This possibility led to studies exploring whether disambiguation biases were present before the vocabulary explosion (or word spurt). If disambiguation strategies indeed play a role in early lexical development, then they should be available to children at an early age, possibly before they learn their first 50 words (Markman et al., 2003). However, if infants do not show evidence of using such strategies at the beginning of word learning, then disambiguation biases might instead reflect learned heuristics that older children find useful for expanding vocabulary, but that are not essential for early vocabulary development (MacWhinney, 1989). McMurray (2007) argued that the emergence of disambiguation biases is not necessary to explain the vocabulary spurt, which could reflect fundamental mathematical principles given the assumption that words are learned in parallel and vary in difficulty. From this perspective, disambiguation biases do not cause the vocabulary spurt, but instead might be the result of vocabulary growth (Mitchell & McMurray, 2009).

Using an offline measure of object choice, Mervis and Bertrand (1994) found that infants who did not show the disambiguation bias produced on average 45 words (out of 680), compared to 95 words produced by children who reliably selected a novel object after hearing a novel label. Other research with infants in the same age range confirmed their conclusion that disambiguation biases are not present at the very onset of lexical development, but reported a considerably higher vocabulary threshold. Graham, Poulin-Dubois, and Baker (1998) found that those children who did not show the disambiguation bias produced 82 words, on average, while those who did show the disambiguation bias had a mean vocabulary of 237 words, well above the hypothesized 50-word criterion conventionally used to define the onset of the vocabulary spurt. In addition, in a study that included infants hearing more than one language, Byers-Heinlein and Werker (2009) found that trilingual infants who were reported to comprehend over 200 words from the CDI still showed no evidence of using disambiguation biases. Approaching this question from another angle, Markman et al. (2003) found that children who knew fewer than 50 words already resisted second labels for objects. This rejection effect differed from the classic measures of disambiguation, but was interpreted as evidence that a broader heuristic called 'mutual exclusivity' was available before the vocabulary spurt "to serve a vital role in the rapid learning of novel words" (Markman et al., 2003, p. 273).

More recent research has begun to explore this question with continuous measures of both referent selection and vocabulary size. These studies have used online looking-time measures to obtain a gradient measure of disambiguation biases in young infants in conjunction with parents' report of productive vocabulary, with mixed results. A longitudinal study of English-learning infants from 14 to 18 months of age found relations between vocabulary at 16 months and success in disambiguation at 18 months (Fernald, Hurtado, Weisleder, & Marchman, 2011). However, a parallel study using looking-time measures with Spanish-learning infants from families much lower in socioeconomic status (SES), found that disambiguation responses were not yet evident at 18 months and were unrelated to concurrent vocabulary size, with links between disambiguation and vocabulary at both 24 and 32 months (Weisleder, Hurtado, Otero, & Fernald, 2012). Houston Price, Caloghiris, and Raviglione (2010) also found a relation between vocabulary and disambiguation biases in children from 17 to 22 months of age, although their analyses did not attempt to distinguish between effects of vocabulary size and effects of age. In two other studies using online measures with infants in this age range, success in referent selection was not related to vocabulary size (Byers-Heinlein & Werker, 2009; Mather & Plunkett, 2009). These conflicting results motivate our interest in exploring further how individual differences in the use of disambiguation biases relate to variation in vocabulary growth.

1.3. What constitutes evidence for proficiency in disambiguation?

As seen in this brief review, for over 30 years researchers have explored the use of disambiguation biases by young children in situations of referential ambiguity, using two main types of experimental paradigm. Starting with Carey (1978), the great majority of studies have relied on offline paradigms, in which referent selection is based on children's explicit choice of one of two or more stimulus objects presented by an experimenter. Successful disambiguation on a given trial is operationalized as the child's manual selection of the unfamiliar object over the familiar object alternatives, when asked to choose an object with a novel name. Since the response is indicated unambiguously by reaching for or pointing to a single object, each trial yields a discrete measure of correct or incorrect performance, from which the mean proportion of correct choices across trials is calculated. In a review of early studies using such offline measures, Merriman and Bowman (1989) addressed the issue of setting rigorous criteria for determining above-chance performance in manual object-choice paradigms, concluding that reliable and consistent evidence of disambiguation biases was found only in children 28 months and older.

The second type of paradigm in research on referent selection uses looking-time measures, which have become increasingly popular across different areas of research on early cognitive development (e.g., Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Haith, 1980). The use of differential looking to visual stimuli in studies with infants, rather than object-choice responses, has two main advantages: First, looking-time paradigms reduce the task demands of procedures requiring more complex responses such as reaching or pointing, yielding a potentially more sensitive measure of infant's differential attention to the visual stimuli. Second, looking-time measures yield continuous rather than categorical measures of attention on every trial. In longitudinal research on real-time processing of familiar words by both English- and Spanish-learning children from 18 to 30 months, such continuous measures of reaction time and accuracy are robustly correlated with concurrent and later measures of vocabulary (Fernald & Marchman, 2012; Fernald, Perfors, & Marchman, 2006; Marchman & Fernald, 2008; Marchman, Fernald, & Hurtado, 2010). These results show that measures of spoken language processing derived from looking-time data can be high in predictive validity and relate meaningfully to a range of offline measures of language proficiency.

Halberda (2003) was the first to use online looking-time measures in a study of referent selection by 14- to 18-month-olds, concluding that infants were successful in disambiguation by the age of 17 months, a result supported by other studies using comparable measures (e.g., Byers-Heinlein & Werker, 2009; Houston Price et al., 2010; White & Morgan, 2008). However, still other studies failed to find evidence that 16-, 19-, and 25-month-olds increase their looks to a novel object after hearing a novel label (Mather & Plunkett, 2009, 2011), although this pattern of response was surprisingly found in 10-month-olds 7.5 s after labeling (Mather & Plunkett, 2010). Thus the conflicting results of previous research using online measures do not yield a coherent account of developmental changes in young children's proficiency in referent selection.

1.4. Overview of research design

The goal of this research is to use online measures to track the development of young children's skill in identifying an ambiguous referent when hearing a novel name, as well as their skill in remembering the names of the novel referents they had previously identified, when tested on Retention trials. Experiment 1 is a preliminary study conducted to validate the looking-while-listening (LWL) procedure (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998) for use in investigating retention of newly learned words by children as young as 18 months. In Experiment 2, children at the ages of 18, 24, and 30 months are presented with Familiar-word and Disambiguation trials, and tested subsequently on their memory for the link between the novel words and novel objects encountered on Disambiguation trials. The results of Experiment 2 enable us to address two questions important to understanding the possible contribution of skill in disambiguation to early word learning: First, how is children's emerging skill in disambiguation related to word learning in the moment, as measured by their success in identifying the correct referent on novel-word Retention trials? And second, what is the relation between skill in referent selection and measures of overall expressive vocabulary size in children from 18 to 30 months?

