

Identifying the distributional sources of children's early vocabulary

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Abstract

Children's early word learning is to a large extent driven by the prevalence of words in their language environment, with words that are spoken more often to children being learned earlier. However, children receive language from a variety of sources, including books, television, and movies meant for children, as well as speech and media that is meant for adults, but overheard by children. Despite considerable similarity of word frequency distributions from these different input sources, there is also significant and predictable variability between them. For example, function words are far more frequent in books than in everyday speech, while early-learned nouns (e.g., 'ball' and 'mommy') are more frequent in child-directed speech than from other sources. Children receive a mixture of these different frequency distributions. The goal of this paper is to better understand the shared and unique variance in these sources of input—in both English and French—and to evaluate how predictive these input frequencies are of children's early word learning.

Keywords: early language learning; CDI; vocabulary development; word frequency distributions.

Introduction

How does speech addressed to children, heard on television, or read in books impact the growth of children's early vocabulary? How does speech from these sources relate to adult-directed sources of speech? And how do these potential language sources combine with parental education to predict young children's vocabulary growth? Children must learn words based on ambient linguistic input, and indeed the amount of child-directed speech a child receives predicts later vocabulary growth (Hart & Risley, 1995). However, children's exposure to different words can vary greatly depending on the source – spoken language vs. books vs. media – and the register – child-directed vs. adult directed – of the language. Moreover, the amount of input children receive from these different input sources may vary from child to child, which may account for some of the great variability seen in children's early vocabulary growth (cf. Fenson et al., 1994). Indeed, higher measures of input quantity and quality have been found to relate to children's faster vocabulary growth, and to often be related to parents' socioeconomic status (SES; Rowe, 2012; Hoff, 2003).

Input word frequency varies significantly depending on the context. Previous studies have shown that frequency matters for children's word learning (for a review, see Ambridge, Kidd, Rowland, & Theakston, 2015), and have observed an association between word frequency in children's language

environments and age of acquisition (Goodman, Dale, & Li, 2008). For instance, word frequency in books is not the same as frequency in conversational speech, with many function words being far more frequent in books than in speech (Dawson, Hsiao, Wei Ming Tan, Banerji, & Nation, 2021; Montag, Jones, & Smith, 2015).

Some differences between frequency distributions are intuitive: "mommy" is quite frequent in child-directed speech, yet not so common in children's books, and even more rare in books meant for all ages. But other differences are less intuitive: "of" is frequent in books meant for all ages, and while still frequent in child-directed speech, it is relatively less frequent as compared to children's books. In general, speech – whether directed to children or to adults – contains relatively fewer function words and tends to score lower on measures of lexical diversity than books, which have a higher ratio of types (unique words) per set of tokens (instances of words; Dawson et al., 2021).

In this paper, we have three goals. First, we examine shared and unique variance in word frequency across different sources of English and French input, ranging from children's books and movies to child-directed speech and even comparing to adult-directed books, movies, and speech. Because of the substantial correlations between these different input sources, we employ principal components analysis (PCA) for dimensionality reduction.

Second, we investigate how well these components predict English- and French-learning children's early word learning, using aggregate MacArthur-Bates Communicative Development Inventories (CDI) data from Wordbank (Frank, Braginsky, Yurovsky, & Marchman, 2017). CDIs are parent report forms for children's early vocabulary, and they have proven to be reliable and valid indicators of child's language (Fenson et al., 1994). Critically, CDI forms provide details about the individual words that children produce. These data allow us to investigate the role of different frequency sources using the Age of Acquisition (AoA) prediction paradigm, in which we use regression models to predict each CDI item's mean Age of Acquisition (AoA) – the mean age (in months) at which 50% of children are expected to know a given word (Braginsky, Yurovsky, Marchman, & Frank, 2019; Goodman et al., 2008).

Third, we examine how well different input sources predict SES differences in word learning for English-learning

children. We index SES using maternal education, a common proxy measure. Young children from higher-SES households tend to have larger vocabulary (Fernald, Marchman, & Weisleder, 2013) and parents with higher-SES tend to report reading more to their young children than parents with lower SES.

