

Phonological Neighbourhood Development in Children's Lexicons

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Abstract

A lexicon can be viewed as network of words connected by phonological similarity relations. In such a network model, words that sound similar are connected to be neighbours. The most often used criterion for defining neighbours is the one-phoneme difference rule (Luce & Pisoni, 1998), which states that any two words that only differ in one phoneme by addition, deletion or substitution are considered as phonological neighbours.

Previous studies have shown that children's phonological neighbourhoods are structurally different than those calculated from the adult lexicon (Charles-Luce & Luce, 1990; Coady & Aslin, 2003, among others). However, we also know that by the time children fully acquire the language, their phonological neighbourhoods should be similar to those in the adult lexicon. Thus the question becomes *how and when does the structural shift take place during language development*. As far as we know, this issue hasn't really been addressed in the literature.

The current study intends to fill in the gap by presenting a developmental analysis of the phonological neighbourhoods in two children's lexicon. The two children, Joel and Ruth, both in their second and third year of life during the study, were selected because their data presented interesting contrast in a previous study on grammar development. Our current results show that the structural properties of these two children's early phonological neighbourhoods are comparable to the findings in previous studies. More detailed network analyses suggest that they use different strategies for acquiring words in different stage. In the very early stage of acquisition, they tend to acquire words that are maximally different from each other but do not necessarily turn out to be structurally important later. Later, after their phonological neighbourhoods have reached a certain level of maturity, they tend to use a different strategy which prefers to acquire words that are structurally important first.

1. Introduction

A lot of things can happen during a year, especially when you are two years old. Among other wonderful things, most babies start to talk during their second year of life. We probably have all been curious (and jealous!) of how swiftly and effortlessly babies pick up the language, but they decide to keep the secret to themselves. This work, along with many others, presents some of the most recent attempts to unveil the mechanism for learning to speak inside a young child's brain.

The main question that we intend to address in this work is how words are organized in the child's mental lexicon, and how the organization changes as the child's language ability develops. We know that words in a lexicon are not isolated islands – they are connected in various ways. For example, the word *cat* and *dog* are semantically similar, both referring to animals that are often kept as pets by humans; on the other hand, the word *cat* and *kit* have similar pronunciation, with /k/ in the beginning and /t/ in the end but a different vowel in the middle. In this paper, we will focus on the latter type of connection, namely the phonological similarity relation.

A large number of studies have shown that the processing of a spoken word is largely dependent on the number of similar sounding words that exist in the lexicon. Words with more similar sounding words (i.e. phonological neighbours) are processed differently than words with fewer neighbours (Jones & Langford, 1987; Maylor, 1990; Schacter, 1999; Harley & Bown, 1998; Vitevitch, 1997; Vitevitch & Sommers, 2003; Vitevitch & Luce, 1999, 2005, among others), which provides evidence for the view that lexicon is organized in such a way that accessing one lexical item would activate other items with similar phonological forms. The most widely-used computational model for this idea is the Neighbourhood Activation Model (NAM; Luce & Pisoni, 1998). In NAM, any two words only in one phoneme by addition, deletion or substitution are defined as phonological neighbours and will be linked together. For instance, the word *cat* will have words such as *kit*, *pat*, *cap* and *bat* in its neighbourhood. Computational analyses such as size (i.e. the number of words in the network) and neighbourhood density (i.e. average number of links in each word) can be performed. Studies have shown that NAM provides a simple by handy way for studying the effect of phonological neighbourhood structure (Munson & Solomon 2004; Scarborough, 2002; Wright 2004).

In the field of child language, the investigation of phonological neighbourhoods have particularly important theoretical implications. The most interesting question is do children organize phonological neighbourhoods the same way as adults? As stated above, phonological neighbourhoods in adult's lexicon are constructed based on phonemic contrasts, therefore the core of the question is whether or not children, too, have phonetic representation for words in the lexicon. It is shown that infants as young as 6 months old can virtually discriminate any phonetic contrasts in the world languages (Aslin, Jusczyk & Pisoni, 1998). However, recent research also suggests that young children do not seem to use this perceptual ability with words. It is found that children before the age of 14 months are not sensible to the phonetic detail of words in the input (Hallé and de Boysson-Bardies, 1994; 1996), and that they fail to learn to associate two objects with two similar-sounding words (e.g. *bih* vs. *dih*), though they do learn to associate them with dissimilar words (e.g. *lif* and *neem*; Stager & Werker, 1997). It has even been argued that preilliterate children in general don't recognize that spoken words are composed of smaller units (Treiman & Breaux, 1982).