2. Experiment 1

The goal of this preliminary study was to demonstrate that 18-month-olds, the youngest children tested in the disambiguation task in Experiment 2, could learn the association between a novel word and a novel object when this link was taught ostensively in an unambiguous labeling situation. The first experiment used exactly the same stimuli used with 18-month-olds in the second experiment, except for the teaching trials. In Experiment 1, each of the two novel objects was presented on its own during labeling; in Experiment 2, a novel object was paired with a familiar object during labeling. Although several previous studies have found evidence of novel word retention after ostensive labeling in a preferential looking task with children from 14 to 18 months of age (Gurteen, Horne, & Erjavec, 2011; Houston Price, Plunkett, & Harris, 2005; Schafer & Plunkett, 1996; Yoshida, Fennell, Swingley, & Werker, 2009), they used different criteria for determining above-chance performance than those used here.

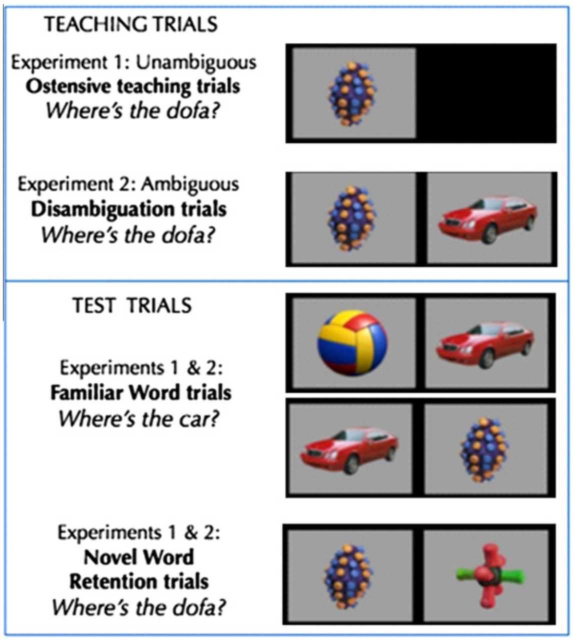

Fig. 1. Trial types in Experiments 1 and 2. Six familiar objects and two novel objects were used as visual stimuli in each experiment.

2.1. Method

2.1.1. Participants

Participants were 24 18-month-old children (M = 18.9 months; range = 18.4–19.6, 5 F). Parents reported that all participants were typically developing children from families where English was the dominant language, and that no child heard a second language for more than 7 h a week. Six participants were excluded from the final analyses because they did not contribute at least three usable trials in each experimental condition.

2.1.2. Visual stimuli

The visual stimuli were pictures of six familiar objects (car, cup, book, ball, cookie, shoe) and two novel objects (see Fig. 1), each centered on a grey background in a 640 × 480 pixel space.

2.1.3. Verbal stimuli

The speech stimuli were sentences consisting of brief carrier frames each ending in the name for one of the six familiar objects or two novel objects (e.g., *modi* and *dofa*), followed by simple questions that served to introduce prosodic variability across trials (e.g., *Where is the car? Can you see it?*). A female native speaker of American English first recorded multiple tokens of each sentence. Exemplars chosen for the final stimulus set were selected based on acoustic measurements of the carrier phrase and the noun. The duration of the target nouns was equated to the mean duration of all nouns (M = 785 ms) and the intensity of the phrases was normalized using Praat speech analysis software (Boersma, 2002).

2.1.4. Procedure

Accuracy in identifying the correct target picture was assessed using the LWL procedure (see Fernald, Zangl, Portillo, & Marchman, 2008). Children sat on their caregiver's lap and viewed pictures of objects as they listened to speech naming one of the pictures. On each trial, either a single picture or a pair of pictures was presented on the screen for approximately 6 s, with the speech stimuli starting after 2 s, followed by 1 s of silence. Each infant was presented with 28 trials, consisting of three different trial types (Fig. 1): On eight *Ostensive Teaching* trials, each novel object served as the target four times, with a single novel object presented during labeling. On eight *Retention* trials, the two novel objects were presented side by side, with each serving as target four times and on twelve *Familiar-Word* trials, each familiar object was paired once with another familiar object and once with a novel object. The Ostensive Teaching trials preceded the Retention trials. The Familiar-word trials were interspersed with Ostensive Teaching and Retention trials. The target object was named only once per trial. Pairings of novel and familiar objects were counterbalanced across participants. Side of presentation of target object was randomized, with the constraint that the target did not appear on the same side of the screen in more than two consecutive trials. To maintain attention, five filler trials with colorful pictures of more complex scenes were interspersed throughout the session, accompanied by encouraging phrases such as "Hey, look at that! That's cool!" Caregivers wore opaque glasses so that they could not influence infants' looking to the correct picture throughout the 5-min procedure.

Participants' eye movements were video-recorded and coded with a precision of 33 ms by observers who were blind to trial type. Inter- and intra-observer reliability checks were conducted for all coders. For 25% of the subjects, two measures of inter-observer reliability were assessed. The first was the proportion of frames (33-ms units) on each trial on which two coders agreed. In this case, agreement was 99%. However, because this analysis included many frames on which the child was maintaining fixation on one picture, we also calculated a more stringent test of reliability (see Fernald et al., 2008). This second measure determined the mean proportion of shifts in gaze on which coders agreed within one frame (33 ms), ignoring steady-state fixations in each trial on which agreement was inevitably high. By this more conservative measure, coders agreed within one frame on 98% of all shifts.

On those trials in which the infant was fixating a picture at the onset of the speech stimulus, accuracy was computed by dividing the time looking to the target object by the time looking to both target and distracter, from 300 to 3300 ms after the onset of the target word. Trials in which infants are were looking away from both pictures or shifting from one to the other were not included in these analyses, consistent with previous studies (Fernald et al., 1998, 2006). Accuracy before 300 ms was not included because shifts to the target occurring in this window had presumably been initiated before the onset of the noun (Haith, Wentworth, & Canfield, 1993). Several previous studies using the LWL procedure to examine familiar word recognition have assessed accuracy over an 1800-ms window from target word onset (e.g., Fernald, Thorpe, & Marchman, 2010; Fernald & Marchman, 2012). However, in Experiments 1 and 2 we used a longer window because on the majority of trials the visual stimuli included one or two novel objects, which elicited more shifting back and forth between target and distracter than do sequences of trials on which only familiar objects are presented. Rather than using different measurement windows for different trial types, we chose to use a standard window of 3300 ms, encompassing the entire trial duration. Accuracy windows longer than 3 s and up to 10 s have been used in previous studies using looking time measures of children's responses to newly learned words (Booth & Waxman, 2009; Houston Price et al., 2005; Mather & Plunkett, 2010). Mean accuracy was then computed for each participant on each trial type as the mean proportion of time looking to the target divided by the mean proportion of time looking to the target or to the distracter.

