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When *veps* cry: Two-year-olds efficiently learn novel words from linguistic contexts alone

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Abstract

We assessed 24-month-old infants' lexical processing efficiency for both novel and familiar words. Prior work documented that 19-month-olds successfully identify referents of familiar words (e.g., *The dog is so little*) as well as novel words whose meanings were informed only by the surrounding sentence (e.g., *The vep is crying*), but that the speed with which they identify the referents of novel words lagged far behind that for familiar words. Here we take a developmental approach, extending this work to 24-month-olds. By comparing the performance of 19- and 24-month-olds directly, we document that during this period of rapid vocabulary growth, infants make significant processing gains for both familiar and novel words. We also offer the first evidence to date that, at both 19- and 24-months, the number of verbs infants know predicts their ability to use known verbs to learn novel nouns. These results reveal that 24-month-olds can efficiently learn novel words just by listening to the conversations around them.

Keywords

language development; word learning; processing; verbs; selectional restrictions

1. Introduction

As infants approach their second birthdays, they not only learn new words at an increasing rate (Dale & Fenson, 1996), but also process the words they already know with increasing efficiency (Fernald, Perfors, & Marchman, 2006; Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Friedrich & Friederici, 2005). Between 18 and 24 months, infants' advances in processing efficiency are striking: the speed with which infants identify the referents of familiar words like *doggie* or *baby* increases by nearly 20% (Fernald et al., 1998). Here we consider how infants' gains in processing efficiency for *familiar* words relates to their efficiency in learning *novel* words whose meanings can be gleaned only from the surrounding sentence.

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Consider the sentence, *The vep is crying*. Although the word *vep* is unfamiliar, adults make inferences about its meaning from its linguistic context, inferring for example that *veps* are likely to be animate objects because *crying* requires that its subjects are animate (Chomsky, 1965; Dale & Fenson, 1996; Jackendoff, 1990; Pinker, 1994; Resnik, 1996). Notice, however, that using linguistic information like this to home in on the referent of a novel word requires efficiency in processing. After all, if the meaning of *crying* is retrieved too slowly, the opportunity to learn *vep* in this episode may go unexploited.

Infants as young as 19 months can make these kinds of inferences, recruiting the words they do know to learn novel ones in sentences such as *The vep is crying* (Brady & Goodman, 2014; Ferguson, Graf, & Waxman, 2014; Goodman, McDonough, & Brown, 2008). In Ferguson et al.'s (2014) design, infants at 15 and 19 months of age participated in twelve trials, six involving familiar words and six involving unfamiliar words. In familiar word trials, infants first viewed images of two familiar objects (e.g., a dog [animate] and a television [inanimate]) on a screen. Next, the objects disappeared, replaced by a colourful screensaver, and infants listened to a brief conversation about one of the familiar objects (e.g., *The dog is so wet*). Finally, at test the two familiar objects reappeared and infants were prompted to identify one of them (e.g., *Where is the dog?*). In unfamiliar trials, the structure of the task was identical, with one exception: the familiar objects were replaced with unfamiliar objects, objects for which infants had no label. Infants viewed the two unfamiliar objects (e.g., an armadillo [animate] and sculpture [inanimate]). These disappeared, replaced by a screensaver, and infants overheard a conversation including a novel noun (e.g., *vep*). What varied across infants was the linguistic context in which this novel noun was embedded. For infants in the Informative condition, the noun was embedded in a phrase that selected exclusively for an animate subject (e.g., *The vep is crying*). In the Neutral condition, it was embedded in a phrase that did not restrict the animacy of the subject (e.g., *The vep is right here*). At test, the two objects re-appeared and infants in both conditions were prompted to identify the referent of the unfamiliar noun (e.g., *Where is the vep?*). Notice that, in all trials and conditions, infants overheard the conversations in the absence of any visual referents. This design therefore assessed whether infants could infer the likely referent of a novel word from its linguistic context alone.

The study yielded three main findings. First, on familiar trials, both 15- and 19-months successfully identified the referents of the familiar nouns and did so with remarkable efficiency; they oriented toward the named object almost immediately after the two objects re-appeared at test. Second, on unfamiliar trials, 19-month-olds (but not 15-month-olds) in the Informative condition successfully recruited the meaning of the known verbs (e.g., *crying*) to identify the referents of novel nouns: 19-month-olds in the Informative condition looked more to the animal than did those in the Neutral condition. Third, 19-month-olds' success in this task, remarkable in itself, also imposed a significant processing burden: differences between performance in the Informative and Neutral conditions at test emerged almost 3 full seconds after the novel noun had been uttered.

Our goal in the current experiment was to place this in a developmental context by extending this design to examine 24-month-olds. Between 19 and 24 months, infants rapidly add new words to their lexicons (Frank, Braginsky, & Yurovsky, 2016) and become increasingly

efficient in processing familiar words (Fernald et al., 1998; 2006). They also make advances in a host of other more general cognitive capacities during this period, including their ability to maintain focused attention (Hood & Atkinson, 1993; Fisher & Kloos, 2006), make predictions (Mani & Huettig, 2012; Krogh-Jespersen, Liberman, & Woodward, 2015), and encode new information in memory (Rose, Feldman, Jankowski, & Van Rossem, 2012).

How might these advances between 19 and 24 months shape infants' ability to learn new words from linguistic contexts? To date, very few studies have traced infants' efficiency in identifying the referents of novel words across the first two years (cf., Bion, Borovsky, & Fernald, 2014; Yurovsky & Frank, 2015), and no study has yet examined infants' gains in processing novel words presented in linguistic contexts, such as *The vep is crying*.

To address this gap, we extended Ferguson et al.'s (2014) paradigm to examine 24-month-old infants' efficiency in using known verbs to identify the referents of novel nouns and to compare their performance with that of 19-month-olds. We also examined individual differences, asking whether characteristics of individual infants' lexicons and their age could predict the speed with which they identified the referents of novel nouns.

