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Extended Statistical Learning as an account for slow vocabulary growth*

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ABSTRACT

Stokes (2010) compared the lexicons of English-speaking late talkers (LT) with those of their typically developing (TD) peers on neighborhood density (ND) and word frequency (WF) characteristics and suggested that LTs employed learning strategies that differed from those of their TD peers. This research sought to explore the cross-linguistic validity of this conclusion. The lexicons (production, not recognition) of 208 French-speaking two-year-old children were coded for ND and WF. Regression revealed that ND and WF together predicted 62% of the variance in vocabulary size, with ND and WF uniquely accounting for 53% and 9% of that variance respectively. Epiphenomenal findings were ruled out by comparison of simulated data sets with the actual data. A generalized Mann–Whitney test showed that children with small vocabularies had significantly higher ND values and significantly lower WF values than children with large vocabularies. An EXTENDED STATISTICAL LEARNING theory is proposed to account for the findings.

This research compares the characteristics of the lexicons of children who have been described as 'late talkers' (LT) with those of their typically developing (TD) peers. LTs have a slow onset of expressive vocabulary,

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while having no other indications of developmental disability (see Demarais, Sylvestre, Meyer, Bairati & Rouleau, 2008, for a review). Not only is onset late in comparison with their TD peers, but these children are usually identified by their small expressive vocabularies, whether it be by the metric of less than 50 words or no word combinations at age 2;0–2;6 (e.g. Paul, 1996), or by the metric of below the 10th or 15th percentile for age (e.g. Bishop, Price, Dale & Plomin, 2003) on the MacArthur-Bates Communicative Development Inventory (MCDI; Fenson, Dale, Reznick, Thal, Bates, Hartung, *et al.*, 1993; Fenson, Marchman, Thal, Dale, Reznick & Bates, 2007). The point is that all current definitions identify a child as being a LT on a QUANTITATIVE measure. In addition, one of the mysteries surrounding LT status is the fact that about two-thirds of these children go on to have language abilities that fall within the normal range, albeit still significantly lower than children who had never been late talkers (e.g. Rescorla, 2002). Children who approach TD performance on language tests between two and four years are referred to as 'late bloomers' (LB).

Stokes (2010) asked whether the lexicons of LTs differed QUALITATIVELY from those of TD children on variables known to affect word learning, specifically phonological neighborhood density and word frequency, and whether there was any indication that these variables could separate LTs from LBs. The term PHONOLOGICAL NEIGHBOR refers to words that differ from all other words by the substitution, deletion or addition of a sound in any word position ($\pm$ one segment; Luce & Pisoni, 1998). Words that have many phonological neighbors are said to reside in dense neighborhoods, while those with few phonological neighbors reside in sparse neighborhoods. Word frequency is generally defined as the rate of occurrence of a given word in a spoken corpus, where the corpus varies depending on purpose, for example, child-directed speech (Swingley, 2003) or the CELEX (Baayen, Piepenbrock & Gulikers, 1995).

Most studies of early vocabulary development have found that first words tend to come from dense phonological neighborhoods in the ambient language. However, there are individual differences across children (Coady & Aslin, 2003; Storkel, 2004; 2009). The impact of word frequency on vocabulary learning is less clear-cut. Goodman, Dale and Li (2008) noted that although there is a general consensus that words that are frequent in child-directed speech (CDS) are learned the earliest, there had not been any direct test of this hypothesis. These authors assigned words on the MCDI to one of six lexical categories: common nouns, people words, verbs, adjectives, closed class and others. (Common nouns were words that encoded objects and substances, like *ball*, *frog* and *juice*, and nouns that labeled events or locations, like *park* and *lunch* were categorized as other.) The relationship between the frequency of each word in CDS and the age of emergence of each word according to the Dale and Fenson (1996) database was examined to test the hypothesis. Word frequency was negatively correlated with age of acquisition for the entire word set, indicating that earliest learned words were of low frequency. When each word category was considered in turn, the expected relationship was found – the higher the word frequency the earlier the word was learned, with the variables being negatively correlated. Goodman *et al.*'s (2008) results are particularly important for understanding Stokes's (2010) results for English (see below).

Findings for British English

Much of the research on early vocabulary development had employed the MCDI (Fenson *et al.*, 1993) as a measurement of vocabulary size, and normative data on vocabulary development has been used as a basis for describing lexical and sublexical characteristics of children's lexicons, such as neighborhood density, word frequency and phonotactic probability (e.g. Storkel, 2004; 2009). In Stokes (2010), 222 parents checked off the words that their toddlers (aged 2;0–2;6) were known to use (speak) on the MCDI (British-English version; Klee & Harrison, 2001). Each word in each child's MCDI list was coded for the neighborhood density (De Cara & Goswami, 2002) of the word in the ambient language (British English), and for the frequency of occurrence of the word (word frequency) from the CELEX database (Baayen *et al.*, 1995). Mean ND and WF values were generated for each child. MCDI scores had a strong, negative and significant correlation with ND scores, and a moderate, positive and significant correlation with WF scores. Large vocabularies had lower density scores, suggesting more words in their inventories from sparse neighborhoods. Children with small vocabularies (LTs) appeared to be learning words that were of low frequency in the input, and came from dense neighborhoods in the ambient language. A hierarchical regression revealed that the variables together accounted for 61% of the variance in vocabulary scores, with ND scores and WF uniquely accounting for 47% and 14% of that variance respectively. Also, children who scored more than one standard deviation below the mean (for age in months; 16th percentile) on the MCDI scored significantly higher on ND and significantly lower on WF than children who scored above the cut point.

A small group of children ($N=27$) had very small vocabularies (more than 1·5 *SD* below the mean for age in months on the MCDI; approximately the 7th percentile). Of these children, nine had mean ND values that resembled the ND values of the TD children. Stokes (2010) suggested that these children may eventually become LBs, as they may have learning strategies that resembled those of TD children. The remaining eighteen children at this cut point had very high mean ND values, which led Stokes to conclude that these children may continue to have atypical language learning strategies, eventually being classified as having a language impairment.

Findings from Wright (2004), Scarborough (2004) and Munson & Solomon (2004) were invoked to account for the results. These authors reported that speakers implicitly regulate production of high-density words to expand the vowel space and increase word duration to maximize listener perception of these words. Stokes (2010) suggested that very young children with relatively poor vocabulary development (LTs) may be tuning into words that are implicitly exaggerated for the listener. This would mean that words from dense neighborhoods were more perceptually salient as formant cues were exaggerated, cues that LTs took advantage of to learn words from dense neighborhoods. Research on younger children provided evidence that infants aged 0;6–0;8 take advantage of prosodic cues to statistical information (exaggerated pitch peaks) in infant-directed speech (Thiessen, Hill & Saffran, 2005), suggesting that this is a plausible account. The implication is a perceptual deficit in LTs, or at least a preference for some types of vowel and duration cues, rather than a preference for highly recurring lead (CV+ e.g. *hat*, *ham*, *have*), rhyme (+VC e.g. *hat*, *cat*, *mat*), or consonant (C+C e.g. *hat*, *hot*, *hut*) combinations in the input.