2.2. Results and discussion

Fig. 2 provides an overview of the responses of 18-month-olds on Familiar- and Novel-word trials in Experiment 1, when novel words were taught ostensively in an unambiguous context. This graph shows the mean proportion of trials on which children were looking at the correct picture, averaged across participants as the trial unfolds over time. As expected, 18-month-olds performed reliably above the chance level of 0.50 on Familiar-word trials ($M = 0.68$, $SD = 0.06$), $t(17) = 12.68$, $p < 0.001$, consistent with previous studies using this paradigm (e.g. Fernald et al., 1998; Fernald et al., 2006). Moreover, on Retention trials children also showed evidence of remembering the mappings between two novel words and two unfamiliar objects ($M = 0.59$, $SD = 0.15$), $t(17) = 2.52$, $p = 0.021$. These findings show that 18-month-olds can learn two novel

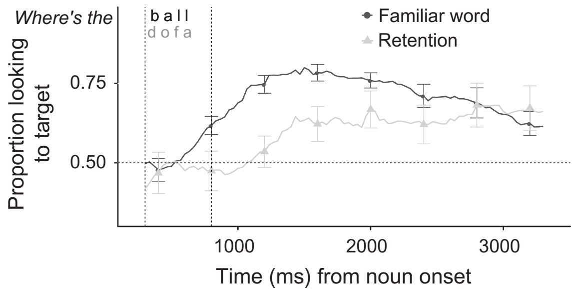

Fig. 2. Overall accuracy of responses on Familiar-word and Retention trials by children at 18 months of age in Experiment 1. Curves show the mean proportion of trials on which children were fixating the target picture at each 33-ms interval as the stimulus sentence unfolded, measured from acoustic onset of the noun. The first vertical dashed line indicates 300-ms after noun onset, and the second marks the mean noun offset (785 ms). The horizontal line represents 0.50, the chance level of proportion of looking time to the correct picture. Error bars indicate standard errors from the means and are graphed every 400-ms. When novel words were taught ostensively, 18-month-olds retained the mappings between novel words and novel objects.

words when taught and tested for retention on these stimuli in this paradigm. This preliminary experiment establishes the validity of this experimental paradigm for investigating the success of children as young as 18 months on Disambiguation and Retention trials in Experiment 2, in which they are exposed to novel words in a more ambiguous context.

3. Experiment 2

In Experiment 2 we investigated how skill in disambiguation develops between the ages of 18 and 30 months, and at what age young children are reliably able to retain the mappings between a novel word and a novel object when this mapping is created in an ambiguous context. This experiment also enabled us to explore how skill in disambiguation relates both to success in immediate word learning, as revealed in performance on Retention trials, as well as to success in word learning over developmental time, as revealed in productive vocabulary size at each age. Experiment 2 included the same types of stimuli presented in three trial types in the same order as in Experiment 1. The important difference was that on labeling trials in Experiment 1, each of the two novel objects was presented four times in an unambiguous context as the sole object present, as the child heard the novel name. In contrast, the exposure trials in Experiment 2 were ambiguous, because the novel objects were always paired with a familiar distracter object. While only 18-month-olds were tested in Experiment 1, children at 18, 24, and 30 months of age were tested in Experiment 2.

3.1. Method

3.1.1. Participants

We tested children at three different ages: 32 18-month-olds ($M = 18.8$ months; range = 18.4–19.3; 17 F); 33 24-month-olds ($M = 24.9$ months; range = 24.2–25.7;

17 F); and 25 30-month-olds (M = 30.8 months; range = 30–31; 7 F). All were typically developing children from families where English was the dominant language. No child heard a second language for more than 9 h a week. Ten of the 18-month-olds were excluded from the final analyses because they did not contribute three or more usable trials per experimental condition. Eight 24-month-olds and five 30-month-olds were excluded for the same reason. Thus the final sample consisted of 22 18-month-olds, 25 24-month-olds, and 20 30-month-olds.[1]

3.1.2. Visual and verbal stimuli

The same stimuli from Experiment 1 were used for the 18-month-olds in Experiment 2. Since some of the 24 month-olds had been tested on Disambiguation trials at 18 months, the novel words (*pifo* and *toma*) and novel objects used with the 24- and 30-month-olds were different from those used with the 18-month-olds.

3.1.3. Procedure

In Experiment 2, the 12 Familiar-word and 8 Retention test trials were the same as those in Experiment 1. However, the 8 unambiguous Ostensive Teaching trials in Experiment 1 were replaced with 8 ambiguous Disambiguation trials, on which both a familiar and novel object were presented and a novel name was used during labeling. The same coding and accuracy measures were used as in Experiment 1. Coding reliability was 98% for proportion of looks and 96% for shift in gazes.

3.1.4. Language measures

At each age, caregivers completed the MacArthur-Bates Communicative Development Inventory: Words & Sentences (CDI; Fenson et al., 2006). The vocabulary score at each age was the number of words parents reported their child produced.

3.2. Results and discussion

The analyses in Experiment 2 addressed three main questions. First, did children's accuracy on Familiar-word, Disambiguation, and Retention trials change from 18 to 30 months of age? Second, was children's performance on Disambiguation trials related to their ability to retain the association between a novel word and a novel object? And third, was children's performance on Disambiguation and Retention trials related to their expressive vocabulary size at each age?

3.2.1. Changes with age in success on Familiar-word, Disambiguation, and Retention trials

Fig. 3 shows the time course of looking to the target as the speech signal unfolded by 18-, 24- and 30-month-olds, with separate curves for the three trial types at each age. Visual inspection of these plots suggests that children's accuracy differed as a function of age and trial type. Accuracy increased with age on Familiar-word and Disambiguation trials, but not as much on Retention trials. And at each age, children's performance appears to differ across conditions, suggesting that children were more accurate on Familiar-word than on Disambiguation trials, and more accurate on Disambiguation than on Retention trials.

To assess these differences statistically, mean accuracy scores were compared in a 3 × 3 ANOVA with Trial Type (Familiar-word, Disambiguation, Retention) as a within-subject factor and Age (18, 24, 30 months) as a between-subject factor. Fig. 4 shows mean accuracy averaged across participants for each age group and trial type. Children's performance improved between 18 and 30 months across conditions, as shown by the significant main effect of age, $F(2,64) = 9.64$, $p < 0.001$, $\eta^2 = 0.231$. Their performance also differed reliably between trial types, $F(2,128) = 55.42$, $p < 0.001$, $\eta^2 = 0.464$. Children were more accurate on Familiar-word trials than on Disambiguation trials, $t(66) = 7.88$, $p < 0.001$, $d = 0.962$, and more accurate on Disambiguation trials than on Retention trials, $t(66) = 4.09$, $p < 0.001$, $d = 0.499$. There was no significant age × trial type interaction, suggesting comparable improvement with age across the three conditions, $F(4,128) = 1.28$, $p = 0.279$, $\eta^2 = 0.039$.