Method

Datasets

Corpora from different sources are used to identify shared and distinct variance in frequencies. These corpora vary widely in size due to data accessibility; several were created for the current study and are available in our GitHub repository.

Child-directed Speech (ChS). Utterances of ChS were extracted from the CHILDES corpus (MacWhinney, 2000), a collection of transcripts of interactions between caregivers and children of ages ranging from 0 to 12 years ($M = 2.9$ years). After cleaning, the CHILDES English corpus yielded 5521000 tokens across 38779 word types. The French ChS yielded 3102000 tokens across 13016 word types.

Child-directed books (ChB). We used a sample of 98 English children’s books from Project Gutenberg’s open-source database, previously used in machine learning research on language comprehension (Hill, Bordes, Chopra, & Weston, 2015). The books were published between 1820 and 1922, but include well-known titles as *The Legend of Sleepy Hollow*. We also used 130 popular French children stories accessible in parenting websites (<https://fr.hellokids.com/>) and 10 French children books from Project Gutenberg. After cleaning, the English ChB corpus totals 4674000 tokens across 42666 word types, and the French ChB totals 1298000 tokens across 17990 word types.

Child-directed Media (ChM). Transcripts were extracted from English television shows (e.g., from PBS Kids and Nickelodeon) and movies (e.g., *Beauty and the Beast*), including 1,078 movies and 4,309 TV episodes taken from Charlesworth, Yang, Mann, Kurdi, & Banaji (2021) (available here: <https://osf.io/kqux5/>). Openly accessible transcripts (<https://www.subsynchro.com/>) were also extracted from 100 French films directed to children. After cleaning, the English ChM totals 6759247 tokens across 84333 word types. The French ChM totals 842000 tokens across 14937 word types.

Adult-directed Speech (AdS). English AdS was obtained from the Switchboard-1 Telephone Speech Corpus (Godfrey & Holliman, 1993), a corpus of transcripts from dyadic telephone conversations. French AdS was obtained from the TCOF corpus (André & Canut, 2010), the CLAPI corpus (Balthasar & Bert, 2005) and the CFPP corpus (Branca-Rosoff, Fleury, Lefevre, & Pires, 2012). After cleaning, the English AdS yielded 3104000 tokens across 27536 word types. The French AdS yielded 1466000 tokens across 14486 word types.

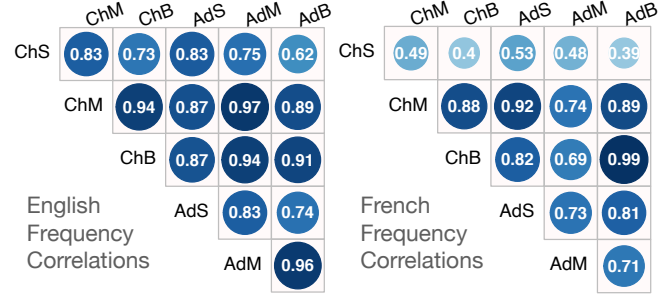


Figure 1: Word frequency correlations between different corpus sources for the matched CDI words in English (left) and French (right).

Adult-directed Books (AdB). The English AdB is comprised of 35144000 tokens across 827414 word types. The French AdB is comprised of books taken from the 1999 Association de Bibliophiles Universels, an open-source database of french books. After cleaning, it yielded 2288000 tokens across 30615 word types.

Adult-directed Media (AdM). The English AdM is comprised of 6167000 tokens across 62876 word types. The French AdM corpus is comprised of 766000 tokens across 15662 word types, after cleaning openly accessible movie subtitles (<https://www.subsynchro.com/>) from 100 films.

Age of Acquisition data Children’s early word learning data is drawn from the CDIs (Fenson et al., 2007), aggregated in the Wordbank database (Frank et al., 2017) (data from 5520 children aged 16-30 months for the American English CDI: Words & Sentences (WS) form, and 641 children for the French French CDI:WS form). Age of acquisition estimates were calculated via the wordbankr package using the XYZ method.