2. Methods

Our methods were identical to those reported in Ferguson et al. (2014).

2.1. Participants

Forty-eight English-acquiring infants were included in the final sample ($M=24.18$ months, $SD=1.08$; 25 females). All were recruited from Evanston, IL and had less than 25% exposure to a second language. Parental report indicated that infants produced 66.25 words on the MCDI ($SD=19.67$), including 37.71 ($SD=10.26$) nouns and 7.00 ($SD=4.41$) verbs (MacArthur Short Form Vocabulary Checklist: Level II (Form A); Fenson et al., 1993). We also queried parents about their infants' comprehension of the familiar verbs in this design (listed below): Each participant comprehended on average 5.96 of the six (99.33%) verbs. Eight infants were excluded and replaced due to fussiness (5), language delay (2), or parental interference (1). Another 20 were excluded as a result of technical difficulties with the eye-tracker (failure to calibrate, 10; severe trackloss, 10). The sample size was established *a priori* using a power analysis based on the effect size for unfamiliar trials observed by Ferguson et al. (2014; $d=.78$). With 24 subjects per condition, we obtained 75% power at $\alpha = 0.05$.

2.2. Apparatus

We used a Tobii T60XL corneal-reflection eye-tracker for stimulus presentation and data collection. Participants sat approximately 60cm from the screen, either in a carseat or on their caregiver's lap

2.3. Materials (Figure 1)

Infants participated in 12 trials: 6 familiar trials followed by 6 unfamiliar trials. Each trial included 3 phases: Preview (6s), Dialogue (10s), and Test (6s). Familiar trials were

identical for all participants. Unfamiliar trials varied as a function of condition (Informative or Neutral).

2.3.1. Visual stimuli.—During the Preview and Test phases of each trial, two pictures of objects were presented side-by-side on the screen. During the intervening Dialogue phase, these pictures were replaced by an abstract illustration that covered the screen.

2.3.2. Auditory stimuli.—Two native speakers of American English – one female and one male, so that they could be readily distinguished by participants – produced the conversations for the Dialogue phase.

2.3.3. Linguistic stimuli.—The familiar nouns and verbs used in this design were selected by Ferguson et al. (2014) because they were likely to be known by the youngest participants in their study, 15-month-olds. In the familiar trials, participants heard *bird*, *bottle*, *cow*, *dog*, *horse*, and *spoon*. In the unfamiliar trials, participants in the Informative condition heard nonce nouns as the subject of the verbs *cry*, *dance*, *drink*, *eat*, *look*, and *sleep*; participants in the Neutral condition heard the same nonce words as the subject of uninformative phrases. The referent objects in the unfamiliar trials included exotic animals (armadillo, lizard, flamingo, hedgehog, lemur, and rhinoceros) and abstract sculptures. (Infants knew an average of 1.8 of the six (30%) animals' names; performance in our task did not differ as a function of infants' comprehension of an animal name.)

2.4. Procedure (Figure 1)

Each experimental session began with a five-point eye-tracking calibration routine.

2.4.1. Familiar trials.—To begin, in the Preview phase, two familiar objects (one animal, one artefact; e.g., a dog and a bottle) – were both presented side-by-side on the screen for 6 seconds. After 1 second, participants heard, “Oh wow! Look here!” to orient the child towards the screen. Next, in the Dialogue phase, the objects disappeared and were replaced by an abstract illustration while participants “overheard” a short conversation that referred to one of the previewed objects (e.g., “The dog is right here!”; see Appendix A in Ferguson et al., 2014 for transcripts). Finally, in the Test phase, participants' eyes were centered on the screen by briefly displaying a red dot, after which the objects simultaneously re-appeared and participants were prompted to look to the object referred to during the dialogue (e.g., “Where is the dog?”). This target word began 1s after the objects re-appeared, leaving participants a total of 5 seconds to observe the objects post-noun onset.

2.4.2. Unfamiliar trials.—During the Preview phase, participants were shown an unfamiliar animal and artefact on the screen (e.g., an armadillo and an abstract sculpture) and heard, “Look here!” to orient them. Next, during the Dialogue phase, participants saw an abstract illustration while they overheard a short conversation that referred to one of these objects using a novel noun. The content of this conversation varied by condition: In the Informative condition, the noun appeared as the subject of a verb that selected for an animate subject (e.g., “The *vep* is crying”). In the Neutral condition, this noun appeared in a sentence that did not select for either referent (e.g., “The *vep* is right here”). Finally, in the

Test phase, the objects re-appeared on screen and participants were prompted to identify the referent of the novel word (e.g., “Where is the *vep*?”).

Notice that in all trials and conditions, when infants overheard the novel words – during the dialogue phase – they had no access to any potential visual referents. This feature of our design permitted us to ask whether infants could use the linguistic context itself to infer the likely referent of a novel word. Although it is possible that infants remembered the two objects they had seen in the preview phase, before the conversation began (Ganea, Fitch, Harris, & Kaldy, 2016; Southgate, Chevallier, & Csibra, 2010), this memory alone is not sufficient to identify which was the likely referent of the novel word presented in the dialogue phase. In our experimental design, infants could identify which object was the likely referent of the novel word *only* if (a) the linguistic context in which that word occurred in the dialogue phase was informative enough to specify one object over the other, and (b) the infant could make use of that linguistic context.