Children's accuracy improved with age on all trial types. However, a more nuanced picture emerged when accuracy was compared against the chance level of 0.50. As shown in Table 1, 18-month-olds were above chance in identifying the correct referent for familiar words, but they did not yet reliably prefer to look at the novel object after hearing a novel label. Although 24-month-olds were significantly above chance on Disambiguation trials, thus showing that they could determine the referent of novel words by exclusion, they did not yet retain these mappings after a minimal delay. By the age of 30 months, children were more consistently able to find the referent of a novel word by exclusion, although their performance was just barely above chance. Thus children in the oldest age group were only beginning to show evidence of retaining the mapping between a novel word and a novel referent.

3.2.2. Links between accuracy on Disambiguation trials and accuracy on Retention trials

The second set of analyses focused on whether children's tendency to select the novel referent when hearing a novel word in an ambiguous context was related to their ability to remember this mapping over time. To answer this question, we calculated the correlation between children's accuracy scores on Disambiguation and Retention trials. This first analysis, which included all children across the three age groups, showed that children who were more accurate in disambiguating the referent of a novel word were also better at retaining the link between the novel word and its referent, $r(65) = 0.46$, $p < 0.001$. However, if

[1] Nine children from the final sample were tested at both 18 and 24 months. This study was originally designed to test children longitudinally at these two age points. However, given high attrition rates and an unanticipated interruption in data collection, we decided to retain the nine children who had provided data at both ages and augment the samples with additional 18- and 24-month-olds in a cross-sectional design, also adding a third group of 30-month-olds. There was no overlap between the samples of Experiments 1 and 2. In all our statistical analyses, the main effects of age and differences across conditions remain significant when participant is included as a random factor.

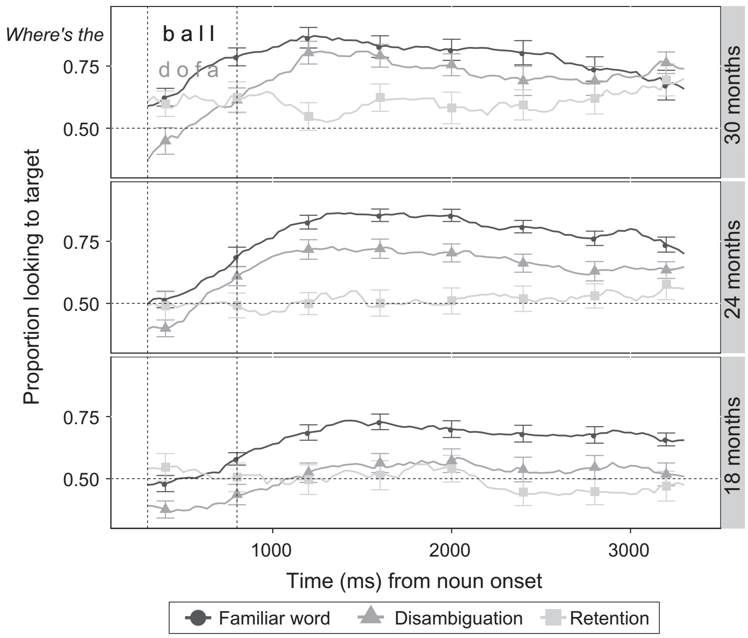

Fig. 3. Overall accuracy of responses on Familiar-word, Disambiguation, and Retention trials, by children at 18, 24, and 30 months of age. Curves show the mean proportion of trials on which children were fixating the target picture at each 33-ms interval as the stimulus sentence unfolded, measured from the acoustic onset of the noun. Error bars indicate standard errors from the means and are graphed every 400-ms. In all age groups, children were above chance on Familiar-word trials. At 24 and 30 months, children were above chance on Disambiguation trials. Only at 30 months were children above chance on Retention trials.

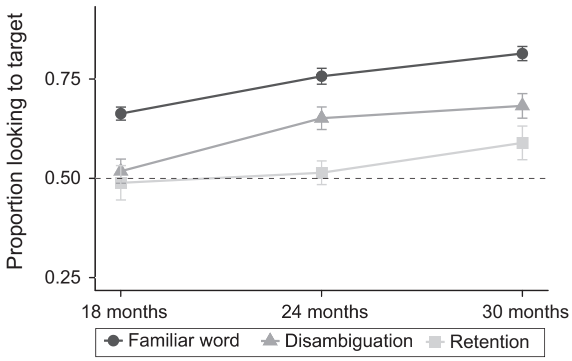

Fig. 4. Mean accuracy on Familiar-word, Disambiguation, and Retention trials, for the three age groups. Error bars represent standard errors of the mean over participants. Children were more accurate on Familiar-word than on Disambiguation trials, and more accurate on Disambiguation than on Retention trials, and they made comparable gains with age across conditions.

Table 1
Mean, standard deviation, *t* statistics, and *p* value for comparisons against chance (0.50) of accuracy on Familiar-word, Disambiguation, and Retention trials, for the three age groups.

Condition and age	*M*	*SD*	*df*	*t*	*p*
Familiar-word					
18 months	0.66	0.08	21	9.93	0.001
24 months	0.76	0.10	24	12.85	0.001
30 months	0.82	0.08	19	17.67	0.001
Disambiguation					
18 months	0.52	0.14	21	0.59	0.562
24 months	0.65	0.13	24	5.34	0.001
30 months	0.68	0.14	19	5.90	0.001
Retention					
18 months	0.49	0.20	21	0.26	0.797
24 months	0.51	0.15	24	0.47	0.642
30 months	0.59	0.18	19	2.11	0.049

older children, or children with larger vocabularies, were more accurate on both Disambiguation and Retention trials, then this result could be attributed to differences in either age or vocabulary. To address this issue, we ran a linear regression with accuracy on Disambiguation trials predicting accuracy on Retention trials, controlling for both age and vocabulary. Again, children who spent a greater proportion of time looking at the novel object on Disambiguation trials were better at remembering the link between the novel word and the novel object at test, independent of their age and vocabulary size, $\beta = 0.43$, $t(60) = 3.06$, $p = 0.003$. Fig. 5 shows that the relation between Disambiguation and Retention was significant or marginally significant at all ages, although strongest at 24 months. Using the Fisher *r*-to-*z* transformation, we confirmed that the correlation coefficients were not significantly different from each other at the different age points (for all comparisons, $p > 0.5$). Taken together, these analyses suggest a relation between children's ability to find the referent of a novel word in an ambiguous situation and their ability to remember the association between the novel word and the appropriate novel object.