An alternative interpretation was also related to children's perceptual abilities, but was more directly focused on learning mechanisms. Stokes (2010) suggested that the LT or low vocabulary children, having become adept at abstracting familiar word structures (recurring CV+, +VC or C+C structures), from the ambient language, failed to move beyond that point, thereby failing to begin to process words from sparser neighborhoods. Simply put, they became stuck in one learning mechanism. The long-standing tradition of research into infant and toddler perceptual learning appears to support this view. Research has demonstrated that up until about age 0;9 infants are able to discriminate between any two phonetic contrasts in human languages, but that after this age, perception begins to approximate adult performance in that the ability to discriminate non-native contrasts diminishes. For example, Japanese adults are unable to discriminate between *ra* and *la* (a non-native contrast), whereas Japanese infants can do so before about age 0;9 (see a summary in Kuhl, 2004).

This suggests that neurological reorganization (called NEURAL COMMITMENT by Kuhl and colleagues, e.g. Kuhl, Conboy, Coffey-Corina, Padden, Rivera-Gaxiola & Nelson, 2008), stimulated by the infant's attention to the statistical and distributional properties of his/her native language, acts as a foundation for subsequent language development. Indeed, Kuhl and colleagues (summarised in Kuhl *et al.*, 2008) have convincingly demonstrated that infants at age 0;7·15 who tune into the statistical and distributional properties of their native language have better subsequent language development (vocabulary and early syntactic complexity) than their peers who do not demonstrate such fine-tuning. Using a head turn paradigm, Kuhl *et al.* measured infants' abilities to discriminate between two syllables in both native and non-native languages. The children with good native discrimination at age 0;7·15 had better language scores at ages 1;6, 2;0 and 2;6 than children with poor native discrimination at 0;7·15 and the children with poor non-native discrimination abilities had better subsequent language scores than those with good non-native discrimination abilities. That is, children who were less tuned to the contrasts of their native language at 0;7·15 had slower language development. This fine-tuning was termed CONSTRAINED STATISTICAL LEARNING by Saffran and colleagues (Aslin & Newport, 2008; Saffran, 2002; 2003) where early constrained statistical learning is a positive influence on later vocabulary growth (Lany & Saffran, 2010).

Stokes (2010) showed that statistical learning could also be an important factor impinging on children's abilities to expand their lexicon past the 50-word stage. She suggested that for language to grow at a satisfactory rate, toddlers, not only infants, need to tune into subtleties of the statistical and distributional properties of their native language. The hypothesis is that having developed appropriate and useful constrained statistical learning mechanisms to find a way into the lexicon (albeit late), LTs fail to loosen these constraints to allow vocabulary expansion. In the normal process of development, children are slower to learn words that have fewer neighbors in the ambient input. In order to expand the lexicon, toddlers need to broaden their attunement to the statistical regularities of words from sparser neighborhoods by loosening constrained statistical learning strategies, expanding the ability to perceive, organize and use words that have fewer phonological neighbors. It is assumed that children with larger lexicons are those who have loosened or broadened their learning strategies in order to perceive, organize and use word forms of lower statistical probability from the ambient input stream. Aslin and Newport (2008) suggested that successful early effective constrained statistical learning could 'block' later learning in some children and we suggest that we have found evidence to support this view. We term this phenomenon EXTENDED STATISTICAL LEARNING (ESL).

While the premise of an ESL mechanism may hold promise for further investigations into the learning mechanisms of LTs, and insights into possible causes for slow vocabulary development, Stokes (2010) reported findings from only British-English-speaking children. Questions remain about whether ESL could be a phenomenon that occurs in children learning languages other than English, that by definition have different distributional frequencies, different (C)V(C) combinatorial constraints and different prosodic structures. For example, Hohle, Bijeljac-Babic, Herold, Weissenborn and Nazzi (2009), among others, report differences between English-, German- and French-speaking children for stress perception. It is possible that different languages present different challenges to toddlers at the onset of using their expressive vocabularies. To explore these possibilities, we

TABLE 1. *Selected phonological features of English and French*

Feature	English[a,b]	French[c]
Stress	Stress-timed	Syllable-timed
Rhythm	Trochaic	Undetermined
Consonants[d]	24 (Average)	21 (Average)
Vowels[d]	15 (Large)	14 (Large)
C/V Ratio[e]	1·6 (Low)	1·5 (Low)
Phonotactics	C(0–3)VC(0–4)[f]	C(0–3)VC(0–3)
Monosyllabic (%)	75·69	72·62
Bisyllabic (%)	16·63	20·67
Open syllables (%)	27·48	55·71
Closed syllables (%)	55·71	26·09
V only syllables (%)	16·81	17·22

Notes: [a] Ladefoged (1999).
[b] Haspelmath, Dryer, Gil & Comrie (2008).
[c] Fourgeron & Smith (1999).
[d] Inventory size and categorization (small, large, etc.) for consonants and vowels, where vowels includes diphthongs, size notation is from Maddieson (2008a).
[e] C/V = Consonant/Vowel Ratio, a representation of the phonological complexity of languages (Maddieson, 2008b).
[f] The notation (0–4) indicates that the number of final consonants could be 0, 1, 2, 3 or 4. Derived from Lexique3 (New *et al.*, 2007).

interrogated a comparable database from French-speaking toddlers, and these findings are the focus for this report.

The phonological features of English and French with which we are primarily concerned (stress, rhythm, number of consonants and vowels, ratio of consonants/vowels and phonotactics), are shown in Table 1. We have chosen French as a comparison language because the languages are essentially similar on all features except stress and rhythm type. There is one primary difference between the two languages that should be noted and that could have an effect on the results. There is a marked difference between the languages in the use of syllable structure for monosyllabic words. The percentage of open, closed and vowel only structures is 55·71%, 26·09% and 17·22% for French, and 27·48%, 55·71% and 16·81% for English. The potential impact of this difference in open and closed syllable structure on the current analysis is not clear, but it is noted here as an a priori factor because it could have an impact on the findings. Our hypothesis was that the lexicons of French-speaking children would show the same types of distributional properties that were found for English (Stokes, 2010).