3. Analysis

3.1. Data preparation

We analyzed participants’ looking during a time window in the Test phase from 500ms before the onset of the target noun to the end of the trial (5.5s). We chose this window because we expected that on familiar trials, infants would anticipate the referent using the label heard during the Dialogue phase (as in Ferguson et al., 2014). For each trial, an area of interest (AOI) of the same size was defined around each of the test objects. Gazes outside these AOIs were excluded from analysis, as were trials in which infants looked to the screen more than two standard deviations below the mean for that trial type. After exclusions, each infant contributed an average of 5.62 ($SD=.76$) out of 6 familiar trials and 5.67 ($SD=.66$) out of 6 unfamiliar trials.

The dependent variable in all primary analyses was the proportion of infants’ looking time devoted to the animal divided by total looking to the animal and artefact combined. In the text, we report raw summary statistics, however, in the analyses, we used arc-sin root transformed proportions to correct for the assumption-violating link between means and variances that otherwise exists in proportional data. All data preparation and analyses were performed with the *eyetrackingR* package (Dink & Ferguson, 2015).

3.2. Aggregate window analyses

Our first analysis was designed to compare infants’ overall attention to the animal in the two conditions (as in, e.g., Arunachalam & Waxman, 2014; Bergelson & Swingley, 2012; Yuan & Fisher, 2009). We calculated a single mean proportion of looking to the animal for each trial. We then submitted this proportion to a linear mixed-effects model with condition (e.g., Informative versus Neutral) as a fixed-effect and subjects and items as random-effects (intercepts only). These models were fit in R (R Development Core Team, 2012) using the *lme4* package (Baayen, Davidson, & Bates, 2008). *P*-values for each factor of interest (e.g., Condition) were obtained by comparing models’ log-likelihoods. These model comparisons yield Chi-square (χ^2) values which, when combined with their respective degrees of

freedom (reflecting the number of parameters by which these models differ), yield p -values (Barr, Levy, Scheepers, & Tily, 2013).

3.3. Time-course analyses

Our second analysis focused on the time-course underlying infants' attention during the test phase, and thus served as a window into processing efficiency. Ferguson et al. (2014) identified processing efficiency by comparing infants' attention between conditions in a series of 250ms bins. Here we opted instead for a more precise analytic approach involving bootstrapped smoothing splines. Although similar in spirit to the time bin approach, this approach offers two main benefits. First, it takes into account the inherent dependence of time-course data by considering the values of neighbouring time points, thus smoothing over short, isolated spikes and valleys in the data (akin to a moving average). This allows for more robust estimates of divergences in data, smoothing over short spikes and valleys that create isolated (and likely spurious) divergences or, conversely, disrupt an otherwise sustained divergence. Second, this smoothing property can be applied without requiring aggregating the data into arbitrary-sized time bins. Taken together, then, this approach offers more stable and precise estimates of the time point at which two groups diverge.

To implement this approach, we first calculated, for each infant, the mean proportion of looking to the animal at each point during the test phase (collapsed across trials within condition). Next, these data were resampled (with replacement) in a bootstrapping procedure. For each of 5000 bootstrapped samples, we fit a cubic smoothing spline (Hastie & Tibshirani, 1990) using R's *smooth.spline* function (R Development Core Team, 2012) that modelled infants' attention over the test phase. Spline models require a smoothing parameter; here we allowed this parameter to be chosen automatically through generalized cross-validation (Wahba, 1985). This bootstrapping procedure yielded an estimated distribution of means for each condition at each time point in the test phase. Next, by calculating differences *between* these distributions, we obtained an approximate distribution of the difference between conditions. Finally, we examined at each 10ms interval whether quantile-based 95% confidence intervals for the estimated difference between conditions included zero – a non-parametric process that can indicate the point at which two conditions' attention diverged (corresponding to an α of .05).

3.4. Developmental comparisons

To compare 24- and 19-month-olds' processing efficiency, we report the analyses of the 24-month-old data as well as relevant reanalyses of the original 19-month-olds data (from Ferguson et al., 2014).

3.5. Predictions

3.5.1. Aggregate window analyses.—We expected, based on prior work, that infants would reveal a general preference for looking at animals over artefacts (Childers & Echols, 2004; Ferguson et al., 2014; LoBue, Bloom Pickard, Sherman, Axford, & DeLoache, 2013), but that this preference would be modulated as function of the familiar label they heard (in familiar trials) or the linguistic context in which the novel word was embedded (in unfamiliar trials). We predicted that on familiar trials, infants prompted with the familiar

name of an artefact would shift their visual attention from the (preferred) animal to the artefact, and that on unfamiliar trials, infants in the Informative condition would maintain attention on the animal, looking more toward the animal than infants in the Neutral condition.

3.5.2. Time-course analyses.—Recall that to succeed on unfamiliar trials, infants must process not only the novel word, but also the familiar words that surrounded them in the dialogue phase. Based on evidence that infants' processing efficiency for familiar words increases between 19- and 24-months (e.g., Fernald et al., 1998), we predicted that on familiar trials, 24-month-olds would orient toward the referents of familiar words more quickly than 19-month-olds. At issue, however, is how this newly-earned efficiency in processing familiar words might influence the time-course underlying 24-month-olds' identification of the referents of novel words, especially those whose meaning is informed by the familiar words that surrounded them.

4. Results

4.1 Familiar Trials

See Figure 2A. As predicted, 24-month-olds' overall preference for looking at the animal ($M=.63$, $SD=.08$, $t(47)=10.10$, $p<.001$) was attenuated by the label they heard: Infants looked reliably longer to the animal when it was named ($M=.77$, $SD=.12$) than when the artefact was named ($M=.37$, $SD=.15$), $\chi(1)=10.78$, $p=.001$, Cohen's $d=2.94$. This outcome provides assurances that this paradigm is sufficiently sensitive to reflect 24-month-olds' word knowledge (as it was for younger infants in Ferguson et al., 2014).