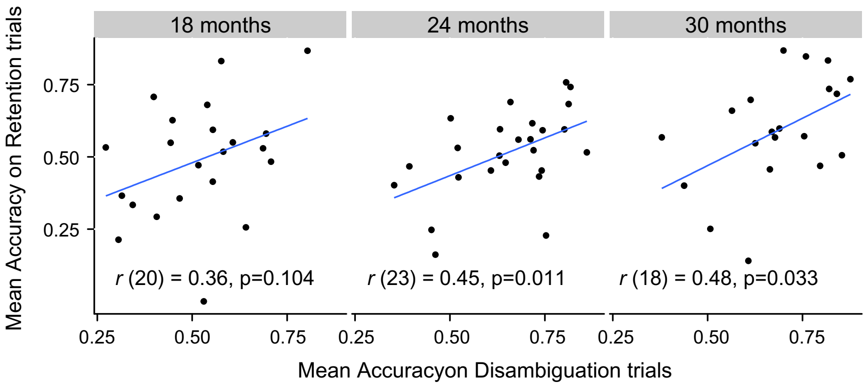

Fig. 5. Correlation between accuracy on Disambiguation trials and accuracy on Retention trials at 18, 24, and 30 months of age. Across age groups, children with higher accuracy on Disambiguation trials were better at remembering the mapping between the novel word and the novel object on Retention trials.

3.2.3. Links between vocabulary size and accuracy on Disambiguation and Retention trials

We next asked how children's concurrent vocabulary related to their accuracy on Disambiguation and Retention trials. The first analysis included all children across the three age groups, with the exception of three 30-month-olds for whom CDI measures were not available. On Disambiguation trials, children with higher vocabulary scores looked significantly more to the novel object than children with lower vocabulary scores, $r(62) = 0.57$, $p < 0.001$. There was also a significant correlation between accuracy on Retention trials and concurrent vocabulary size, $r(62) = 0.30$, $p < 0.001$.

As in the analyses of links between Disambiguation and Retention trials, the next step was to investigate whether the significant correlation between vocabulary size and accuracy was attributable to differences in age between children with larger and smaller vocabularies. To address this potential confound, a partial correlation was used to assess the degree of association between vocabulary and accuracy, removing the contribution of age. For Disambiguation trials, the correlation between accuracy and productive vocabulary was significant even after controlling for age of the child, $r(61) = 0.37$, $p = 0.003$. As shown in Fig. 6, the correlation between Disambiguation and Retention was in the expected direction at all age points, although the effect was driven mainly by the 24-month-olds – most likely due to the low vocabulary level of many 18-month-olds and a ceiling effect on the CDI measures of vocabulary at 30 months. The median vocabulary size of the 30-month-olds was 534 words, and several children with higher vocabularies were at or near the 680-word limit of the instrument, resulting in an artificial restriction of range. Taken together, these analyses showed that children with larger vocabularies at each age were relatively more accurate in identifying the novel referent on Disambiguation trials, especially at 24 months. Using the Fisher *r*-to-*z* transformation, we found that the correlation coefficient at 18 months of age was marginally different from the coefficient at 24 months, $z = 1.68$, $p = 0.093$, with no reliable difference for the other two comparisons (both $p > 0.50$).

On Retention trials there was no relation between accuracy and vocabulary size when the contribution of age was removed, $r(61) = 0.18$, $p = 0.157$. However, when each age group was examined separately, accuracy on Retention tri-

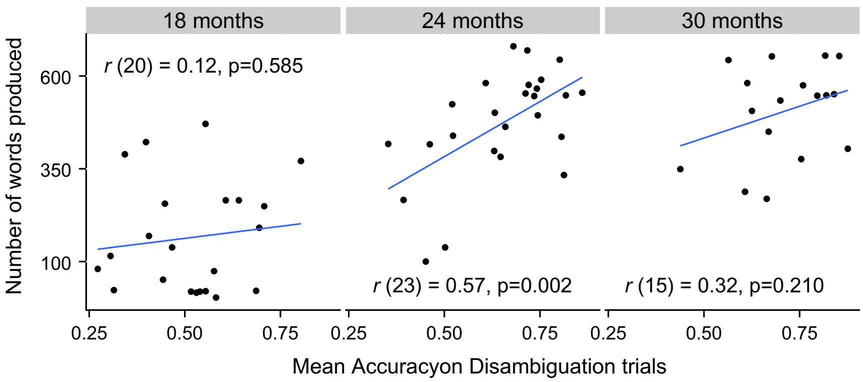

Fig. 6. Correlations between accuracy on Disambiguation trials and productive vocabulary (CDI) at 18, 24, and 30 months of age. Children with higher vocabularies spent a greater proportion of time looking at the novel object after hearing a novel label.

als was significantly correlated with vocabulary size at 30 months, $r(15) = 0.56$, $p = 0.019$, although not at either of the younger ages ($p > 0.40$). These findings provide some evidence that by 30 months, children's emerging ability to retain the link between a novel word and a novel referent identified through disambiguation is related to their concurrent vocabulary.

4. General discussion

Three main findings emerged in this research. First, young children's ability to identify an appropriate referent when hearing a novel name in a situation of referential ambiguity, and their success in remembering that word–object association over time, were both skills that improved gradually between the ages of 18 and 30 months. Second, these two skills – disambiguation and retention – were related, but should not be conflated. Children who looked relatively more at the novel object after hearing a novel name were also likely to spend a greater proportion of time looking at the correct referent on subsequent Retention trials. However, although 24-month-olds were successful overall in disambiguating novel words, they showed no evidence as a group of remembering these mappings when tested on Retention trials. The third finding was that the tendency to look at the novel object as the referent in ambiguous situations was related to children's productive vocabulary size. Those children with higher productive vocabulary scores also spent relatively more time looking at the novel object on Disambiguation trials than did children with lower vocabulary scores. However, the reported productive vocabulary of those children who did not yet appear to use a disambiguation strategy comprised hundreds of words. Thus we cannot conclude that the ability to identify a novel referent in an ambiguous situation is essential for early word learning, given that some of the children in this study who had already learned hundreds of words showed no evidence of success in disambiguation.

4.1. The gradual development of efficiency in recognizing familiar words, disambiguating novel words, and retaining word–object mappings

Our first major finding was that children's accuracy in interpreting familiar and novel words gradually improves with age. The familiar words used as stimuli here were among the most common words in the early vocabulary of English-learning children, reportedly known by nearly 90% of 16-month-olds (Dale & Fenson, 1996). As expected, children were above chance in identifying correct referents for these words at 18 months. Yet, between 18 and 30 months, there were impressive gains in children's efficiency in recognizing these same familiar words, consistent with previous findings (Fernald & Marchman, 2012; Fernald et al., 1998; Hurtado, Marchman, & Fernald, 2007).