Thus the current literature presents two conflicting views. On one hand, children have the ability to detect and analyse subtle phonetic information well before they start to produce spoken words, but on the hand, they don't seem to put it into use when acquiring words till much later. If we assume that both views are correct, there are three issues that immediately arise. First, what is the reason that young children do not use their perceptual ability in acquiring words? Second, given the size of children's lexicon, is it adequate to use global strategies to maintain and acquire words? Third, since we know that at some point they must make the shift from holistic representation to a phonetically detailed one, when and how does the shift take place? And relatedly, how do their phonological neighbourhoods gradually develop into the form of adults' phonological neighbourhoods?

Regarding the first question, two possible factors have been suggested (Burke, 1976; Charles-Luce & Luce, 1990, among others). The first is that even though young children were sensitive to fine phonetic detail, they were not able to organize it into bundles of phonetic features in the right linear order as in the word. The second factor was due to the limitations on the cognitive ability to pay attention to and maintain all the information in the memory.

In response to the second question, a number of computational analyses of children's lexicons have been conducted in recent years. Charles-Luce

& Luce (1990) built phonological neighbourhoods for 5- and 7- year olds' expressive lexicons, and compared them with the adult lexicon. They found that there was an increase in both lexicon size and neighbourhood density across the lexicon in 7-year-old lexicon compared to the 5-year-old one. But when compared to the adult lexicon, both 5- and 7-year-old lexicons were lower in size and neighbourhood density. For example, most of the 3 phoneme words in children's lexicons (71% in 5-year-old; 66% in 7-year-old) have five or fewer neighbours, but very few of the same words (2% and 3% respectively) have five or fewer neighbours in adult lexicon. The results showed that words in children's lexicons were more structurally unique, which made it possible for holistic representation. Logan (1992) examined the lexicons of children between 1;6 and 2;0 of age, and found similar results. In particular, in addition to phonemic neighbourhoods, Logan also constructed neighbourhoods according to the similarity in place of articulation and manner of articulation. He found that coding words by place of articulation resulted in denser networks but coding by manner of articulation was comparable to coding by phonemic sequences, which suggests that only coding the manner of articulation could be one candidate for holistic representations. Coady & Aslin (2003) did a similar study for kids at the age of 3;6. Interestingly, they found that children's lexicons were denser than previously found. For children at the age of 3;6, words in their lexicon had on average six phonological neighbours. Their results questioned the possibility of using only holistic representation in early lexical acquisition. They also suggested that words with more frequent sounds were acquired first and later words with less frequent sounds were filled in. Along the same line, Storkel's (2004) examined the age of acquisition of nouns in children's lexicons, and found that word length, word frequency and neighbourhood density all predicted the age of acquisition. Early acquired words were on average higher in density, higher in word frequency and shorter in length than late acquired words.

To our knowledge, there hasn't been much investigation on the third question, which considers the development of phonological neighbourhoods. Most computational analyses, as listed above, study a snapshot of the developing lexicon, using either production data or parental vocabulary report. In this work, we intend to fill in the gap by providing developmental analyses of two children's phonological neighbourhoods over a time course of one year. We use spontaneous production data as

input to the network model, and special attention is paid to the relation between neighbourhood density and the sequence of acquisition.

2. Methods

2.1. Database

The dataset we use is the Manchester corpus in the CHILDES database (Child Language Data Exchange System; McWhinney, 1991). The corpus contains data from 12 children, 6 boys and 6 girls, all from monolingual English-speaking families in Manchester. At the beginning of the study, the children ranged in age from 1;8.22 to 2;0.25, with MLUs between 1.06 and 2.27. During the year-long study, each child was visited by the experimenter and recorded twice every three weeks, resulting in 34 visits in total. Each recording session lasted for about an hour. During the recording session, the child was engaged in normal play activities with the main care-taker (usually the mother) and the experimenter. All speech, including that of the caretaker's and the experimenter's was transcribed in English orthography in CHAT file format (MacWhinney, 1991). Only spontaneous utterances from the children are extracted from the transcripts, and comprise the dataset for the current study; utterances that are immediate repetition or imitation are removed.

Two of the twelve children, Joel [1;11- 2;10] and Ruth ([2;0 – 2;11]), are chosen for the current study because they showed interesting contrasts in our previous study. In Ke & Yao (2008), we reported a computational analysis of grammatical development using the same database. We built collocation networks based on the children's utterances (e.g. for the utterance *I like mama*, two links will be added to the network $I \rightarrow like$ and $like \rightarrow mama$). Our results showed a great deal of individual difference in terms of network size and connectivity. In specific, Joel always had large but sparse collocation networks, while Ruth had small but dense networks. The difference in network structure between the two children cannot simply be explained by the different acquisition rate. We concluded that grammatical development in the two children was probably along different lines, and there was reason to believe that they employed different learning strategies for acquiring language in general.