4.1.1. Comparing 24- and 19-month-olds' processing efficiency.—Figures 2A and 2B reveal that 24-month-olds exhibit a 230ms gain in processing efficiency in identifying the referents of familiar words for objects to which they had been only briefly familiarized. At 24 months, attention to the animal and artefact targets began to diverge at 320ms pre-noun onset; at 19 months, this divergence appeared later, at 90ms pre-noun onset.

4.2 Unfamiliar Trials (Figure 2C)

As in the familiar trials, 24-month-olds exhibited an overall preference for the animal ($M=.58$, $SD=.14$, $t(47)=4.14$, $p<.001$); as predicted, this preference varied reliably as a function of the linguistic context in which the word is presented: Infants in the Informative condition looked reliably longer to the animal ($M=.63$, $SD=.14$) than did those in the Neutral condition ($M=.55$, $SD=.13$), $\chi(1)=4.83$, $p=.028$, $d=.67$, replicating Ferguson et al.'s (2014) results at 19 months with a new group of infants at 24 months.

4.2.1. Comparing 24- and 19-month-olds' efficiency.—As can be seen in Figures 2C and 2D, 24-month-olds exhibit a dramatic 2170ms gain in the speed with which they identify referents of novel words. At 24 months, infants' looking in the Informative and Neutral conditions diverged at 480ms post-noun onset. At 19 months, infants' looking in the Informative and Neutral conditions did not diverge until 2650ms post-noun onset.

4.3 Individual differences

We used a series of models to assess whether and how infants' performance at both 19- and 24-months was related to individual characteristics of each infant, including (a) infant's age (continuous), and (b) the number of nouns they were reported to know on the MCDI, or (c) the number of verbs they were reported to know on the MCDI. Given that identifying the referents of known words and learning words from linguistic contexts both rely on infants' current knowledge states (e.g., which words they know and how these words relate to one another), we expected that infants' vocabulary and their performance on our task might be related.

4.3.1 Familiar Trials.—On familiar trials, because Animate and Inanimate target conditions were manipulated within-subjects, we calculated for each infant a difference score (preference for the animate object in Animate trials minus preference for the animate object in Inanimate trials). We then fit a linear model predicting this difference score using age, number of known verbs, and number of known nouns as predictors. (Before fitting the model to the data, all predictors were centered so that the intercept represented the average difference score across subjects, and each predictor's effect represented a main effect holding other predictors at their average.) We found no significant effects of age, number of known verbs, number of known nouns, nor any significant interactions among them. Unsurprisingly, however, the intercept in this model was significant ($\beta=.43$, $SE=.036$, $p<.001$), confirming that infants looked more to the animal when it was named than when the inanimate was named, when controlling for the predictors in this model.

4.3.2 Unfamiliar Trials.—On unfamiliar trials, where condition was manipulated between-subjects, we examined individual differences in each condition separately to assess whether infants' performance on our task was related to their age, number of known verbs, and number of known nouns. In the Informative condition, infants' performance was related to the number of verbs they reportedly knew. As can be seen in Figure 3, at both 19- and 24-months, infants who knew more verbs looked more to the animate object ($\beta=.052$, $SE=.018$, $p=.0084$). There were no other significant effects or interactions, suggesting that infants' performance in this task related more closely to their verb lexicon than their age or noun lexicon. Thus, although most infants understood the *particular* verbs used in the dialogue phase, those with more verbs in their receptive vocabulary more successfully used the verbs they knew to identify the referents of the novel nouns.

We expected no such correlation between known verbs and performance in the Neutral condition because, in this condition, the linguistic information could not lead infants to favor one test object over the other. Indeed, there was no relation between number of known verbs and infants' performance in the Neutral condition, ($\beta=-.033$, $SE=.023$, $p=.15$). This correlation, present in the Informative and absent in the Neutral condition, is important because it indicates that the relation between verb comprehension and infants' speed in the Informative condition reflects their use of linguistic information provided in the dialogue phase.

5. Discussion

These findings reveal infants' increasing efficiency, between 19 and 24 months, in identifying the referents of both familiar and novel words. Their modest increase in efficiency with familiar words during this active developmental period converges well with prior evidence (Fernald et al., 1998; 2006) and extends it to a new paradigm. More striking was the magnitude of infants' increased efficiency for novel words during this same developmental period: at 19 months, infants took roughly 2 seconds (2175 ms) to identify the referent of a novel word, while at 24 months, infants took less than a quarter of second (230 ms) to do so.

Why did we observe such a dramatic increase in efficiency from 19 to 24 months in the unfamiliar trials? Several factors likely contribute. First, infants' advances in processing familiar words may be linked to their efficiency in processing novel words. As infants more rapidly process the words they do know (as measured in familiar trials), they can more efficiently use these words to home in on the meanings the words they do not yet know (measured in unfamiliar trials). Indeed, our analysis of individual differences revealed exactly this coupling between infants' existing vocabulary and their ability to use known words to learn novel ones: infants in the Informative condition who knew more verbs were better able to identify the referent of the novel words. Moreover, because our design requires that infants process entire sentences and not target words embedded in a single carrier phrases (e.g., Where's the *vep*?) as in most studies (e.g., Fernald et al., 1998; 2006), it is possible that 24-month-olds' relatively modest advances in processing *individual* familiar words snowballed word-by-word, leading to larger gains in processing the target unfamiliar word in unfamiliar trials.

More general cognitive advances between 19 and 24 months may have also contributed to gains in infants' processing efficiency. For example, 24-month-olds may have been better than 19-month-olds at encoding the unfamiliar object images when they first saw them during familiarization (Rose et al., 2012), recalling their location on the screen, maintaining attention throughout the task (Hood & Atkinson, 1993; Fisher & Kloos, 2006), or predicting which of the two objects presented in the familiarization phase would likely be singled out in the test phase based on what they heard during the dialogue phase (Mani & Huettig, 2012; Krogh-Jespersen, Liberman, & Woodward, 2015). Notice, however, that general cognitive advances like these are equally relevant to both familiar and unfamiliar trials. They cannot, on their own, account for the finding that the rapidity with which infants identified the referents of novel nouns so far outstripped their gains in identifying the referents of familiar ones.