Since children identified familiar target words correctly at 18, 24, and 30 months, they showed evidence of "knowing" these words at every age. But to be satisfied with this static, categorical description of word knowledge is to ignore how efficiency in interpreting spoken words continues to improve. As children gain more experience with language, they respond with increasing speed and reliability in identifying familiar words and become better at interpreting these words in increasingly complex contexts. Marchman and Fernald (2008) found that even after controlling for differences in vocabulary size, 2-year-olds who were more efficient in recognizing familiar words developed better language skills and performed better on a working memory task 6 years later. Moreover, early differences in processing efficiency were more powerful in accounting for variability in later cognitive and linguistic outcomes than were categorical measures of language knowledge. One possible explanation for the high predictive validity of early processing measures is that children who are better at identifying familiar words have more resources available to encode upcoming linguistic input, relying on their emerging knowledge of familiar words to discover the meaning of novel words using strategies other than disambiguation biases.

Such gradual improvement in word recognition is also consistent with recent computational models, which suggest that the same general mechanisms responsible for associative learning and online competition could subserve the processing of both familiar and novel words (McMurray et al., 2009, in press). These models predict that disambiguation biases also develop gradually over time, consistent with our finding that on Disambiguation trials, children's tendency to look at an unfamiliar object on hearing a novel name increased with age. Although 18 month-olds were not reliably above chance, 24-month-olds looked significantly more at a novel object after hearing a novel label, with further improvement by 30 months. Thus, just as children became faster and more reliable in interpreting familiar words, they also became increasingly efficient in using their knowledge of familiar words to figure out the referent of new words in ambiguous contexts.

The finding that 18-month-olds as a group did not look reliably at an unfamiliar object after hearing a novel name appears to be inconsistent with previous studies reporting evidence for a disambiguation bias in younger infants (e.g. Byers-Heinlein & Werker, 2009; Halberda, 2003). One likely reason for this discrepancy is the use of different criteria for concluding that children used a disambiguation strategy at a particular age. In our study, we concluded that a reliable disambiguation bias was evident in those children whose mean accuracy was significantly above 0.50 after labeling. In contrast, most previous studies using looking-time measures to study disambiguation have relied on difference scores in reference to pre-naming baselines. In these studies, 17- and 18-month-olds increased their looks to a novel object above baseline preference after hearing a novel label, a response that was interpreted as evidence that infants at this age were reliably demonstrating a disambiguation bias (e.g. Byers-Heinlein & Werker, 2009; Halberda, 2003). However, as these authors acknowledge, these positive difference scores did not necessarily indicate an absolute preference for the target after labeling, the criterion commonly taken as evidence for a disambiguation bias in offline tasks using manual choice as a dependent measure.[2]

The discrepancies between our results and those of Mather and Plunkett (2009, 2010, 2011) are harder to explain. These authors claimed that novel labels guide very young infants' attention to novel objects, based on evidence that 10-month-olds increased their looks to an unfamiliar object between 7.5 and 10 s. after hearing a novel label, even though infants at this age could not yet reliably identify the familiar competitor objects (Mather & Plunkett, 2010). In other studies, however, children as old as 25-months did not increase their looks to a novel object after hearing a novel label, although at 16 months they did show evidence of learning new words by exclusion, even without succeeding on Disambiguation trials (Mather & Plunkett, 2009, 2011). Rather than attempting to reconcile such disparate findings, we emphasize once again that the goal of determining categorically the precise age at which infants "show disambiguation biases" overlooks the gradually developing nature of this ability.

On Retention trials, improvement across age was much more limited; the 18- and 24-month-olds did not remember the names for the novel objects, while 30-month-olds showed some fragile evidence of retention. Horst and Samuelson (2008) also found that although 24-month-olds were very accurate on Disambiguation trials, they showed no evidence of retaining the link between a novel word and a novel object. Although their negative findings could be related to the specific task demands of their offline referent-selection test trials, our study confirmed their results in a less demanding task using gradient measures of accuracy. It is important to note that children's failure on Retention trials at 18 and 24 months was not due to limitations of the LWL procedure, or to our more conservative criterion for success in learning. The 18-month-olds in Experiment 1 performed reliably above chance on comparable test trials, retaining the mapping between two novel words and two novel objects after four instances of ostensive labeling in a referentially unambiguous context.

To summarize so far, one central conclusion of this research is that skill in recognizing familiar and novel words develops gradually. Looking-time measures are widely used in studies of infant cognition, and are often taken as evidence of high-level cognitive abilities that are characterized dichotomously (e.g. Baillargeon & Graber, 1987; Hamlin, Wynn, & Bloom, 2010; Spelke, 1994; Wynn, 1992). But instead of asking whether infants "have it or not," Haith (1998, 1999) argues that graded characterizations of learning are more appropriate, incorporating the notion of partial accomplishment with several steps along the way. According to this view, an increase in infants' proportion of looking to a novel object after hearing a novel label, compared to their initial preference for the familiar object prior to labeling – even if it does not meet the conservative criterion we used here of >0.50 accuracy – could be interpreted as evidence of partial success in a disambiguation task. This early precursor of a disambiguation bias will later develop into a reliable preference for looking at the novel object after hearing the novel word, which may be more functionally comparable to the manual choice behavior observed in studies using offline tasks.

4.2. Links between accuracy on Disambiguation trials and accuracy on Retention trials

Our second finding was that although disambiguation biases and success in retention are related, these two skills should not be conflated. In all three age groups, children who spent a greater proportion of time looking at the novel object on Disambiguation trials were also relatively more accurate on Retention trials. However, success in disambiguation did not entail success in retention. Although 24-month-olds as a group performed well on Disambiguation trials, they were not reliably above chance on Retention trials. A central question posed in the introduction was whether success in identifying the correct referent for a novel word implies success in word learning, as has frequently been assumed in the literature exploring the disambiguation phenomenon. These results address this question by showing that success in disambiguation is not the same as "learning" a new word–object mapping. If disambiguation is characterized dichotomously as a skill that is either present or not, then 90% of the 24- and 30-month-olds "used" disambiguation strategies (i.e., their mean accuracy on Disambiguation trials was >0.50). Yet, among these children there was considerable variation in their efficiency in interpreting novel names, and these differences were linked to their success in learning new words in the moment.