Merging the Corpora

We focus our analysis on the 670 words from the English CDI that we were able to identify in at least some of the corpora, and 632 words from the French CDI. For French, because of the presence of more complex morphology, CDI words were matched to related words in corpora via a stemmer. For any CDI words that failed to appear in a given corpus, we replaced the missing word’s frequency with a normalized count of 10 TPM, or the minimum normalized frequency for that distribution, whichever was smaller. All word frequencies were normalized to number of tokens per million (TPM).

Results

Cross-corpus Frequency Correlations (Q1)

Figure 1 shows the word frequency correlations between different corpus sources ([Adult- vs. Child-directed] x [Speech, Books, Media]) for the matched CDI words (left: English, right: French). Unsurprisingly, there were strong correlations across these different corpora, but correlations were stronger

within register and within source for both English and French.

We thus turned to PCA to disentangle these correlated distributions and to understand their relationship. PCA allows us to project word frequencies into a space in which the first dimension captures the shared variance between frequencies from different sources and registers, and subsequent dimensions capture other consistent sources of variation. Since the logarithm of frequency is typically used as a psycholinguistic predictor in previous studies (Braginsky et al., 2019; Goodman et al., 2008), we perform our PCA over log frequencies.

Table 1 shows the standard deviation (Std Dev) and proportion of variance explained, both individually (Prop Var) and cumulatively (Cum Prop Var) by the principal components (PC1-PC6) for each language. PC1 already explains the bulk of the variance (89% for English and 90.1% for French); and PC2-PC4 each only capture an additional 2-4% of the variance for English, and 5-8% for French.

Table 2 summarizes the eigenvectors of the principal components (PC1-PC6) in relation to the original six frequency distributions for English and French. The first PC is similar for both English and French, and captures shared variance between all frequency sources, representing words that are high or low frequency across registers and sources. This component captures, for example, that ‘the’ (EN), ‘le’ (FR ‘the’), ‘et’ (FR ‘and’) are frequent in spoken and written sources, whether directed to adults or children. For English, PC2 (3.8% of variance) mostly captures child-directed speech, differentiating it from the other registers. For example, words such as ‘peekaboo’ are more present in child-directed speech. For French, PC2 (4.4% of variance) also captures child-directed speech (e.g., ‘gâteau’ = ‘sweet’), distinguishing it from adult- and child-directed books.

For English, PC3 (3.2% of variance) captures adult-directed speech, differentiating it from the other registers. It captures words such as ‘mower’, ‘downtown’ or ‘vitamins’, frequent in discussions between adults. For French, PC3 (2.6%) similarly captures adult-directed speech, with words such as ... For English, PC4 (2.3% of variance) captures the similarity of child- and adult-directed media, distinguishing them from child- and adult-directed books. This component captures that some words are very frequent in media in general, but infrequent in books (e.g. ‘camera’, ‘TV’) and vice-versa (e.g. ‘none’, ‘beads’, ‘poor’). For French, PC4 (1.6% of variance) captures the similarity of child- and adult-directed media (e.g. ‘étoile’ = ‘star’), distinguishing them from child- and adult-directed speech (e.g. ‘voiture’ = ‘car’).

For English, PC5 (1.1% of variance) captures child-directed speech, distinguishing it from child-directed books. This component captures that some words are very frequent in child-directed speech, but infrequent in child-directed books (e.g. ‘mommy’, ‘juice’) and vice-versa (e.g. ‘firetruck’, ‘snowsuit’). For French, PC5 (0.9% of variance) distinguishes child-directed media (e.g. ‘ferme’ = ‘farm’) from adult-media (e.g. ‘café’). Lastly, for English, PC6 (<1% of variance) is similar to PC5 in French (0.9% of variance), cap-

turing child-directed media (.73), and distinguishing it in particular from adult-directed media. This component captures that some words are very frequent in child-directed media, but infrequent in adult-directed media (e.g. ‘penguin’, ‘snowman’) and vice versa (e.g. ‘drawer’, ‘medicine’).