These findings offer a new perspective onto pressing questions concerning the significant and stable disparities in vocabulary size that appear so early in development (Dale & Fenson, 1996; Fenson et al., 1994; Frank et al., 2016). Until recently, investigations into the sources of these disparities appealed primarily to the quality and quantity of the language input directed to infants and young children (Fernald, Marchman, & Weisleder, 2012; Hart & Risley, 1995; Hoff, 2006; Hurtado, Marchman, & Fernald, 2008; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Weisleder & Fernald, 2013). More recently, researchers

have moved the discussion beyond the input alone, suggesting that this link between input and vocabulary might be mediated by differences in processing speed; that is, that more language experience in the first years of life strengthens processing skills which, in turn, promote later word learning (Fernald & Marchman, 2011; Weisleder & Fernald, 2013). Unfortunately, questions about *how* processing efficiency mediates the acquisition of new vocabulary have remained unaddressed. The methods presented here takes two important steps in answering them, first, by documenting infants' performance in a task that *requires* them to process familiar words to learn new ones, and, second, by examining their efficiency in doing so at two key junctions during a very active stage of vocabulary development.

This work also opens the door for new investigations aimed at specifying the conditions that support infants' burgeoning ability to use the words they do know to learn new ones. For example, it will be important to identify more precisely how 24-month-old infants' dramatic increase in efficiency interacts with their ability to acquire new words from the input. It will also be important to better characterize the constellation of capacities that support infants' remarkable ability to learn novel words from the sentences in which they are embedded, and the mechanisms that permit them to do so more efficiently over time (Swingley, 2010). Another avenue will be to pursue further analyses of individual differences. For example, individuals with slower syntactic processing (e.g., of word order; Candan et al., 2012) might struggle to take advantage of syntactic cues to words' meanings (e.g., Arunachalam & Waxman, 2010; Booth & Waxman, 2003; Fisher, Gertner, Scott, & Yuan, 2010; Gleitman, 1990; Naigles & Kako, 1993; Yuan & Fisher, 2009). By weaving together observational and experimental work in future studies, we can better understand how developmental and individual differences in processing efficiency lay the foundations for successful word learning.

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References

- Arunachalam S, & Waxman SR (2010). Meaning from syntax: Evidence from 2-year-olds. *Cognition*, 114, 442–446. doi:10.1016/j.cognition.2009.10.015 [PubMed: 19945696]
- Arunachalam S, & Waxman SR (2014). Let's see a boy and a balloon: Argument labels and syntactic frame in verb learning. *Language Learning and Development*, 1–28.
- Baayen RH, Davidson DJ, & Bates DM (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59(4), 390–412. doi:10.1016/j.jml.2007.12.005
- Barr DJ, Levy R, Scheepers C, & Tily JJ (2013). Random effects structure in mixed-effects models: Keep it maximal. *Journal of Memory and Language*, 68(3), 1–38. doi:10.1016/j.jml.2012.11.001

- Bergelson E, & Swingley D (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the United States of America*, 109(9), 3253–3258. doi:10.1073/pnas.1113380109 [PubMed: 22331874]
- Bion RAH, Borovsky A, & Fernald A (2013). Fast mapping, slow learning: Disambiguation of novel word-object mappings in relation to vocabulary learning at 18, 24, and 30 months. *Cognition*, 126(1), 39–53. 10.1016/j.cognition.2012.08.008 [PubMed: 23063233]
- Booth A, & Waxman SR (2003). Mapping words to the world in infancy: Infants' expectations for count nouns and adjectives. *Journal of Cognition and Development*, 4(3), 357–381.
- Brady KW, & Goodman JC (2014). The Type, but Not the Amount, of Information Available Influences Toddlers' Fast Mapping and Retention of New Words. *American Journal of Speech-Language Pathology*, 23(2), 120. doi:10.1044/2013_AJSLP-13-0013 [PubMed: 24686405]
- Candan A, Küntay AC, Yeh Y-C, Cheung H, Wagner L, & Naigles LR (2012). Language and age effects in children's processing of word order. *Cognitive Development*, 27(3), 205–221. doi: 10.1016/j.cogdev.2011.12.001
- Carey S (2009). *The Origin of Concepts*. Oxford University Press, USA.
- Childers JB, & Echols CH (2004). 2½-Year-Old Children Use Animacy and Syntax to Learn a New Noun. *Infancy*, 5(1), 109–125. doi:10.1207/s15327078in0501_5
- Chomsky N (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.
- Dale PS, & Fenson L (1996). Lexical development norms for young children. *Behavioral Research Methods, Instruments, & Computers*, 28(1), 125–127.
- Dink JW, & Ferguson B (2015). *eyetrackingR: An R Package for Eye-tracking Data Analysis*. Retrieved from <http://www.eyetracking-r.com>
- Fenson L, Dale PS, Reznick JS, Bates E, Thal DJ, Pethick SJ, et al. (1994). Variability in Early Communicative Development. *Monographs of the Society for Research in Child Development*, 59(5).
- Ferguson B, Graf E, & Waxman SR (2014). Infants use known verbs to learn novel nouns: Evidence from 15- and 19-month-olds. *Cognition*, 131(1), 139–146. doi:10.1016/j.cognition.2013.12.014 [PubMed: 24463934]
- Fernald A, & Marchman VA (2011). Individual Differences in Lexical Processing at 18 Months Predict Vocabulary Growth in Typically Developing and Late-Talking Toddlers. *Child Development*, 83(1), 203–222. doi:10.1111/j.1467-8624.2011.01692.x [PubMed: 22172209]
- Fernald A, Marchman VA, & Weisleder A (2012). SES differences in language processing skill and vocabulary are evident at 18 months. *Developmental Science*, 16(2), 234–248. doi:10.1111/desc.12019 [PubMed: 23432833]
- Fernald A, Perfors A, & Marchman VA (2006). Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. *Developmental Psychology*, 42(1), 98–116. doi:10.1037/0012-1649.42.1.98 [PubMed: 16420121]
- Fernald A, Pinto JP, Swingley D, Weinberg A, & McRoberts GW (1998). Rapid gains in speed of verbal processing by infants in the 2nd year. *Psychological Science*, 9(3), 228–231.
- Fisher C, Gertner Y, Scott RM, & Yuan S (2010). Syntactic bootstrapping. *Wiley Interdisciplinary Reviews: Cognitive Science*, 1, 143–149. [PubMed: 26271229]
- Fisher A, & Kloos H (2016). Development of selective sustained attention: The role of executive functions In Griffin JA, McCardle P, & Freund LS (Eds.), *Executive Function in Preschool-Age Children Integrating Measurement, Neurodevelopment, and Translational Research* (pp. 215–237). 10.1037/14797-010
- Frank MC, Braginsky M, & Yurovsky D (2016). Wordbank: An open repository for developmental vocabulary data. *Journal of Child Language*, 1–18. 10.1017/s0305000916000209
- Friedrich M, & Friederici AD (2005). Semantic sentence processing reflected in the event-related potentials of one- and two-year-old children. *NeuroReport*, 16(16), 1801–1804. [PubMed: 16237330]
- Ganea PA, Fitch A, Harris PL, & Kaldy Z (2016). Sixteen-month-olds can use language to update their expectations about the visual world. *Journal of Experimental Child Psychology*, 1–12. 10.1016/j.jecp.2015.12.005
- Gleitman LR (1990). The Structural Sources of Verb Meanings. *Language Acquisition*, 1(1), 3–55.

