Frequent vs. infrequent words shape toddlers' real-time sentence processing

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Acknowledgments: We would like to thank the participating families and members of the Princeton Baby Lab, especially Kennedy Casey, Ellie Breitfeld, Katie Vasquez, Rinat Tal, and Ariella Cohen. This work was funded by grants from NICHD (F32 HD093139, R01HD095912).

Stimuli, data, and supplemental materials are available at

https://osf.io/frvx7/?view_only=c206dd17b5654f80b94710439d35fb00.

Keywords: language development; language processing; statistical learning; word representations; frequency effects

Abstract

We examined how noun frequency and the typicality of surrounding linguistic context contribute to children's real-time language comprehension. Monolingual English-learning toddlers viewed pairs of pictures while hearing sentences with typical or atypical sentence frames (*Look at the...* vs. *Examine the...*), followed by nouns that were higher- or lower-frequency labels for a referent (*horse* vs. *pony*). Toddlers showed equally successful comprehension of nouns in typical and atypical sentence frames. However, they were less accurate in recognizing lower-frequency nouns, particularly among toddlers with smaller vocabularies. We conclude that toddlers can recognize nouns in diverse sentence contexts, but their representations develop gradually.

Keywords: language development; language processing; statistical learning; word representations; frequency effects

Introduction

Theories of statistical learning posit that infants track basic information about the words they hear, such as their frequency and their co-occurrence with nearby words, which provide the foundation for more complex knowledge (e.g., Lany, 2014; Saffran, 2003; Thiessen & Erickson, 2013). If this is true, then children must be able to navigate the complexities of incoming speech in real time. Speakers have many options available to them when talking to children, and children therefore encounter words more or less frequently in a variety of sentence contexts. For example, a parent trying to direct a child's attention might say *Look at the horse*, yet theoretically they could also say *Examine the pony*; *Behold the equine*; or *This thing is a beast*, among endless options. Yet, what we know about children's early language processing is based almost entirely on frequent, prototypical sentences. By exploring how comprehension may differ for typical vs. atypical phrasings, we will be positioned better to evaluate how statistical regularities in children's environments shape language processing and language learning.

From a young age, infants show a capacity to learn how words co-occur in their input. Infants detect and recognize frequent combinations of words (Mintz, 2003; Skarbela et al., 2021), and children and adults are better able to process, remember, and repeat frequent phrases (Arnon & Clark, 2011; Arnon & Snider, 2010; Bannard & Matthews, 2008). This suggests that learners are proficient in using their knowledge of common patterns from their language experiences. It has also been found that highly typical sentence frames, such as *Look at the...*, support toddlers' ability to recognize subsequent words, compared to when words appear in isolation or occur after the word *Look* by itself (Fernald & Hurtado, 2006; Morini & Newman, 2019). This work shows that infants use co-occurrence statistics to inform their comprehension

in real time and reveals how they may benefit from hearing words in contexts that are most typical of their prior experience.

While infants also show broad sensitivity to frequency, there is less direct evidence concerning how they use frequency information in real time. Children learn frequent words at younger ages (Ambridge et al., 2015; Goodman et al., 2008), showing that they benefit from simply encountering words often. In addition, bilingual toddlers tend to show enhanced processing of words produced in the language they hear more often, and they have greater difficulty understanding words in their less-frequently-heard language (Hurtado et al., 2014; Morini & Newman, 2019). More specifically, bilingual toddlers have greater difficulty understanding words in their weaker language when those words appear in atypical sentence contexts (Potter et al., 2019). This pattern of results illustrates how children's comprehension can be influenced by both the frequency of individual words and the typicality of the context in which they appear. Thus, a statistical learning framework that spans multiple words in a sentence offers a tool for understanding children's real-time processing of diverse sentences (Lany et al., 2018).

To test relative contributions of frequency and co-occurrence statistics, we investigated monolingual English-learning toddlers' processing of frequent vs. infrequent target words that appeared in typical vs. atypical sentence contexts. Using the looking-while-listening procedure, we monitored toddlers' eye movements as they viewed pairs of familiar images and heard sentences labeling one object (Fernald et al., 2008). Target nouns were high- or low-frequency labels for the same objects (e.g., *horse* vs. *pony*; *plate* vs. *dish*). Toddlers were tested on their understanding of these nouns following typical or atypical sentence frames (e.g., *Look at the...* vs. *Examine the...; Do you like the... vs. Would you prefer the...*). Our hypothesis was that

toddlers' processing would be affected by both word frequency and the typicality of the preceding sentence context. Specifically, we predicted that toddlers would show weaker comprehension of less (vs. more) frequent words, particularly if they occurred in atypical (vs. typical) sentence contexts.