For French, PC6 (0.5%) distinguishes child-directed books (e.g. ‘ours’ = ‘bear’) from adult-directed books (e.g. ‘tuer’ = ‘kill’).

In summary, the PCs align surprisingly well with particular dimensions of the English frequency distributions: PC1 with overall frequency, PC2 with child-directed speech, PC3 with adult-directed speech, PC4 with media vs. books, PC5 with child-directed books vs. speech, and PC6 with adult-vs. child-directed media. For French, we observe a similar pattern of findings for PC1-PC4, although the amount of variance explained is not quite the same. In PC5 and PC6, some frequency differences across different registers are more pronounced for French than for English.

Table 1: Importance of components from PCA for English (above) and French (below).

	PC1	PC2	PC3	PC4	PC5	PC6
EN StdDev	5.10	1.05	0.97	0.82	0.57	0.44
EN PropVar	0.89	0.04	0.03	0.02	0.01	0.01
EN CumPropVar	0.89	0.93	0.96	0.98	0.99	1.00
FR StdDev	4.13	0.92	0.70	0.54	0.41	0.29
FR PropVar	0.90	0.04	0.03	0.02	0.01	0.00
FR CumPropVar	0.90	0.95	0.97	0.99	1.00	1.00

PCA-based Age of Acquisition Regression (Q2)

Next, we turned to our second question: how well different frequency distributions predict English- and French-learning children’s early word learning. Our approach was to fit a linear regression model predicting each CDI word’s mean AoA, following previous work (Braginsky et al., 2019; Goodman et al., 2008).

Multicollinearity makes it unwise to include multiple raw frequency distributions in a regression, however, as the re-

Table 2: Highlights from principal components’ rotation in the original coordinate system.

Order	EN	FR
PC1	Freq: -.31...-.52	Freq: -.39...-.44
PC2	ChS: .65; AdB: -.47	ChS: .63; AdB: -.67
PC3	AdS: .79; ChM: -.35	AdS: .67; ChM: -.68
PC4	M Ch: .40 A: .48; B Ch: -.63 A: -.44	ChM: .55; ChS: -.63
PC5	ChS: -.60; ChB: .53	AdM: -.83; AdS: .50
PC6	ChM: .73; AdM: -.53	ChB: .79; AdB: -.56

Table 3: English principal components’ rotation in the original coordinate system.

	PC1	PC2	PC3	PC4	PC5	PC6
ChM	-0.31	0.15	-0.35	0.40	0.28	0.73
ChB	-0.34	0.25	-0.32	-0.63	0.53	-0.21
ChS	-0.26	0.65	-0.30	0.12	-0.60	-0.22
AdM	-0.47	-0.45	-0.24	0.48	0.13	-0.53
AdB	-0.49	-0.47	-0.01	-0.44	-0.50	0.32
AdS	-0.52	0.27	0.79	0.10	0.14	-0.01

Table 4: French principal components’ rotation in the original coordinate system.

	PC1	PC2	PC3	PC4	PC5	PC6
ChM	-0.41	0.09	-0.05	0.65	-0.56	-0.31
ChB	-0.41	-0.54	-0.21	-0.13	-0.26	0.64
ChS	-0.36	0.51	-0.73	-0.22	0.16	-0.02
AdM	-0.42	0.19	0.34	0.42	0.62	0.34
AdB	-0.41	-0.54	-0.02	-0.18	0.36	-0.62
AdS	-0.42	0.34	0.55	-0.55	-0.30	-0.04

sults will be unstable. We verified that this situation was the case by running a regression predicting AoA with the logarithm of word frequency from each of the six distributions as a predictor. The Variance Inflation Factor (VIF) estimates the inflation of the variance of a regression coefficient when there is correlation between predictors (Dodge, 2008). The higher the VIF for a predictor, the less reliable the regression results are when that predictor is included. The VIF for every distribution was $\gg 1$ (and many > 5), indicating that these variables show strong multicollinearity which may compromise the reliability of the regression results. We thus used the CDI items’ PCA loadings in lieu of the frequency distributions to predict AoA.