- Goodman JC, McDonough L, & Brown NB (2008). The Role of Semantic Context and Memory in the Acquisition of Novel Nouns. *Child Development*, 69(5), 1330–1344. doi:10.1111/j.1467-8624.1998.tb06215.x
- Hart B, & Risley TR (1995). Meaningful differences in the everyday experience of young american children. Baltimore, MD: Paul Brookes.
- Hastie TJ, & Tibshirani RJ (1990). *Generalized Additive Models*. London: Chapman & Hall.
- Hoff E (2006). How social contexts support and shape language development. *Developmental Review*, 26(1), 55–88. doi:10.1016/j.dr.2005.11.002
- Hood BM, & Atkinson J (1993). Disengaging visual attention in the infant and adult. *Infant Behavior and Development*, 16(4), 405–422. 10.1016/0163-6383(93)80001-o
- Hurtado N, Marchman VA, & Fernald A (2008). Does input influence uptake? Links between maternal talk, processing speed and vocabulary size in Spanish-learning children. *Developmental Science*, 11(6), F31–F39. doi:10.1111/j.1467-7687.2008.00768.x [PubMed: 19046145]
- Huttenlocher J, Waterfall H, Vasilyeva M, Vevea J, & Hedges LV (2010). Sources of variability in children’s language growth. *Infant Pathways to Language: Methods, Models and Research Directions*, 61(4), 343–365. doi:10.1016/j.cogpsych.2010.08.002
- Jackendoff R (1990). *Semantic structures*. Cambridge, MA: MIT Press.
- Krogh-Jespersen S, Liberman Z, & Woodward AL (2015). Think fast! The relationship between goal prediction speed and social competence in infants. *Developmental Science*, 18(5), 815–823. 10.1111/desc.12249 [PubMed: 25659980]
- LoBue V, Bloom Pickard M, Sherman K, Axford C, & DeLoache JS (2013). Young children’s interest in live animals. *British Journal of Developmental Psychology*, 31(1), 57–69. doi:10.1111/j.2044-835X.2012.02078.x [PubMed: 23331106]
- Mani N, & Huettig F (2012). Prediction during language processing is a piece of cake—But only for skilled producers. *Journal of Experimental Psychology: Human Perception and Performance*, 38(4), 843–847. 10.1037/a0029284 [PubMed: 22774799]
- Naigles LR, & Kako ET (1993). First Contact in Verb Acquisition: Defining a Role for Syntax. *Child Development*, 64(6), 1665–1687. doi:10.1111/j.1467-8624.1993.tb04206.x [PubMed: 8112112]
- Pinker S (1994). How could a child use verb syntax to learn verb semantics? *Lingua*, 92(1), 377–410. doi:10.1016/0024-3841(94)90347-6
- R Development Core Team. (2012). R: A language and environment for statistical computing. Vienna, AU: R Foundation for Statistical Computing Retrieved from <http://www.r-project.org>
- Resnik P (1996). Selectional constraints: An information-theoretic model and its computational realization. *Cognition*, 61(1), 127–159. [PubMed: 8990970]
- Rose SA, Feldman JF, Jankowski JJ, & Van Rossem R (2012). Information processing from infancy to 11 years: Continuities and prediction of IQ. *Intelligence*, 40(5), 445–457. 10.1016/j.intell.2012.05.007 [PubMed: 23162179]
- Southgate V, Chevallier C, & Csibra G (2010). Seventeen-month-olds appeal to false beliefs to interpret others’ referential communication. *Developmental Science*, 13(6), 907–912. 10.1111/j.1467-7687.2009.00946.x [PubMed: 20977561]
- Swingle D (2010). Fast Mapping and Slow Mapping in Children’s Word Learning. *Language Learning and Development*, 6(3), 179–183. 10.1080/15475441.2010.484412
- Swingle D, Pinto JP, & Fernald A (1999). Continuous processing in word recognition at 24 months. *Cognition*, 71(2), 73–108. 10.1016/s0010-0277(99)00021-9 [PubMed: 10444905]
- Wahba G (1985). A comparison of GCV and GML for choosing the smoothing parameter in the generalized spline smoothing problem. *The Annals of Statistics*, 1378–1402.
- Waxman SR, & Markow DB (1998). Object Properties and Object Kind: Twenty-One-Month-Old Infants’ Extension of Novel Adjectives. *Child Development*, 69(5), 1313–1329. doi:10.1111/j.1467-8624.1998.tb06214.x [PubMed: 9839418]
- Weisleder A, & Fernald A (2013). Talking to Children Matters: Early Language Experience Strengthens Processing and Builds Vocabulary. *Psychological Science*. doi:10.1177/0956797613488145