Method

Participants

The final sample included 34 full-term typically developing monolingual English-learning toddlers of ages 21 to 27 months (15 female, $M = 23.7$ months, $SD = 2.1$) from the Northeastern United States. Parents of all participants provided informed consent, and all procedures were approved by the Princeton University Institutional Review Board. An *a priori* power analysis (Faul et al., 2007) indicated this sample size would have .81 power to detect a medium effect ($f = .25$). Eighteen additional toddlers were tested but excluded for reported language delay (1), fussiness (9), equipment error (2), failure to contribute at least two usable trials in all conditions (5), or an ill-timed fire alarm (1).

Stimuli

Auditory stimuli. Auditory stimuli were produced by a female native English speaker using child-directed speech. Each sentence included a Typical or Atypical sentence frame (Table 1) and a High- or Low-Frequency target noun.

Table 1

Sentence frames

Typical	Atypical
<i>Do you like the...?</i>	<i>Would you prefer the...?</i>
<i>Look at the...!</i>	<i>Examine the...!</i>
<i>Can you find the...?</i>	<i>Could you locate the...?</i>
<i>Show me the...!</i>	<i>Identify the ...!</i>

Target nouns were selected based on what children of this age would be expected to know, according to norms for the MacArthur-Bates Communicative Development Inventory: Words and Sentences (MCDI; Fenson et al., 2007). We chose items that were reportedly produced by at least 30% of 24-month-olds and more than 50% of 30-month-olds to ensure that these were likely to be familiar words, and parental reports confirmed that the majority of children understood both the High- and Low-Frequency labels. For all items, data from the CHILDES corpus indicated that High-Frequency labels were at least twice as frequent in North American child-directed speech (Table 2).

Each of 16 target nouns occurred once following a Typical frame and once following an Atypical frame. Sentences were edited to match both intensity (65db) and duration of sentence frames (1151ms) and target nouns (665ms).

Table 2.*Target Nouns*

High-Frequency Nouns				Low-Frequency Nouns				
Label	Parent-reported comprehension (%) ^a	WordBank Norm (%) ^b	CHILDES Freq ^c	Label	Parent-reported comprehension (%) ^a	WordBank Norm (%) ^b	CHILDES Freq ^c	CHILDES ratio ^d
Horse	100	79	403	Pony	59	31	55	7.3
Bird	100	88	772	Goose	74	35	85	9.1
Plate	100	57	84	Dish	65	33	37	2.3
Light	100	77	564	Lamp	74	31	21	26.9
Candy	65	66	68	Lollipop	68	32	23	3.0
Pants	100	69	264	Jeans	65	34	22	12.0
Sheep	97	60	351	Lamb	79	39	149	2.4
Chicken	97	66	320	Rooster	76	32	113	2.8
<i>Average</i>	95	70	353		70	33	63	8.2

^aPercentage of children in the current study who were reported to understand the label

^bPercentage of 24-month-old American English-learning infants reported to produce the label, according to MCDI norms (Frank et al., 2017)

^cFrequency (per million words) in the CHILDES corpus for North American English (MacWhinney, 2000)

^dRatio of occurrence of the High- vs. Low-frequency label in the CHILDES corpus

Visual stimuli. Visual stimuli were pairs of images of familiar objects presented side-by-side on grey backgrounds (Figure 1). Images always occurred in yoked pairs matched for animacy and salience (*horse/bird, plate/light, candy/pants, sheep/chicken*). Each visual image could be labeled with equal plausibility by a High- and Low-Frequency noun. All tokens appeared equally often on the right and left side and equally often as the target and distracter. Stimuli are available through OSF [https://osf.io/frvx7/?view_only=c206dd17b5654f80b94710439d35fb00].

Figure 1

Sample visual stimuli and target sentences for all conditions

Procedure

Toddlers sat on their parents' laps in a sound-attenuated, darkened room. Parents wore opaque glasses and were asked not to interfere. Visual stimuli appeared on a 55" monitor, and speech stimuli played over a loudspeaker. On each trial, images were presented in silence for 2s. Participants then heard a sentence labeling one object, followed by a sentence used to maintain

attention (e.g., *Look at the horse! Do you see it?*) and 1.5s of silence, for a total trial duration of 6.7s.