Table 5: Correlation of English AoA with PC loadings by lexical class.

lexical_class	PC1	PC2	PC3	PC4	PC5	PC6
adjectives	-0.01	-0.40	-0.06	-0.35	0.17	0.11
function_words	0.18	-0.39	0.15	-0.35	0.09	-0.01
nouns	0.40	-0.27	0.20	-0.24	0.33	0.02
other	-0.33	-0.72	0.52	-0.22	0.26	-0.15
verbs	0.17	-0.31	0.30	-0.11	0.20	0.04

Given that past research has found that lexical class strongly modulates influences of word frequency, we next examined the interaction of lexical class (LC) with PC1 - PC6 in our regression. We also included the number of letters as a

Table 6: Correlation of French AoA with PC loadings by lexical class.

lexical_class	PC1	PC2	PC3	PC4	PC5	PC6
adjectives	-0.14	-0.31	0.12	-0.29	-0.01	0.13
function_words	-0.23	-0.05	-0.10	0.06	0.34	0.18
nouns	0.01	-0.15	0.01	0.09	-0.06	0.03
other	-0.17	-0.39	0.20	0.08	-0.03	-0.19
verbs	0.10	-0.19	0.05	-0.06	-0.05	-0.02

predictor (Nletters) to help control for the overall difficulty of each word. To determine if the inclusion of all PCs was justified, we ran a series of ANOVAs building up from PC1 to PC6—in decreasing order of the variance they accounted for in the PCA¹. The more complex model was always significantly preferred, including up to the inclusion of PC6 (English: $R^2 = .58$, French: $R^2 = .16$). Figure 2 shows the coefficient estimates with $p < 0.05$ for both languages.

In general, we observed that registers and sources both matter for early word learning. For English, PC1, PC2, PC3, PC4 and PC5 predict the age of acquisition. Overall frequency (PC1) is a predictor; words which are frequent in general are learned earlier than less frequent words. Child-directed speech (PC2) is a negative predictor; words which are frequent in this register are learned earlier on. On the contrary, adult-directed speech (PC3) is a positive predictor; words which are frequent in this register are learned later on. The frequency of words in media distinguished from books is a predictor (PC4). Frequency of words in child-directed speech distinguished from words in child-directed books is also a significant predictor, with earlier acquisition predicted for more speechy/less booky words. We also observe that overall frequency interacts with lexical class, verbs, function words and adjectives being learned later than nouns. PC2 interacts with verbs, which are learned later than nouns. PC3 and PC6 each interacted with function words, which are learned later than nouns.

For French, both registers and sources were important predictors of word learning. PC1, PC2, PC3, PC4 and PC5 are significant predictors, showing that speech, books, media and the child-directed register are all important. Overall frequency (PC1) is a predictor; words which are frequent in general are learned earlier than less frequent words. Book frequency (PC2) is a predictor; words which are especially frequent in books are learned later on. Child-directed speech (PC3) is a predictor; words which are especially frequent in this register are learned earlier on. PC4 includes words which are often found in media versus speech, and PC5 includes words in child-directed versus adult-directed media. Simi-

¹The R syntax for the sequence of regressions was $\text{AoA} \sim \text{PC1} * \text{LC}$, $\text{AoA} \sim (\text{PC1} + \text{PC2}) * \text{LC}$, ..., $\text{AoA} \sim (\text{PC1} + \text{PC2} + \text{PC3} + \text{PC4} + \text{PC5} + \text{PC6}) * \text{LC}$, with noun as the baseline LC.

larly to English, we also observe that overall frequency interacts with lexical class, with verbs, function words, and adjectives being learned later than nouns. Book frequency (PC2) interacts with verbs, and child-directed media (PC5) interacted with function words. There is no significant effect of word length.

In sum, in both languages, we observe that the predictive value of word frequency comes from speech, media and book sources, and mostly the child-directed register. The main differences across languages are that for English, the difference and difficulty of adult-directed speech is emphasized. For French, the difference and difficulty of text, independent of register, is emphasized.