- Yuan S, & Fisher C (2009). Really? He blicked the cat?": Two-year-olds learn distributional facts about verbs in the absence of a referential context. *Psychological Science*, 20(5), 619–626. doi: 10.1111/j.1467-9280.2009.02341.x [PubMed: 19476591]
- Yurovsky D, & Frank MC (2015). Beyond naïve cue combination: salience and social cues in early word learning. *Developmental Science* 10.1111/desc.12349

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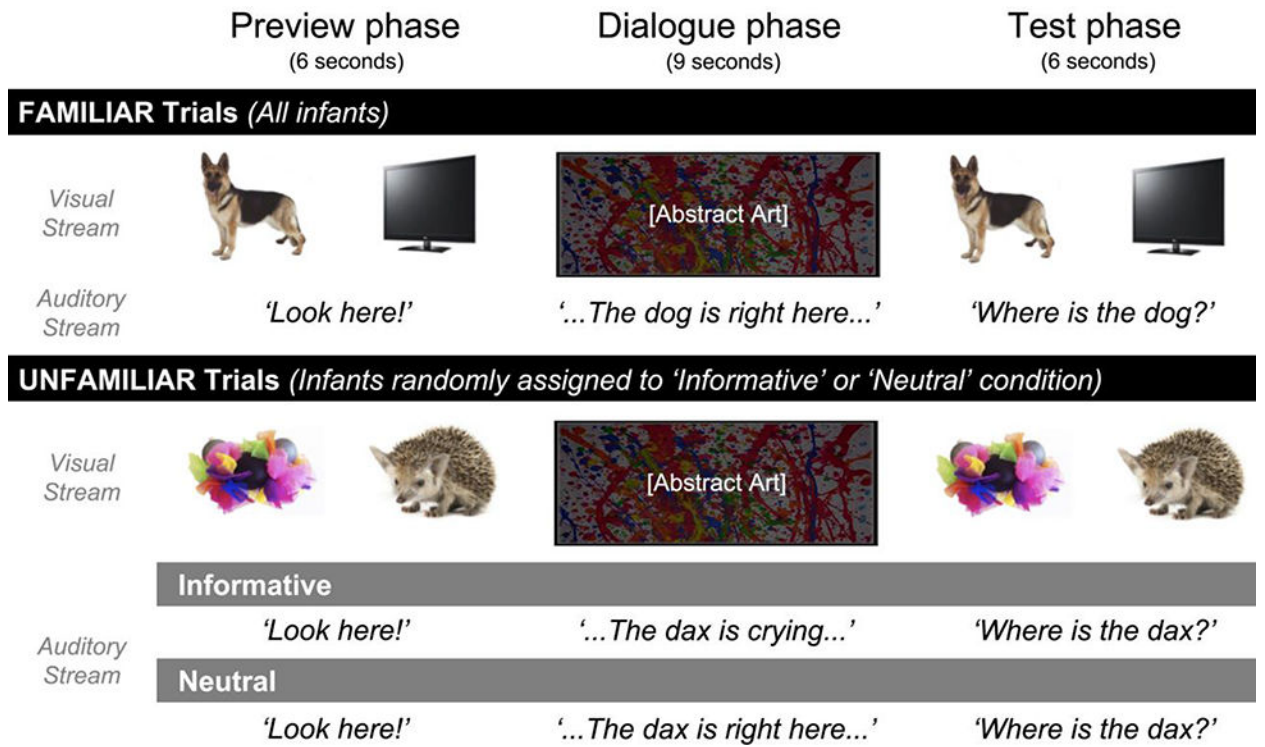


Figure 1. An example of the experimental design (Ferguson et al., 2014), reprinted with permission from Elsevier. Each experimental session lasted approximately 4.5 minutes in total.