Testing sessions were divided into four 8-trial blocks. Within each block, toddlers heard one type of sentence frame (Typical or Atypical), and half of trials involved High-Frequency target nouns. Toddlers heard alternating blocks of Typical vs. Atypical sentences, and we counterbalanced across participants which type of frame occurred first. Between each block, toddlers saw a filler trial to engage interest. Trial orders were pseudorandomized such that there were never more than three consecutive trials with the same type of target noun (High- or Low-Frequency), and toddlers were randomly assigned to one of four experimental orders.

Following testing, all parents reported whether their children understood and said each target noun. Thirty two of 34 parents also filled out the MCDI to provide a measure of children's vocabulary ($M = 299$ words, range = 11-582, $SD = 176$).

Coding

Trained coders, blind to condition, recorded at 33ms intervals whether the child was looking right, left, or at neither image. We excluded trials where the child was not looking at either image at noun onset or for more than 500ms continuously during our analysis window. Twenty percent of sessions were re-coded by a second coder. Coders agreed on the gaze location on 99% of frames and agreed within a single frame on 98% of frames surrounding shift events.

Results

To evaluate children's recognition of words and their referents, we computed toddlers' mean accuracy, defined as the proportion of time looking at the target image divided by time

viewing either image during the window from 367-2000ms following the onset of the target noun. All data and supplemental analyses can be found at

[https://osf.io/frvx7/?view_only=c206dd17b5654f80b94710439d35fb00].

For all trial types, single-sample two-tailed t -tests revealed that toddlers significantly exceeded chance (.5) in looking to the target ($M = .66$, all $p < .00001$, Table 3), demonstrating successful comprehension, on average, of both frequent and infrequent labels across different sentences.

Table 3

Mean performance and comparison to chance (.5) across conditions.

Sentence Frame	Target Noun	Mean accuracy	SD	t	95% CI
Typical	High-Frequency	.689	.111	9.90	[.65, .73]
Typical	Low-Frequency	.645	.143	5.89	[.59, .69]
Atypical	High-Frequency	.677	.130	7.94	[.63, .72]
Atypical	Low-Frequency	.634	.142	5.50	[.58, .68]

Note: Performance across all trial types significantly exceeded chance, $p < .00001$

We then tested the influences of sentence typicality and word frequency using a 2x2 within-subjects ANOVA (Sentence Frame: Typical vs. Atypical, Target Noun: High- vs. Low-Frequency, Figure 2). The effect of Frame was not significant, $F(1,33) = 0.25$, $p = .62$, and there was no interaction between Frame and Noun, $F(1,33) = 0.001$, $p = .97$, indicating that toddlers looked to the target equally following Typical or Atypical sentence frames. However, there was a significant main effect of Target Noun, $F(1,33) = 4.36$, $p = .04$, $\eta_p^2 = .12$; accuracy was higher for High-Frequency nouns. Exploratory analyses revealed no significant order effects or changes

across blocks (see Figures S1-S3 in supplementary materials). Thus, while toddlers recognized both High- and Low-Frequency labels in real time, they showed better understanding of frequent words.

Figure 2

Toddlers' mean accuracy in looking to the target

Note. Accuracy was computed from 367 to 2000ms following noun onset. Dashed line represents chance (.5). Error bars denote standard errors of the mean.

Finally, we conducted exploratory analyses to test associations between real-time comprehension and vocabulary knowledge. MCDI scores were not significantly correlated with overall accuracy, $r = .17$, $p = .34$, $95\% CI = [-.19, .49]$. We then tested how toddlers' vocabulary related to their sensitivity to word frequency. To do so, we calculated a difference score for each

toddler that captured the difference between their accuracy on trials with High- vs. Low-Frequency targets. Difference scores were significantly correlated with vocabulary size, $r = -.38$, $p = .03$, $95\% CI = [-.64, -.038]$, indicating that toddlers with smaller vocabularies showed increased discrepancies in processing of High- vs. Low-Frequency words (see Figure S4).

Discussion

This study tested monolingual toddlers' sensitivity to the statistical patterns in their language input by exploring their processing of frequent vs. infrequent target nouns that appeared in typical vs. atypical sentence frames. Toddlers successfully demonstrated comprehension of all sentence types, but they were less accurate in recognizing low-frequency words, and differences were especially pronounced for children with smaller vocabularies. These results yielded two important insights. First, toddlers' real-time processing is flexible enough to contend with sentence contexts that involve relatively unfamiliar sequences of words – at least in a controlled lab setting. Second, frequency information affects children's real-time processing of nouns, indicating that the robustness of children's knowledge of a target word is a key factor in their processing efficiency.