Although these results provide the first experimental evidence using continuous measures for a link between disambiguation biases and retention, they also reveal that skill in disambiguation does not necessarily lead to success in word learning. The partial dissociation between these two skills is supported by results from previous offline studies (Horst & Samuelson, 2008) and by computational models (Horst, McMurray, & Samuelson, 2006). Children use their knowledge of familiar words and objects to figure out what speakers are talking about. Referent selection requires that children give their best guess in a specific ambiguous situation, but word learning operates over a much longer time scale. Although disambiguation can be viewed as the *product* of learning that has occurred up to that point, for younger children it does not necessarily result in learning a new word. However, the experience of

[2] At a reviewer's request, we reanalyzed our data to enable comparison of results based on our standard measures of accuracy with results based on difference scores. As our baseline measure, we computed accuracy from the onset of the carrier phrase up to 300 ms after target noun onset, a 1100-ms window representing children's looking preferences prior to labeling. Difference scores were calculated by subtracting mean accuracy during the baseline window from mean accuracy during the 300–3300-ms window after the onset of the target word. Although most of the findings reported in Experiment 2 were confirmed using difference scores to assess children's performance, there were four exceptions: (1) On Disambiguation trials, 18-month-olds' showed a marginally significant ($p = 0.054$) increase in looking to the novel object after hearing the novel word; (2) the correlation between disambiguation and retention was not significant using difference scores ($p = 0.162$); (3) the correlation between retention and concurrent vocabulary was not significant using difference scores ($p = 0.154$); and (4) performance on Retention trials at 30 months was also not significant using difference scores ($p = 0.951$). Ongoing research that directly compares these two approaches to analyzing looking time data will help to elucidate such discrepancies.

identifying a novel referent for an unfamiliar word could leave traces that accumulate over subsequent experiences with the word, ultimately leading to word learning with long-term retention.

This approach to vocabulary learning and disambiguation biases was proposed by McMurray et al. (in press, 2009), whose model predicts results consistent with those of the present study. Their model succeeded both in learning familiar words and in identifying the novel referent on Disambiguation-like trials, but failed on Retention trials. However, despite not reaching the set criterion for learning on Retention trials, there was still statistically significant evidence that some learning had occurred, when the weight matrix of the novel words was analyzed. Although a single Disambiguation trial might not create enough weight change for successful performance on Retention trials, it could still drive learning over several trials. On Disambiguation trials, the model quickly evaluates multiple constraints and selects the correct referent, exceeding the knowledge stored in its weights. By combining online constraint-satisfaction to explain performance, and co-occurrence statistics to explain slow statistical learning, this model could explain why the children in Experiment 2 succeeded on Disambiguation trials yet failed on subsequent Retention trials. This perspective also explains why Disambiguation and word learning are related, but should not be conflated.

4.3. Links between vocabulary size and accuracy on Disambiguation and Retention trials

Our third finding was that those children who tended to be more accurate on Disambiguation trials were also those who produced more words. However, we cannot conclude from this relation that disambiguation biases are therefore essential for early vocabulary learning. The 18-month-olds in this study spoke on average 165 words, but they did not show evidence overall of disambiguation biases. Note that according to Mayor and Plunkett (2011), a raw CDI score of this magnitude corresponds to an estimated total vocabulary size of 221 words. In fact, those 18-month-olds whose accuracy scores on Disambiguation trials were lower than 0.50 were reported to produce as many as 389 words (estimated: 714 words), and those 24-month-olds who failed to show a disambiguation bias produced as many as 417 words (estimated: 796 words). Although it has often been argued that skill in mapping a novel word to an unfamiliar object in an ambiguous context is critical to early vocabulary development, these results reveal that children can learn hundreds of words without showing evidence of reliance on disambiguation biases.

What are the reasons for this link between accuracy on Disambiguation trials and vocabulary size? One possibility is that stronger disambiguation biases lead to faster vocabulary growth, if children who are better at identifying the referent of a new name in an ambiguous context thus have more opportunities to create and retain new mappings between novel words and referents in their environment. Or the relation between vocabulary and disambiguation biases might work in the other direction, if having a larger vocabulary is what enables the development of stronger disambiguation biases. In this case, knowing more words would help to narrow the hypothesis space in situations of referential ambiguity. In addition, as children learn more words, they might attend more to the consistency of adults' mappings of words and referents, which could subsequently lead to stronger disambiguation biases. The most likely scenario is that vocabulary growth and disambiguation biases work together through feedback loops in a mutually influential fashion.

A related explanation is that vocabulary size could be an index of other aspects of children's linguistic knowledge, such as the strength of representation of familiar words. When a child is confronted with a novel object in the presence of multiple familiar objects as competitors, the time spent rejecting familiar distracters could reduce the cognitive resources necessary to encode the novel word–object association (Horst, Scott, & Pollard, 2009). We speculate that variability in children's degree of confidence about the name of the familiar object in different situations could also influence their use of disambiguation and success in subsequent retention. Rather than viewing a disambiguation bias as a general heuristic that is either present or not for a particular child at a given age, we suggest that referent selection in ambiguous contexts is influenced by children's previous encounters with familiar and novel objects and their respective labels. In addition, vocabulary size could be an index of the degree to which irrelevant associations between words and objects have been suppressed (McMurray et al., 2008; Regier, 1996, 2003). Initially, the child might postulate that any word could refer to any object. Every time a word is heard, the connections that are not used are pruned or suppressed (e.g., connections between the auditory input and objects that are not present in the environment). Therefore, a bulk of word learning consists of learning the words and objects that *do not* go together, rather than the words that do go together.

Variability in children's use of disambiguation biases might also be related to quite different aspects of their early language experience. Byers-Heinlein and Werker (2009) found that on ambiguous trials, 18-month-olds regularly exposed to two or three languages were less likely than monolinguals to look at the unfamiliar object after hearing a novel name, a finding replicated with bilingual infants from 17 to 22 months of age (Houston Price et al., 2010). These results suggest that the presence of disambiguation strategies is fragile at earlier ages, and might be influenced by aspects of early experience such as the number of languages heard at home. And regardless of the number of languages heard, the sheer amount of speech directed to the child could also be influential. The amount of child-directed speech available to infants is linked to growth in both vocabulary and processing efficiency (Hurtado, Marchman, & Fernald, 2008). Moreover, Weisleder et al. (2012) have found that variability in the amount of child-directed speech, as well as the frequency with which parents label objects, are also related to children's use of disambiguation strategies. In ongoing research, we are investigating whether differences among children in the structure of their vocabularies might influence their ability to learn new words by exclusion, building on insights from recent studies with typically developing children and late talkers (Beckage, Smith, & Hills, 2011; Yurovsky, Bion, Smith, & Fernald, 2012).