The aim of the study was to explore the lexical characteristics of the expressive vocabularies of French-speaking two-year-old children. In order to test if Stokes's (2010) findings for English hold for French, we explored the same two lexical characteristics: neighborhood density (ND) and word frequency (WF). The ND metric used was the $\pm$ one phoneme substitution, addition or deletion definition (Ph$\pm$1 metric, e.g. Charles-Luce & Luce, 1990), for example for English, *hat* neighbors include *hot, cat, ham*, and for French, *bulle* neighbors include *mule, bel, bus*. WF was defined as the number of times a given word appears in more than 50 million words (see 'Method' below). Before turning to the study proper, there is one final issue that should be addressed, albeit briefly: that of the concept of frequency-weighted neighborhood density.

Some readers may be inclined to question the validity of the current research given that it does not use frequency-weighted neighborhood density as a measurement variable. The issue is covered at some length in Stokes (2010), to which the reader is referred. In brief, while historically high-frequency words were thought to have more neighbors than low-frequency words, closer examination of the derivation of these claims reveals that the metric does not hold for phonological neighbors and all word lengths, but rather is germane to orthographic neighbors of words four letters in length.

The research questions were:

1. How much variance in vocabulary size is accounted for by neighborhood density and word frequency together and independently in French-speaking two-year-old children?
2. Is there a significant difference between children with small and large vocabularies in neighborhood density and word frequency?
3. Are the distributions for English and French similar?

METHOD

Participants

The sample consisted of 220 children (110 girls) aged between 2;0 and 2;6 who were a subset of the 663 children (age range 1;4–2;6) studied for the French standardization of the MacArthur-Bates Communicative Development Inventory (*L'Inventaire Français du Développement Communicatif*, IFDC; Kern, 2003). Exclusion criteria were any of the following: being other than 2;0–2;6, having a non-native French-speaking parent, repeated ear infections, diagnosed developmental delays, premature birth or twin status. In addition, of the 220 who met the inclusion criteria, 12 children were dropped from the analysis; four children were reported to use less than 25 words, five children had incomplete datasets, and the parents of three children reported a native language other than French. Table 2 shows the number of boys and girls at each age.

Procedures

The IFDC (Kern, 2003; Kern & Gayraud, 2010) was distributed to parents by pediatricians (members of the French Association of Ambulatory

TABLE 2. *Age (months) and sex breakdown for the sample*

Age	24	25	26	27	28	29	30	Total
Female	11	18	12	15	16	17	16	105
Male	15	20	17	8	16	16	11	103
Total	26	38	29	23	32	33	27	208

Pediatricians) during a home visit. Parents filled in the forms alone and mailed them back directly to the research group. The IFDC is comprised of 690 words arranged in 22 categories, similar to checklists for other languages (animal names, toys, adjectives, quantifiers, articles, verbs, etc). Consistent with Stokes (2010), only 12 categories (518 words) were retained, those that represented core vocabulary that was likely to be shared across children rather than being context specific. (Examples of categories that cannot be shared across children are pets' names and baby-sitter's name.) Included categories were verbs ($N=102$), food and drink (73), adjectives (65), small household objects (56), animals (43), furniture (33), clothing (32), outside things (31), body parts (28), places to go (23), toys (18), and vehicles (14). The range of scores (of a possible 518 words) for the 208 children was 28–499.

Data reduction

Of the 518 words, only monosyllabic words were chosen for data coding by ND and WF. This decision was driven by three reasons. First, 76% and 73% of all words in English and French respectively are monosyllabic. Second, although some words larger than one syllable do have neighbors (e.g. *converse*, *converge*, *convert*), many do not (e.g. *popcorn*), and adding longer words would significantly skew the data. Third, other studies of this type have also included only monosyllabic words (e.g. Storkel, 2004; Zamuner, 2009). Selection criteria included the presence of a vowel, regardless of the number of consonants (e.g. 'tree' *arbre*). Words that were notionally bisyllabic but included an unmarked schwa in the first syllable were counted as monosyllabic (e.g. 'little' *petite* is realized as /pti/), although words of this structure, but with complex onsets were not included (e.g. 'frog' *grenouille*/grnuj/). Finally, for all verbs with a mono- or bisyllabic lemma, the most frequent or only monosyllabic form was chosen (e.g. the monosyllabic lemma 'to take' *prendre* /pʁɑ̃dʁ/ has several monosyllabic forms, the more frequent one is /pʁɑ̃/; the bisyllabic lemma 'to walk' *marcher* /maʁʃe/ has only one monosyllabic form /maʁʃ/). This resulted in a selected list of 223 words: 134 nouns, 30 adjectives, 3 adverbs and 56 verbs. As for English, the three words that appeared twice on the list were restricted to one occurrence, for example 'water' (*eau*) appears in both 'food' and 'outside objects'. The other duplicated words were 'park' (*parc*) and 'pot' (*pot*), leaving a final list of 220 words.

Neighborhood density

Both ND and WF were generated from the Lexique3 reference database, a corpus of adult language (more than 50 million words; New, Brysbaert, Veronis, & Pallier, 2007). This decision may be queried by some readers, however Gierut and Dale (2007) make the excellent point that it would be difficult to know how to limit a child-directed-speech (CDS) corpus for use in a study on child vocabulary development. Does one only select the words actually addressed to children aged 2;0 for those children, and others that were definitely spoken to children aged 2;6 for that age group? Where is the cut point? This is an empirical question that may need to be addressed in future work. However, there are now at least three lines of argumentation to support the use of adult corpora. The first is that children are not only exposed to child-directed speech. They are exposed to adult–adult and child–child conversations too. As Jusczyk, Luce and Charles-Luce (1994) noted, children do indeed extract the patterns of adult language, a fact reported many times by Storkel (e.g. 2008) in justification of the use of adult corpora. Second, corpora should be very large to generate realistic and reliable WF and ND values. Small corpora such as those usually found in the French CDS database on CHILDES are just too small (eight children). Third, our own comparison of WF values in a CDS corpus with an adult corpus showed that the results were strongly correlated ($r(222)=0{\cdot}90$, $p<0{\cdot}001$; Stokes, 2010), a finding similar to that reported by Gierut and Dale (2007) and Jusczyk *et al.* (1994).

Neighborhood density for word type was calculated from the most frequent phonological form in the Lexique3. For example, for the verb 'to sing' *chanter* /ʃɑ̃te/, ND was calculated from the form /ʃɑ̃t/, and for the verb 'to take' *prendre* /pʁɑ̃dʁ/, only the form /pʁɑ̃/ was taken into account.