Across different sentences, toddlers displayed better understanding of nouns that are more common in child-directed speech, illustrating how toddlers' ability to track frequency information has a measurable effect on their real-time processing. Interestingly, the relation we observed between vocabulary size and the difference in recognizing high- vs. low-frequency nouns tentatively suggests that when children are in earlier periods of vocabulary growth – or perhaps when they have received less input from caregivers – they may be particularly sensitive to how often they have encountered a given word. That is, frequency effects in word recognition

may be especially pronounced when a child has not yet had the chance to form a robust representation. Crucially, high- and low-frequency labels referred to identical visual tokens, ensuring that differences were attributable to familiarity with words, not objects (Kartushina & Mayor, 2019). This imbalance mirrors data from adults showing that word frequency reliably predicts comprehension across a variety of tasks (Ellis, 2002; Gerhand & Barry, 1998; Morton, 1969) and is consistent with studies showing that children's ability to correctly select a label's referent depends on their familiarity with that word (Kucker et al., 2018).

Unexpectedly, the typicality or atypicality of the sentence frame had no observable effect on toddlers' comprehension. That is, even when hearing an unusual frame, toddlers recognized the noun that followed, suggesting that they were relatively insensitive to the unexpectedness of the atypical sentences. This does not mean that toddlers are *unaffected* by prior linguistic context. Indeed, studies suggest that toddlers exploit semantic, morphosyntactic, and phonetic cues in real-time processing (Borovsky et al., 2012; Fernald et al., 2008; Lew-Williams & Fernald, 2007; Mahr et al., 2015), so familiar linguistic contexts could have facilitated downstream processing. One explanation for the observed lack of an effect of sentence frame is that the frames were not sufficiently different in this experimental environment. For our atypical sentences, we chose to use frames that are quite uncommon in child-directed speech, yet maintained reasonable naturalness. For example, all sentences included natural co-articulation and prosody, which play a role in supporting more seamless processing of upcoming words (e.g., De Carvalho et al., 2017; Mahr et al., 2015; Paquette-Smith et al., 2016). Another explanation is that infants can perhaps 'listen through' uninformative or unusual parts of a sentence (Thorpe & Fernald, 2006) and attend primarily to target nouns, or other meaningful information that arrives downstream. None of our sentence frames, either Typical or Atypical, reliably predicted any

particular referent, therefore any of the subsequent target nouns were equally likely or unlikely to follow. Future studies will continue to examine whether infants benefit from hearing words in predictable contexts, which will inform current understanding of how they exploit different types of prior experience and what kinds of regularities most strongly shape infants' processing.

Importantly, while toddlers showed reduced understanding of low-frequency nouns, they still recognized more than one label for the identical visual token. This contrasts with views of early word learning proposing that young children are unwilling to accept multiple names for a single referent (Markman & Wachtel, 1998) and suggests that toddlers, like older children, recognize that the same object can be labeled in more than one way (Waxman & Hatch, 1992). Thus, simplified descriptions of word learning as the process of mapping a single label onto each item in the environment (e.g., Stevens et al., 2017; Smith & Yu, 2008) may underestimate young children's flexibility in processing objects, labels, and meanings. Instead, these findings are more consistent with models of word learning in which learners track probabilistic information about words, referents, and events as their knowledge develops (Benitez et al., 2016; Kucker et al., 2015).

These results also converge with recent research on early bilingualism. Studies have shown that toddlers from multilingual homes (who regularly hear the same object labeled with different words) do not tend to be bound by the heuristic that there will be one-to-one mappings between objects and labels (Byers-Heinlein & Werker, 2009; Kandhadai et al., 2017). Our data suggest that this phenomenon is not unique to bilingual environments; even in monolingual environments, toddlers readily recognize multiple labels for a single object. In addition, monolingual toddlers' difficulty understanding low-frequency words is analogous to bilingual toddlers' reduced comprehension of words in their weaker and/or less-frequently-heard language

(Hurtado et al., 2014; Potter et al., 2019). The current results, in conjunction with findings from bilingual participants, illustrate that children from different language backgrounds construct their knowledge through experience with words encountered more and less frequently, and suggest that a statistical learning framework can unite research on early learning across monolingual and bilingual environments.

Broadly, these results demonstrate how the distributional statistics of children's language input shape real-time comprehension and offer a potential mechanism underlying reported links between the amount of language children hear in their everyday lives and their language processing skills (Weisleder & Fernald, 2013). We often think of input in an aggregated sense, but when a child hears more *total* words compared to another child, they will also likely hear individual words more often (at least on average). This increased word-level experience could support the development of robust representations that facilitate increasingly efficient processing. Thus, we suggest that statistical learning principles can explain how children understand frequent and infrequent words in their input. Namely, over time, children's representations strengthen as they encounter the same words in new contexts.

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