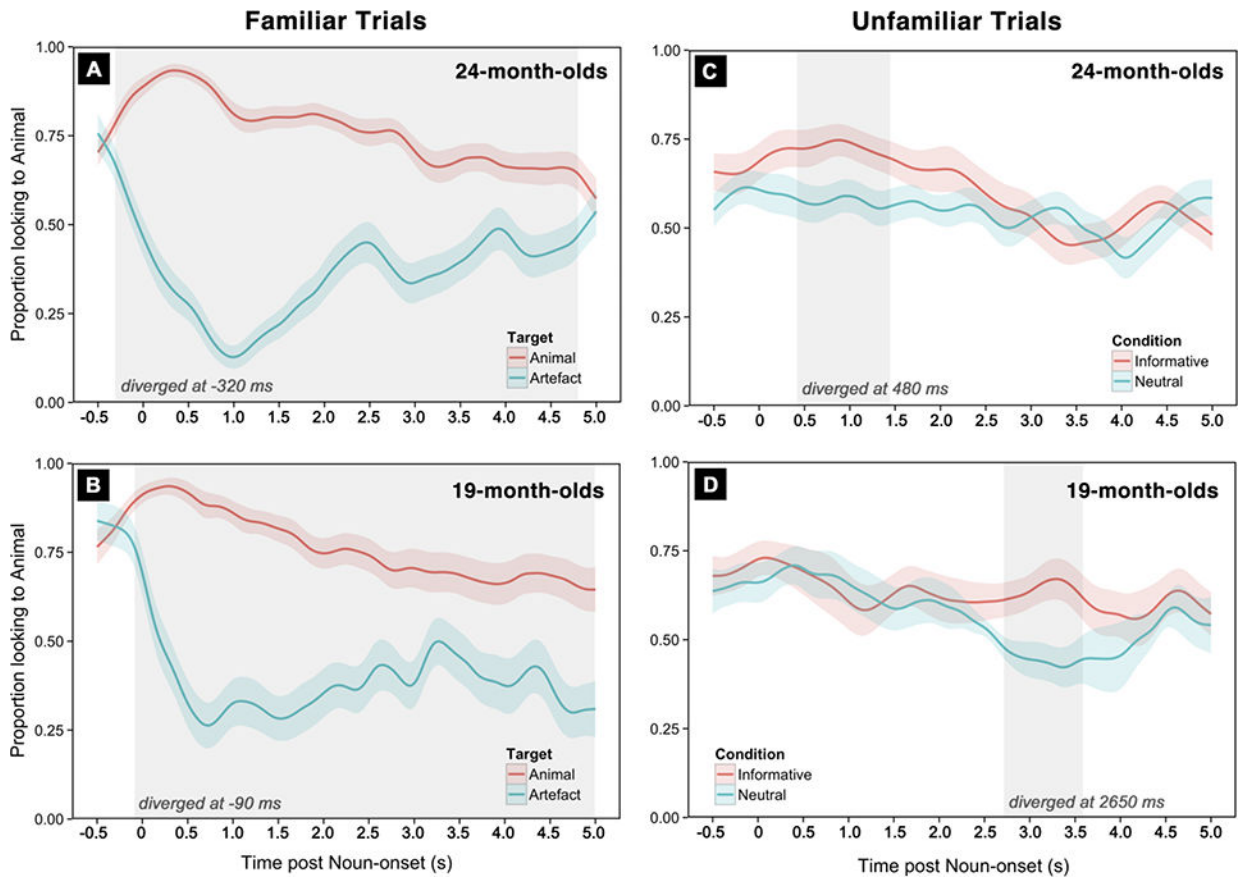


Figure 2.

Infants' processing efficiency at 24 and 19 months when identifying referents of familiar words (panels A and B) and unfamiliar words (panels C and D). Data from infants at 19 months adapted from Ferguson et al. (2014). Coloured shading represents ± 1 SEM. Grey shaded areas indicate the period during which performance in the two conditions diverged.

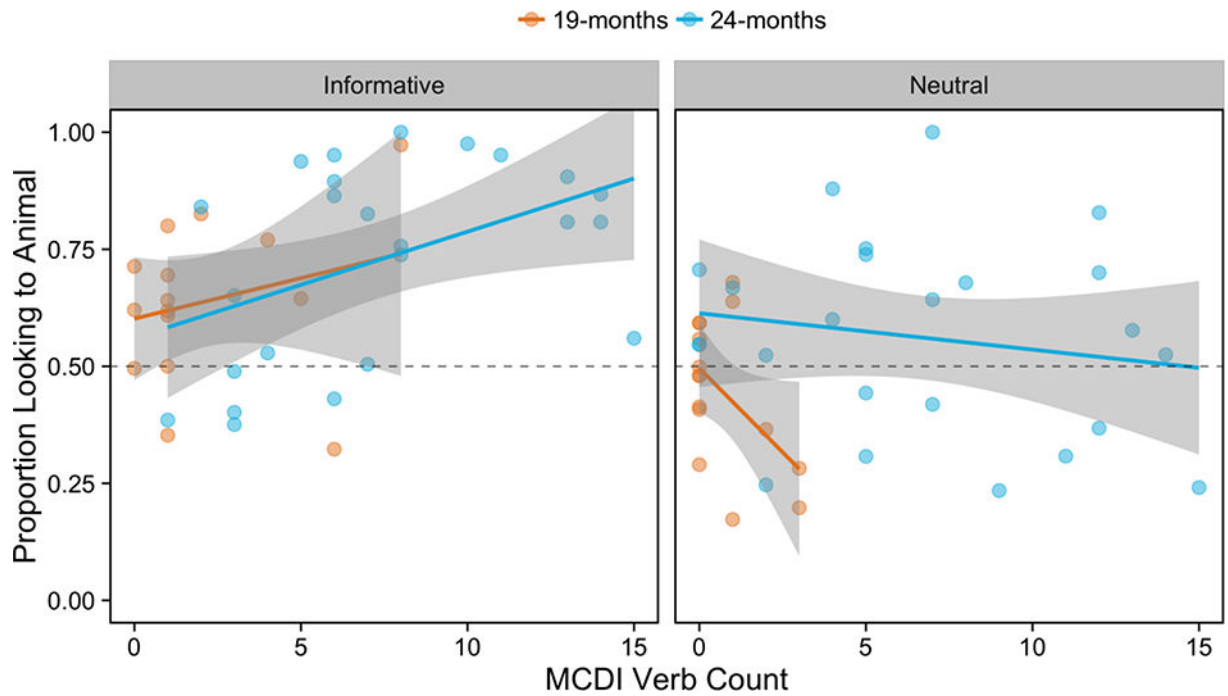


Figure 3.

Proportion of looking to the animal in unfamiliar trials by Condition. Across both 19- and 24-month-olds, infants who were reported to know more verbs on the MCDI looked more to the animal in the Informative condition. No such relation was found in the Neutral condition.