Word frequency

The frequency of occurrence of each word was also determined using the Lexique3 reference database (New *et al.*, 2007). In this database, the frequency of each word is reported for each category in which it appears. For example, words like 'big' (*grand*) or 'eat' (*manger*) can be part of different word classes depending on the context 'eat' (*manger*) can appear as a verb, 'eat chocolate' (*manger du chocolat*), or a noun, 'I brought my food' (*j'ai apporté mon manger*). As *manger* is part of the category 'action words' in the IFDC, only the frequency of the verb and not the frequency of the noun was included. For nouns, singular and plural homophonic forms are summed into one count, for example, 'lion' and 'lions' because both are pronounced as /ljɔ̃/. Each word for each child was coded for ND and WF and a mean value was generated for each child.

RESULTS

In order to exactly replicate Stokes's (2010) findings for English, the same statistical analyses were conducted, and findings were reported using the same terminology and similar phrasing. First, the data were standardized by age group (see below). Then ND and WF were examined as predictors of vocabulary size in French, followed by between-group comparisons for ND and WF distributions for 'high' and 'low' vocabulary children. Next, data simulations were generated to examine whether or not the results were authentic or epiphenomenal, as was done for English, in order to rule out artifactual effects. Finally, the British and French distribution patterns were compared.

Data transformation

A multivariate analysis of variance showed that there was a significant effect of Age on ND, WF and IFDC scores ($F(6,201)=2{\cdot}90$, $p=0{\cdot}01$, *partial* $\eta^2=0{\cdot}08$; $F(6,201)=2{\cdot}34$, $p=0{\cdot}03$, *partial* $\eta^2=0{\cdot}07$; and $F(6,201)=5{\cdot}23$, $p<0{\cdot}001$, *partial* $\eta^2=0{\cdot}14$ respectively), although the effect sizes were small. Age was also significantly correlated with the other variables ($r(208)$ Age by IFDC$=0{\cdot}35$, $p<0{\cdot}001$; $r(208)$ Age by ND$=-0{\cdot}25$, $p<0{\cdot}001$; and $r(208)$ Age by WF$=0{\cdot}21$, $p=0{\cdot}002$), so all variables were converted to Z scores within age groups for subsequent analyses, for example IFDC for age 2;0, 2;1, etc. This effectively controls for Age in all analyses.

Predicting vocabulary size

In preparation for answering the first research question (How much variance in vocabulary size is accounted for by ND and WF together and independently in two-year-old children?), correlations among the variables were examined. IFDC score had a moderate, positive, significant correlation with WF and a strong, negative, significant correlation with ND ($r(208)=0{\cdot}48$, $p<0{\cdot}001$; $r(208)=-0{\cdot}73$, $p<0{\cdot}001$ respectively). That is, as vocabulary size increased, WF increased and ND decreased. ND and WF were weakly and negatively correlated ($r(208)=-0{\cdot}25$, $p<0{\cdot}001$).

Plots of these relationships are shown in Figures 1 and 2. The plot for IFDC by ND reflects the significant negative correlation, with low vocabularies being comprised of high NDs relative to larger vocabularies. The plot for IFDC by WF reflects the significant positive correlation, with low

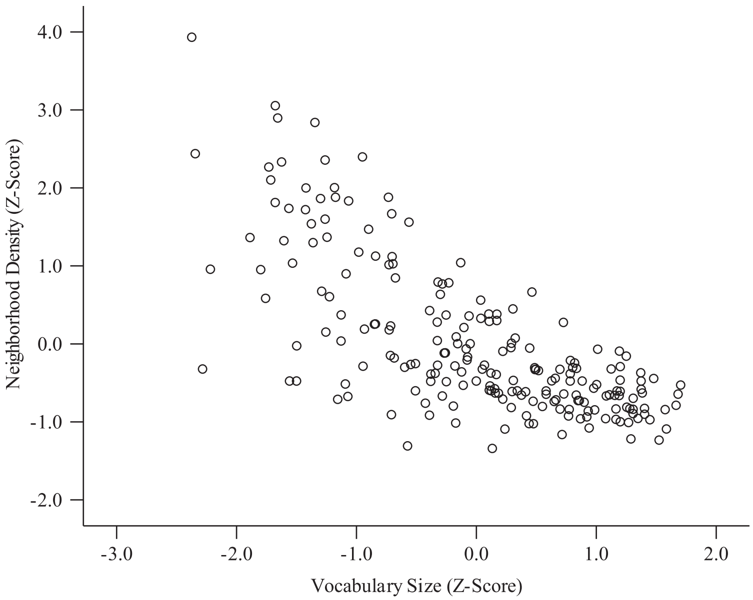

Fig. 1. Scatterplot of neighborhood density by vocabulary size.

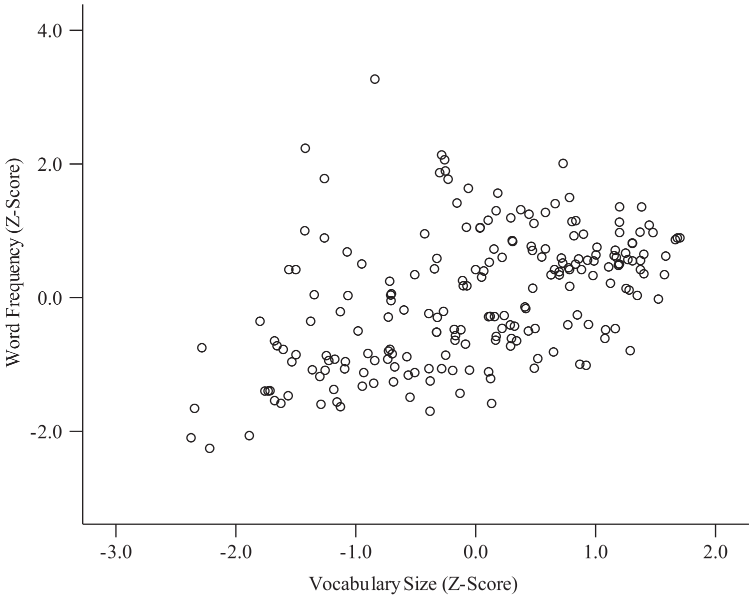

Fig. 2. Scatterplot of word frequency by vocabulary size.

TABLE 3. *Table of coefficients for the multiple regression predicting IFDC scores*

	Standardized coefficients			
	B	*t*	*p*	Confidence interval
(Constant)		0·00	1·0	
ND	−0·65	−14·50	0·000	−0·73 to −0·56
WF	.32	7·12	.000	0·23 to 0·41

Note: ND = neighborhood density; WF = word frequency.

vocabularies being generally comprised of low WF, although it is clear that there is some variability in both WF and ND values for the lowest vocabulary scores. A curve estimation regression revealed that both linear and quadratic relationships fit the data. While both were significant ($F(1, 206) = 222{\cdot}60$, $p < 0{\cdot}001$ and $F(2, 205) = 129{\cdot}12$, $p < 0{\cdot}001$ respectively), the linear fit was stronger and was chosen for subsequent analyses.