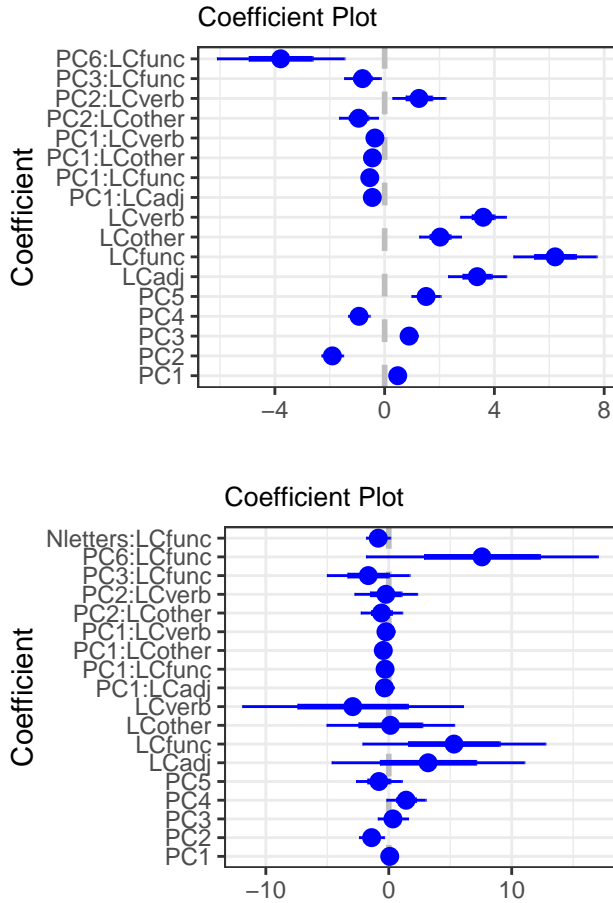


Figure 2: Regression coefficients for predicting CDI AoAs with PCs and lexical class for English (top) and French (bottom).

Combining distributions with demographic data (Q3)

Previous findings relate SES status to book reading (Shen & Del Tufo, 2022), which is in turn related to better language skills (Bus, Van Ijzendoorn, & Pellegrini, 1995). These findings suggest that the vocabulary composition of children from higher-SES households may be better predicted by the word frequencies seen in child-directed books, rather than those

from child-directed speech. To test this idea, we did an exploratory logistic regression using the first four PCs to predict the number of children in Wordbank who produce or don't produce each item, along with interactions of mother's education and children's age. Due to lack of maternal education data for French data, we focus on American English-learning children. American English data from Wordbank contained 2,776 CDI:WS administrations with mother's education coded as a factor (baseline (0): no more than secondary education (N=547), 1 for some/all college (N=1483), and 2 for at least some graduate school (N=746)).

There were significant main effects of age, mother's education, and PC1-PC4 (all $p < .001$). There were significant interactions of age with mother's education ($p < .001$), PC2 ($p < .001$), and PC4 ($p = .009$). There were significant interactions of mother's education with PC1-PC3 (all $p < .001$), shown in Figure 3.

	Beta	SE	t-val	p-val
(Intercept)	-5.33	0.05	-117.54	0.00
age	0.21	0.00	204.85	0.00
MotherEdCollege	-1.54	0.03	-53.74	0.00
MotherEdGraduate	-1.76	0.03	-55.35	0.00
PC1	0.07	0.01	7.39	0.00
PC2	0.31	0.04	7.53	0.00
PC3	-0.29	0.05	-6.08	0.00
PC4	0.15	0.05	2.81	0.00
age:MotherEdCollege	0.07	0.00	59.18	0.00
age:MotherEdGraduate	0.09	0.00	67.84	0.00
age:PC1	-0.00	0.00	-7.94	0.00
age:PC2	-0.01	0.00	-6.89	0.00
age:PC3	0.00	0.00	3.92	0.00
age:PC4	0.00	0.00	3.03	0.00

Table 7: Regression coefficients for predicting English CDI items using PCs and mother's education.