4.4. Disambiguation biases emerge gradually and are not essential for early vocabulary development

The gradual view of word learning that we propose here is not new (Carey, 1978; Carey, 2010; Fernald et al., 2006; McMurray et al., 2009; Swingley, 2010), but it is in striking contrast with claims that children "know" the meaning of words after one exposure in ambiguous contexts. Studies focusing on fast-mapping frequently cite statistics about the rapid rate at which children learn new words – up to 9 new words a day – and propose that this rate can only be achieved if children rely on innate word learning constraints (Markman et al., 2003) or learn words in brief "eureka" moments (Medina, Snedeker, Trueswell, & Gleitman, 2011). However, a more complex picture emerges if one examines the sources on which these estimates are based. Carey's (1978) claim that 6-year-olds know 14,000 words has been frequently reiterated in the developmental literature. But this claim was based on Templin's (1957) estimates of comprehensive vocabulary that included both inflected and derived words (i.e., *walks*, *walked*, *walking*) collected from 60 children from high- and low-SES families. If these numbers are broken down separately for the two groups – one of the main goals of Templin's original study – the lower-SES children were estimated to understand 7000 fewer words on average than their more advantaged peers. When only root forms were counted as separate words, the mean receptive vocabulary of higher- and lower-SES children dropped to 11,000 and 6000 words respectively. Thus, assuming constant growth starting after the first birthday, lower-SES children in this study "learned" around three new word roots a day.

More recent estimates of vocabulary development in infancy confirm the substantial variability across children, and are far more conservative in their estimates of vocabulary size. For example, Mayor and Plunkett (2011) estimate that from 18 to 30 months of age, children in the 90th percentile on productive-vocabulary norms produce four new words a day, on average, while children in the lowest 10th percentile produce 1.5 new words a day. Other studies estimate that 1-year-olds learn one word every 2 days, while 2-year-olds learn about two new words a day (Fenson et al., 1994), and that high-SES 6-year-olds learn on average three words a day (Anglin, 1993, p. 151). Considering that infants in some families hear as many as 25,000 words of child-directed speech a day (Hart & Risley, 1995), and might produce from 0.5 up to 4 new words a day, they will have heard from 6000 to 50,000 word tokens for every new word learned. Recent studies provide rough estimates that by age 3 years, children have typically heard those words in their vocabulary that are highest in frequency around 3 million times, and the lowest frequency words over 1000 times (Frank, Tenenbaum, & Gibson, under review). In contrast to the 'fast mapping' observed in the context of laboratory experiments, word learning in children's daily lives actually appears to be rather slow. In fact, attempting to specify the number of words that children "learn in a day" is not the best way to characterize word learning, given that lexical representations are built up gradually from infancy on, through repeated experiences across a variety of situations (McMurray et al., in press).

In evaluating the potential contribution of disambiguation biases to word learning, it is also important to consider the actual ecology of children's early language development. We know from observational studies of child-directed speech that parents frequently name objects ostensively (e.g., Fernald & Morikawa, 1993), and also use devices such as repetition and presenting words in isolation that could further reduce ambiguity (Brent & Siskind, 2001). Given that many infants may hear thousands of words of child-directed speech a day, it is inevitable that they will frequently happen to be looking at some combination of familiar and novel objects in close proximity as they hear an unfamiliar word. But are these the situations in which early word learning actually occurs? An extreme view of the automaticity of disambiguation would posit that children associate the hundreds of novel words heard in daily interaction with whatever novel objects are most salient in their immediate surroundings, a response that would lead to countless mapping errors. This caricature is clearly not representative of children's actual experience, but neither are the experimental paradigms commonly used in developmental studies. Situations in which a child hears a completely novel word in the presence of a single novel object paired with one or two highly familiar objects, with no supporting pragmatic, semantic, or social cues available, may actually be relatively uncommon in children's everyday experience (see Yu & Smith, in press). And even if such situations do occur, this may not be the context in which very young children learn most readily. As they grow older and can make richer use of linguistic and pragmatic context in interpreting new words, learning by exclusion will become increasingly valuable as a strategy for figuring out what an unfamiliar word refers to. But the necessity of this strategy in very early word learning cannot simply be assumed.

We are not saying that children cannot learn new words in ambiguous contexts in which familiar and novel objects are present. Instead, we argue that most early word learning results from the accumulation of information across multiple situations, and not from a single perfect disambiguation opportunity. Words are learned gradually and do not switch suddenly from "not known" to "known." And lexical learning continues even after the child has met some arbitrary criterion used to measure word knowledge. Partial knowledge of word–object mappings is fundamental to incremental models of cross-situational learning (McMurray et al., in press; Siskind, 1996; Yurovsky, Fricker, Yu, & Smith, 2010), and some models propose a link between disambiguation biases and word learning without either conflating these skills or invoking word-learning constraints (Horst et al., 2006). On Disambiguation trials, children rely on their partial knowledge of words and objects in the context of the immediate situation, in order to find the most likely solution to a specific problem. In these models, the real-time dimension of referent selection does not imply learning, since word learning unfolds over a much longer time scale. But the repetition of these dynamics changes the representations of words, which may eventually cross a given conventional threshold used to attribute word knowledge to the child (Horst et al., 2006; McMurray et al., 2009). In addition to more experience with the pairings of words and objects, other aspects of children's experiences could foster learning. For example, Kucker and Samuelson (2011) demonstrated that 24-month-olds could retain words for novel objects with which they had some familiarity, if they had been able to play with the object prior to hearing it named on a Disambiguation trial. Other studies also show that children's prior experiences with objects influence their responses on Disambiguation trials (Horst, Samuelson, Kucker, & McMurray, 2011; Mather & Plunkett, 2012).

This view of disambiguation and word learning as related yet distinct accomplishments explains both the complex links and the lack of determinism that we observed in this research. Children might be better at figuring out the referent for novel words in ambiguous contexts because they have better lexical representations or because they "know" more words, and this early advantage might subsequently and recursively lead to even better encoding and additional learning across different situations and with repeated experience. This framework explains some of the cascading effects of early language experiences and skills, in another version of the "rich get richer." It also leaves open the possibility that our participants may have gained some partial knowledge of the novel words despite the lack of evidence for retention, and would have remembered the word–object mappings given additional learning opportunities.

Throughout this paper, we have characterized disambiguation as a gradually emerging skill which does not necessarily lead immediately to word learning, and which is not required for early vocabulary development. Instead of focusing on one-trial learning that depends heavily on disambiguation biases, word learning should be viewed as a gradual process, in which children rely on semantic cues (Goodman, McDonough, & Brown, 1998), cross-situational statistics (e.g., Frank, Goodman, & Tenenbaum, 2009), pragmatic and social clues (Baldwin, 1991, 1993), syntax (Brown, 1957), and – why not – disambiguation biases. Our view of word learning as a prolonged and gradual process is supported by experimental evidence that proficiency in word recognition takes years to unfold, despite the fact that children show evidence of making provisional mappings between novel words and novel referents at a very early age. Word learning is slow, and slow learning is an optimal solution that prevents infants from committing prematurely to mappings based on ambiguous encounters with novel words and unfamiliar objects. Moreover, the speed of learning varies across children. To ignore variation in the number of words children have already learned and in children's efficiency in recognizing and retaining familiar and novel words is to ignore influential factors in early lexical development.

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