A multiple regression was conducted with IFDC as the outcome variable, and ND and WF predictors entered together, using the backward method. Probability plots suggested that the residuals were satisfactorily distributed, so the linear model was used. The model was significant ($F(2, 205) = 166{\cdot}53$, $p < 0{\cdot}001$), with WF and ND accounting for 62% of the variance in vocabulary scores. Inspection of the t values in the table of coefficients (Table 3) shows that ND was the strongest predictor, followed by WF. The partial correlation for ND was $r = -0{\cdot}71$, and for WF it was $r = 0{\cdot}48$, suggesting that WF and ND should be considered as separate factors contributing to the variance in vocabulary scores. With these results, a hierarchical multiple regression was run in which ND accounted for 53% of unique variance in IFDC scores ($F(1, 206) = 227{\cdot}60$, $p < 0{\cdot}001$), and WF accounted for 9% of additional unique variance ($F(1, 205) = 50{\cdot}63$, $p < 0{\cdot}001$).

Overall then, neighborhood density was inversely related to vocabulary size and was a strong predictor of vocabulary size in these two-year-old children. Larger vocabularies contained more words from sparse neighborhoods in the ambient language. Word frequency was directly related to vocabulary size; as vocabulary size increased, so did word frequency.

Group differences on neighborhood density

To answer the second research question (Is there a significant difference between children with small and large vocabularies in ND and WF?), children who scored at or below 1 SD on the IFDC for age were coded as

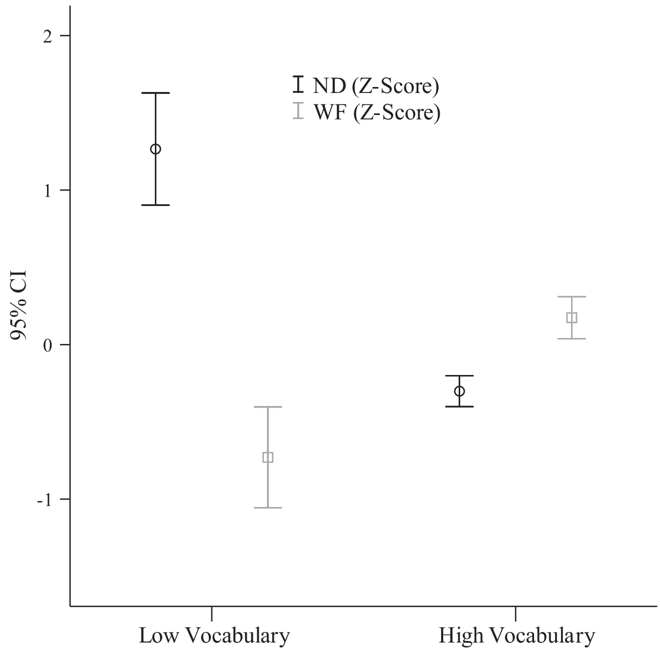

Fig. 3. Error bar plots for low and high vocabulary groups for neighborhood density and word frequency.

'low vocabulary' yielding 40 children in the low vocabulary group and 168 in the high vocabulary group. Inspection of the distributions of ND scores for the two groups indicated a lack of homogeneity of variance. A non-parametric Generalized Mann–Whitney test for unequal sample sizes (Odeh, 1972) revealed a significant difference between low and high vocabulary children in ND values ($U=846{\cdot}5$, $p<0{\cdot}001$). Children who scored at or more than 1 SD below the mean for age on the IFDC had higher ND than children scoring above 1SD below the mean ($M=1{\cdot}27$, $SD=1{\cdot}13$, and $M=-0{\cdot}30$, $SD=0{\cdot}65$, respectively).

The same analysis was conducted for WF scores. The children with low IFDC scores scored significantly lower on WF than the children with higher vocabulary scores ($U=1568{\cdot}5$, $p<0{\cdot}001$; $M=-0{\cdot}73$, $SD=1{\cdot}02$; and $M=0{\cdot}17$, $SD=0{\cdot}89$ for low and high vocabulary groups). Figure 3 shows the error bar plots (bars indicate confidence interval for the mean) for the two groups. Clearly there is more variability in the low vocabulary group for both ND and WF (discussed below). In summary, the lexicons of children with small vocabularies are comprised of words that are of high ND and low WF in the ambient language.

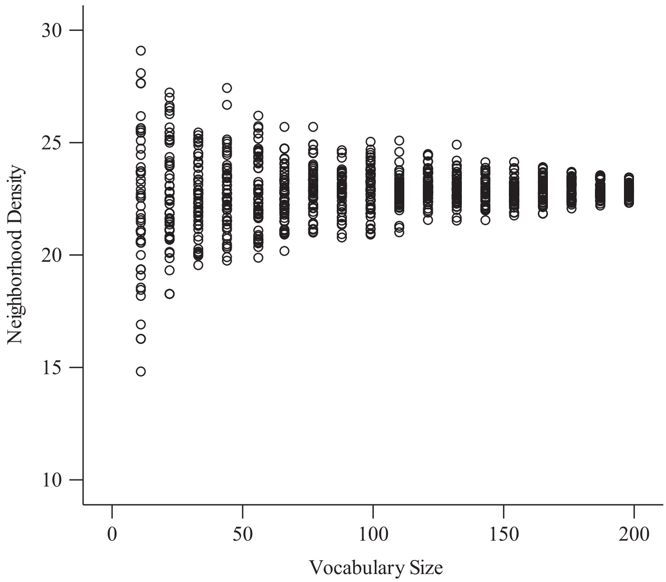

Fig. 4. Scatterplot of neighborhood density by vocabulary size for 900 simulated cases.

Fact or artifact?

Just as for English (Stokes, 2010), it was necessary to rule out possible artifact effects on the outcomes. The question 'Are these child vocabulary results authentic or epiphenomenal of the dataset?' must be asked. Simulations of random distributions of the 220 words in the database were generated using SPSS to explore the possibility that the results for the 208 two-year-old children were simply an artifact of the IFDC dataset. First, using SPSS Macros, syntax commands were written to generate 50 random samples at each of 5%, 10%, 15% … 90% of the data, that is, 50 samples of a lexicon size of 11 words, 50 samples of a lexicon of 22 words, etc. (900 random samples). For each sample, average ND and WF were generated, just as had been done for the child data. The scatterplots of IFDC by ND and IFDC by WF for these random samples are shown in Figures 4 and 5. Both ND and WF show extreme variability for small vocabulary sizes, and reduced variability in larger vocabularies (heteroscedasticity). For example, for the smallest vocabulary size the mean ND value could be anywhere between <15 to >28 and the mean WF value could be anywhere between <10 to >1000.