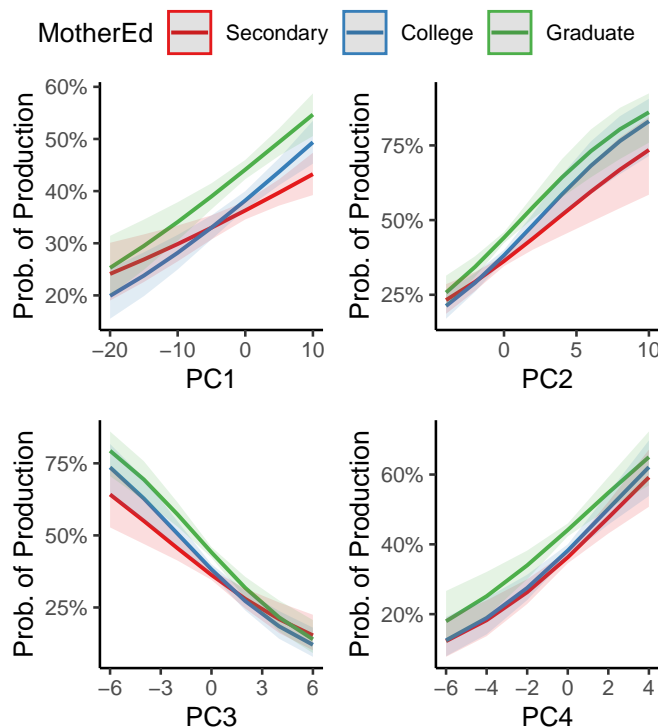


Figure 3: Predicted effects of maternal education and PC1-PC4 on the probability of children producing CDI words.

Discussion

We set out to investigate the sources of linguistic input and registers that children may experience, using word frequency distributions garnered from child-directed and adult-directed corpora of speech, books, and media (TV and movies). We found the principal components (PCs) of these distributions, and described how these PCs capture variation both in adult- vs. child-directedness, as well as between modalities (e.g., books and speech).

Our findings show that PC1 explains 95% of the variance in frequency distributions. This means that most frequency is shared by the different sources, thus accounted for by that one component. Moreover, multiple components are predictive of children's age of acquisition of words from the CDI. Speech, but also books and media are all relevant in predicting age of acquisition, as well as child-directed speech. This suggests that children's environmental exposure to different language sources, even when these include books or even media, could impact their word learning trajectory. It is somewhat surprising that even sources of input that young children rarely encounter (e.g., adult-directed books) contribute significantly to predicting variation in children's early word learning.

We also used English Wordbank data to examine how well the frequency components combine with mother's education—a measure of SES that has been found in the past to be positively related to early word learning, and to more child-directed reading—to predict children's early word learning. This analysis revealed significant contributions of multiple PCs, as well as the interaction of mother's education with PC1

(overall frequency), PC2 (child-directed speech), and PC3 (adult-directed speech), but not of the child-directed books component (PC4).

These findings are important for educational reasons and could inform future interventions on the importance of including language from different sources. A target for future research is to predict individual children's learning of particular words using these principal components, in combination with parent-reported measures of how much time their child spends daily receiving input from each of the input sources ([adult- vs. child-directed] x [books, media, and speech]).

Finally, there was overwhelming similarity of word frequency distributions from different sources and their predictive value in English and French data, which supports the robustness of the results. At the same time, these distributions show systematic variation—at least in English and in French, which can predict some of the variation in children's early word learning. We should also notice that different data and corpus sizes were used to represent the sources for each language. Differences could also be partly attributed to this e.g., the French corpora were composed of several smaller ones, due to the lack of large accessible corpora, and had slightly different use e.g. small stories in French, large books in English.

By better understanding the similarity and differences between word frequencies children experience in different contexts, future research in this vein holds the promise to predict individual differences in children's early word learning on the basis of their daily routines.

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