Second, from the 900 simulated children, five random samples of 208 cases (comparable to our start point for this study) were generated for comparison with our real dataset. Figures 6 and 7 show the scatterplots of

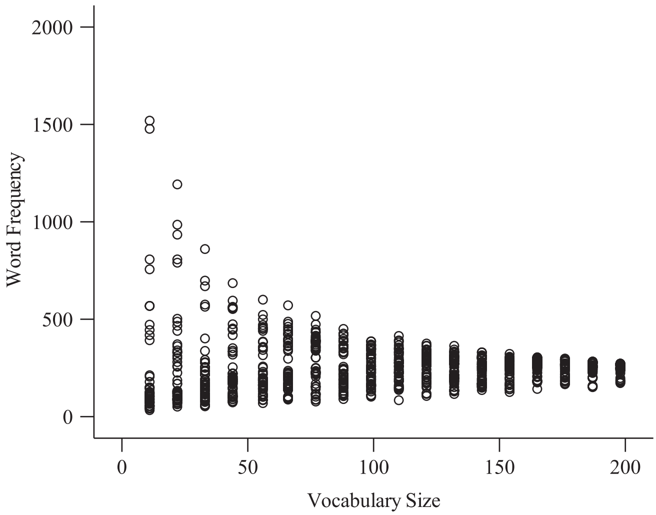

Fig. 5. Scatterplot of word frequency by vocabulary size for 900 simulated cases.

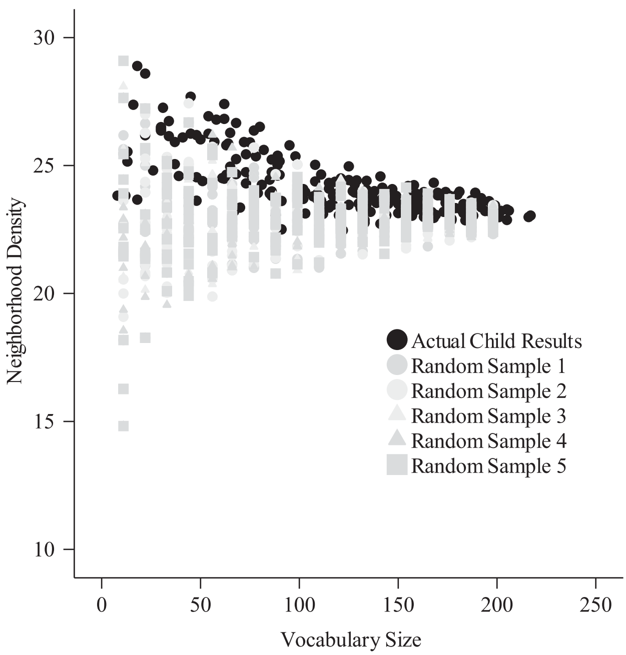

Fig. 6. Scatterplot of neighborhood density by vocabulary size for five random samples and actual child data.

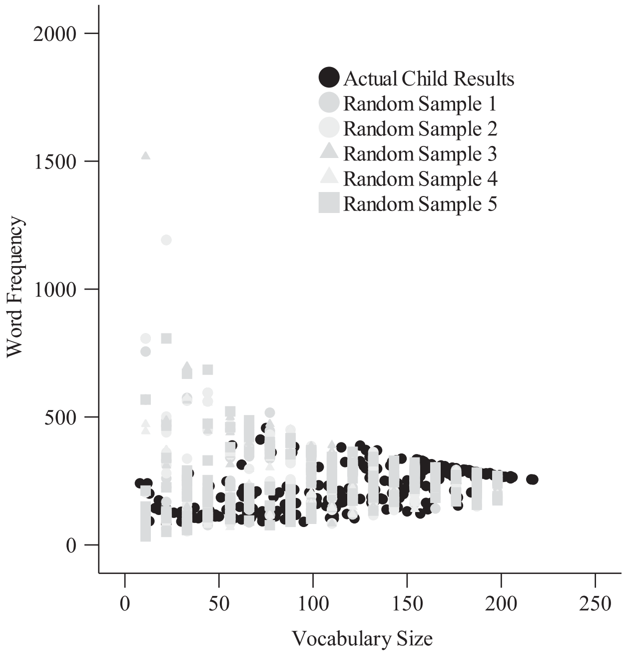

Fig. 7. Scatterplot of word frequency by vocabulary size for five random samples and actual child data.

these five random samples with the scores from our real cases. For ND the actual child data does not map onto the random samples, having a more linear distribution, indicating that the results of this study are authentic rather than epiphenomenal, that is, these are non-random developmental profiles. For ND, the children appear to score higher than the random samples. For WF, there appears to be more overlap in mean scores of the actual data with some of the random samples. For WF, the children appear to score lower than some of the random samples.

In order to find statistical evidence for this visual pattern, two one-way ANOVAs were run to determine whether or not the distributions differed among groups. (Levene's test of equality of error variances was not violated; $F(5, 1242) = 1{\cdot}09$, $p = 0{\cdot}36$.) For ND, there was a significant difference between the actual child data and all random samples although the effect size was small, but no differences among the random samples ($F(1, 5) = 38{\cdot}56$, $p < 0{\cdot}01$, *partial* $\eta^2 = 0{\cdot}13$). For WF the difference was not significant ($F(1, 5) = 2{\cdot}21$, $p = 0{\cdot}051$, *partial* $\eta^2 = 0{\cdot}009$). Box plots of ND and WF for simulated and real samples (95% confidence intervals for group means on the ordinal axis) are shown in Figure 8. The statistical analysis

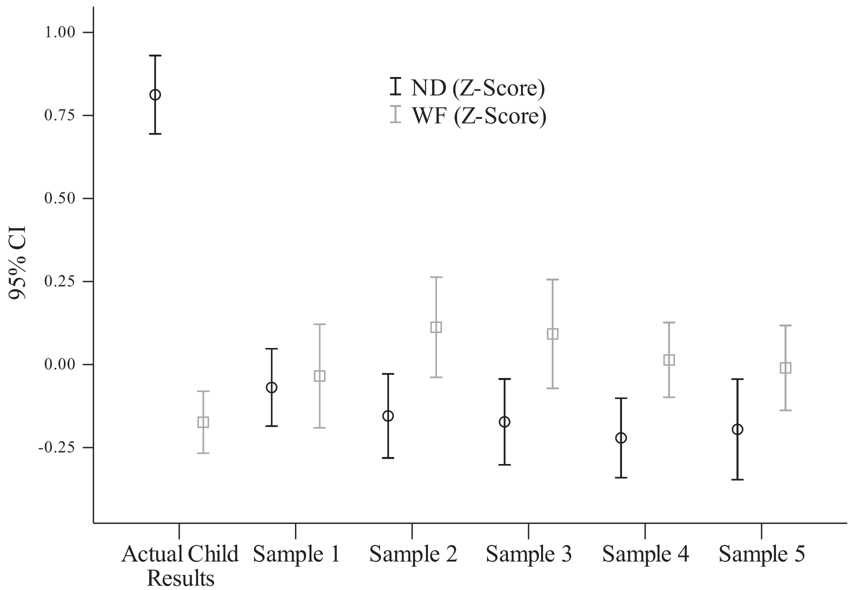

Fig. 8. Error bar plots for neighborhood density and word frequency for five random samples and actual child data.

shows that the probability that the child distributions for both WF and ND arose by chance was $<0{\cdot}06$.

From these simulations we can conclude that the results for the 208 children were not artifactual but truly reflect the propensity of children with small vocabularies to learn words from dense neighborhoods in the ambient language. The result was not as clear-cut for WF, where the scores had a 5% chance of occurring at random.

Comparison with English

Table 4 summarizes the findings for the two languages. First, for both languages ND and WF together account for a high proportion of the variance in vocabulary scores, and ND was a strong predictor, having an inverse relationship with vocabulary size. When the samples were split into low and high vocabulary groups, there is a slight difference between English and French. For the low vocabulary groups, there is marked variability in ND and WF values for both languages. For the high vocabulary group, while together the variables accounted for a high proportion of the variance in vocabulary size (44% and 48%), the contributions of the two predictors differ. WF accounted for one-third of the variance in vocabulary size for

TABLE 4. *Variance in vocabulary scores accounted for by neighborhood density and word frequency in English and French for the total sample and low and high vocabulary groups*

		English	French
[a]MCDI/IFDC	R^2 Total	0·61**	0·62**
R^2	ND	0·47**	0·53**
R^2	WF	0·14**	0·09**

		Vocabulary size			
		Low	High	Low	High
MCDI/IFDC	R^2 Total	0·37**	0·44**	0·22*	0·48**
R^2	ND	0·34**	0·11**	0·10 (n.s.)	0·36**
R^2	WF	—	0·32**	0·11*	0·12**

Notes: * $p < 0·05$, ** $p < 0·01$.
[a] MCDI and the IFDC indicate the MacArthur-Bates Communicative Development Inventory (Fenson *et al.*, 1993; Fenson *et al.*, 2007), British version (Klee & Harrison, 2001) and the French Communicative Development Inventory (Kern, 2003; Kern & Gayraud, 2010).

English but ND accounted for one-third of the variance in vocabulary for French. This difference may simply reflect the degree of variability in scores for the two languages for vocabulary size in the normal range for this age group. The relationships between WF and ND and WF and vocabulary size are discussed in Stokes (2010). While the relationships are weak, this is an issue that requires further exploration.

Summary of findings

Neighborhood density had a strong inverse relationship with vocabulary size and predicted 53% and 47% of the variance in vocabulary size for French and English respectively. Word frequency did predict vocabulary size, but it only accounted for 9% (French) and 14% (English) of the variance once neighborhood density had been accounted for. Children with CDI scores more than 1 SD below the mean for their age had significantly higher ND values and significantly lower WF values than children with average to large lexicons.

DISCUSSION

This research addressed three questions: How much variance in vocabulary size is accounted for by neighborhood density and word frequency together and independently in French-speaking two-year-old children? Is there a significant difference between children with small and large vocabularies in neighborhood density and word frequency? Are the distributions for English and French similar? Our hypotheses were that ND would be a very strong predictor of vocabulary size, that children with small vocabularies would be significantly different from the children with average–large lexicons in ND and WF values, and that the results for English and French would be similar. All hypotheses were confirmed.

Predicting vocabulary size

For this French sample, ND and WF together accounted for 62% of the variance in vocabulary size. ND alone accounted for 53% of the variance in vocabulary size, and WF contributed 9%. This strength of this relationship is unprecedented in the search for factors that predict vocabulary size. The first study for the English sample (Stokes & Klee, 2009) compared demographic, cognitive, behavioral and psycholinguistic predictors of vocabulary size and found that nonword repetition scores (36%), sex (5%) and age (4%) all contributed uniquely to variance accounted for in vocabulary size. The second study (Stokes, 2010) reported that ND and WF together accounted for 61% of the variance in vocabulary size, with ND accounting for 47% of unique variance. The French data confirmed the findings for English, that ND is a very strong predictor of vocabulary size and that children at the earliest point of lexical development are more likely to learn words that come from dense neighborhoods in the ambient language (Coady & Aslin, 2003; Storkel, 2004). This does not mean that if we examined the ACTUAL expressive lexicons of children with small vocabularies (within-child lexicons) we would find that all of the words sounded the same. They don't, although Dollaghan (1994) showed that of all the monosyllabic words on an earlier version of parent checklists, 84% of the words had a least one neighbor.

As is the case for English, French-speaking children with small vocabularies seemed to be learning words that came from dense phonological neighborhoods in the ambient language. Given the phonotactic differences between the two languages, it was possible that the results for French would differ from those for English. Recall that the percentage of open, closed and vowel only word structures (ending in a vowel, a consonant or comprising vowel only) is 55·71%, 26·09% and 17·22% for French, and 27·48%, 55·71% and 16·81% for English. With ND being defined as lead, rhyme and consonant neighbors, it was possible that this difference in word structure would contribute to across-language differences, but none emerged. Further exploration of neighborhood types could be interesting.

The lexicons of children with low vocabulary scores were qualitatively different from those of children with higher vocabulary scores. The question is why. There are detailed accounts of both behavioral (Saffran & Graf Estes, 2006) and computational evidence (Christiansen, Onnis, & Hockema, 2009) of statistical learning of phonological detail in early lexical development. Children with small vocabularies, who are slow to expand their lexicons, are learning words that have many phonological neighbors in the input stream (overlapping word forms; Saffran & Graf Estes, 2006). We suggest that late vocabulary learning is indicative of slowness to attune to the statistical regularities of the input language, but once attunement has been achieved, and constrained statistical learning has developed as a mechanism for learning first words, some of these toddlers continue to employ this strategy for an extended period of time (Extended Statistical Learning). This could be indicative of protolexical learning (Swingley, 2005). Swingley proposed that success with statistical learning enabled infants to generate a protolexicon of word forms that enabled less labored word learning, releasing cognitive processing to allow sound–meaning mapping. This constrained statistical learning may well be a necessary step en route to developing a lexicon. At some period, this constrained learning mechanism must be loosened, broadened or abandoned to allow mapping of words from sparser neighborhoods. How might this be achieved?

Our theory is that in early lexical learning, words from dense neighborhoods provide a recognizable familiar phoneme stream which is less taxing of short-term memory abilities than words from sparse neighborhoods (Saffran & Graf Estes, 2006; Swingley, 2005). Words from dense neighborhoods presumably lay down representations in long-term memory that can be called on to aid new word learning. Mirman, Graf Estes and Magnuson (2010), in a study of network learning, demonstrated that high transitional probability generated distinct phonological representations that allowed for fast learning of novel 'words' that were partly comprised of the high-probability syllables. High-density words may serve the same function perhaps in a processing mechanism akin to redintegration (Gathercole, 1999; Stokes, Wong, Fletcher & Leonard, 2006; Stuart & Hulme, 2009). These representations are organized into lexical networks (Vitevitch, 2008). In early lexical learning, words that come from dense neighborhoods need not be networked to each other, for example *ball* and *bird* are both of high densities (43 and 31 type neighbors respectively in British English) and both are learned early in development (Dale & Fenson, 1996). Representations would not be linked initially, but eventually their neighborhoods would be linked due to links formed from shared neighbors (e.g. *bird – bed – fed – fell – fall – ball*) as is shown in the network example (generated using Pajek; Batagelj & Mrvar, 1998), in Figure 9.

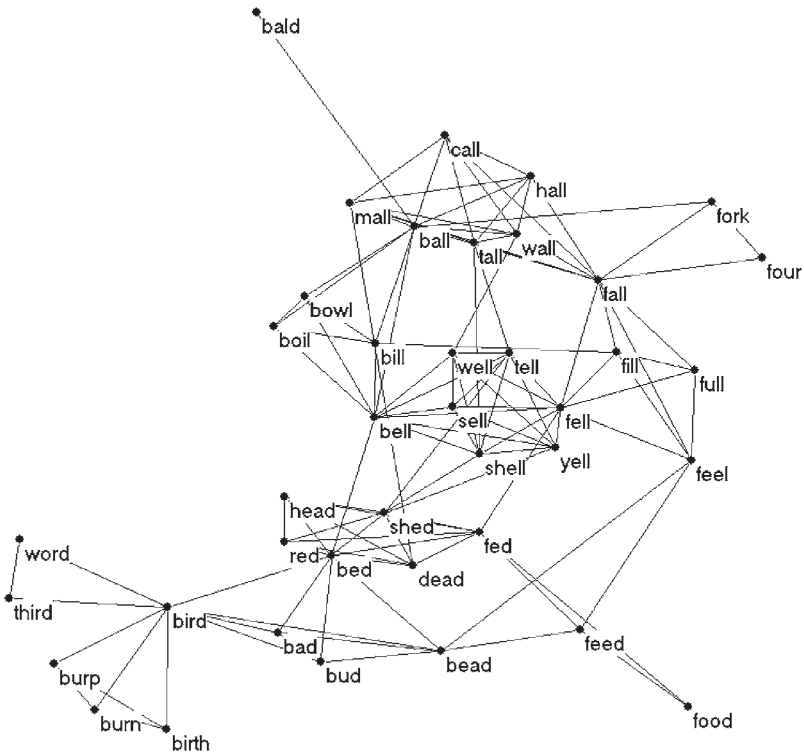

Fig. 9. An example of how *bird* and *ball* can be linked within a lexicon.

We believe that it is at this point that the child's constrained statistical learning mechanism is relaxed or broadened, as the overlap in words creates larger networks that facilitate new word learning. Thus long-term memory (stored phonological structures of words) begins to influence new word learning. Recall that some children with very small lexicons had ND values within the range of their more able peers. It is possible that these children have failed to yet use a statistical learning mechanism, restricting word learning to highly functional words. Confirmation of this hypothesis awaits analysis of actual words in the lexicons of these children. Obviously this is speculative and requires testing with longitudinal data from children. Only analyses of within-child lexicons will answer this question.

Finally, it is important to note that this study on French confirmed the surprising results for WF found for English, that of a direct relationship with vocabulary size, whereas prior research (Storkel, 2004) predicted that small lexicons would be comprised of highly frequent words. As vocabulary size was positively correlated with age, we found the same results that

Goodman *et al.* (2008) found for their entire word set. It is possible that our results resemble the whole-sample results from Goodman *et al.* because of the impact of adjectives and verbs in the current study. From Goodman *et al.* we know that verbs and adjectives tend to be acquired later than common nouns and that the correlation between the two former categories and word frequency was $r(90) = 0\cdot22$ and $r(55) = 0\cdot28$ respectively, compared with common nouns at $r(256) = 0\cdot55$ (see Figure 1 and Table 2 in Goodman *et al.*, 2008). Focusing only on open-class words, Goodman *et al.* found, as had Storkel (2004), that words of higher frequency were learned earlier. Further investigation is warranted to unpack how word frequency and lexical categories interact in word learning.

Limitations and further research

There are a number of possible limitations that should be considered in this study. First, phonological strings are not the only determinants of word learning. There are a host of other variables that play a role, for example, conceptual, linguistic, social-pragmatic and perceptual sources of information (Booth & Waxman, 2008; Thiessen *et al.*, 2005) that have not been explored here. Second, we considered only monosyllables for derivation of ND as other researchers have done. Multisyllabic words could be included but the effect is likely to be a skew in ND values because many multisyllabic words do not have neighbors (e.g. *popcorn*). Third, we studied only expressive vocabulary, not receptive vocabulary, and then only from parent-reported lexicons. Examining receptive and expressive vocabularies in the same children would be instructive. Fourth, it would also be instructive to carefully track the expanding lexicons of individual children to describe more finely the relationship between WF and lexical growth. Fifth, the distributions of neighborhood types should be examined (e.g. lead versus rhyme versus consonant neighborhoods; Zamuner, 2009) to test where the mapping occurs most easily. Finally, longitudinal data, computational modeling and experimental studies of word learning (see Saffran, 2009) should be used to examine the hypothesis proposed to account for the findings. It is possible that the relationship between neighborhood density and vocabulary size is an inverted U shape. Lexicons from a large sample of younger children would shed light on this possibility.

Summary

We have suggested that children who are slow to learn vocabulary (albeit typically developing in every other respect) may be slow to capitalize on the statistical regularities of the input language, and slow to use a statistical learning mechanism, and once they do so, may be slow to move on from this, thereby showing a period of EXTENDED STATISTICAL LEARNING. A network model of neighborhood densities was invoked to explain how a statistical learning mechanism could be broadened or loosened to enable learning of words from sparse neighborhoods in the input stream. The theory is also able to account for late talkers who appear to be learning sparse words early in lexical development. The theory should account for other cases of late talkers, and for children learning other languages. This work may move us forward to examining intersections across experimental, computational and corpora-based research in language learning.

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