2.2. Stage division

As per Ke & Yao (2008), we divide the one-year period into several stages in order to monitor the dynamics of language acquisition. Our main criterion for dividing stages is MLU. MLU is within [1,1.5] in stage 1, and increases by 0.5 in every succeeding stage (i.e. [2,2.5] in stage 2, [2.5, 3] in stage 3, and so on). We also control for the time span of each stage, as well as the number of transcript files. Each stage lasted about 40 days in time has 5 recording transcripts as input, which equals to 5 hours of recording. If a certain MLU stage is too long for a single stage, we either drop transcripts or divide the stage into two. Thus, Joel has stage 1, 2, 3, 4-1 (for early stage 4), 4-2 (for late stage 4), and 5; Ruth has stage 1, 2, 3-1 (for early stage 3), 3-2 (for late stage 3), 4, and 5.

2.3. Network model

In each stage, a stage lexicon is constructed using the five input transcripts. As per Coady & Aslin (2003), regular inflected forms and contracted forms whose base forms also existed in the current stage lexicon are removed. For instance, the word *runs* and *running* will be excluded if *run* already exists, but the word *went* will be kept even if *go* already exists. Similarly, *are'nt* will be excluded if *are* exists. Compound forms are broken into individual words (e.g. *Mr+grumpy* is broken into *Mr* and *grumpy*). Proper names (e.g. *Peggy*), onomatopoeic terms (e.g. *cockadoodledo*) and child forms (e.g. *choo*) are kept. Phonetic transcription is obtained from the CELEX database of British English. If the word has more than one primary pronunciation, all of them will be coded as variation forms for the same word in the network. The one-phoneme-difference rule is adopted for defining phonological neighbours. If a word has more than one pronunciation, all variation forms will be compared in determining neighbours.¹

3. Results

3.1. Preliminary results

Figure 1 and 2 below show the size and average density of the lexicons over time. In both children's networks, there is a general increase in size

over time. At all stages, Joel's network has more words than Ruth's networks. The raw counts of average neighbourhood density, on the other hand, are harder to interpret, as neighbourhood density is closely related to word length (see Storkel, 2004 for a detailed discussion). In the following section, we study the neighbourhood density distribution in more detail when word length is controlled.

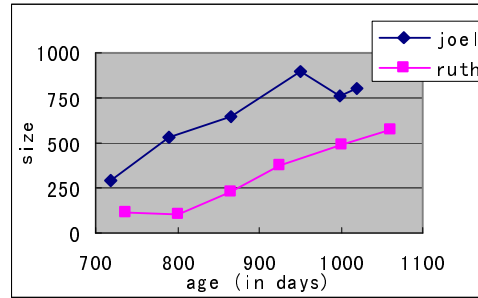


Figure 1 Size of lexicons over time. X-axis is the middle time point of the stage. Y-axis is the size of the lexicon. Each data point corresponds to a stage lexicon.

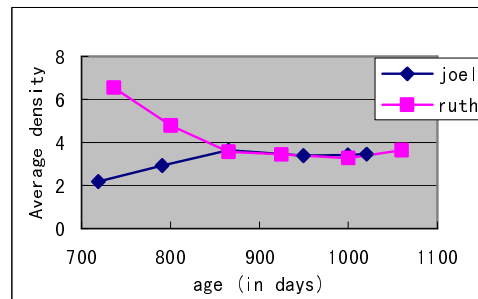


Figure 2 Average density of lexicons over time. X-axis is the middle time point of the stage. Y-axis is the average density of the lexicon. Each data point corresponds to a stage lexicon.

3.2 Examining neighbourhood density with controlled word length

First we will look at some general measures of word length. Figure 3 shows the average word length in phonemes over time. Figure 4 shows the proportion of words at each length in both children's stage lexicons. As shown in Figure 4ab, 3 phoneme words outnumber words of other

lengths, comprising about 30%-40% of the lexicon at all times, which is consistent with previous findings on child lexicons.

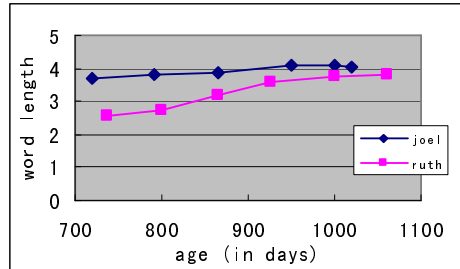


Figure 3 Average word length in both children's stage lexicons. X-axis is the middle time point of the stage. Y-axis is the average density of the lexicon. Each data point corresponds to a stage lexicon.

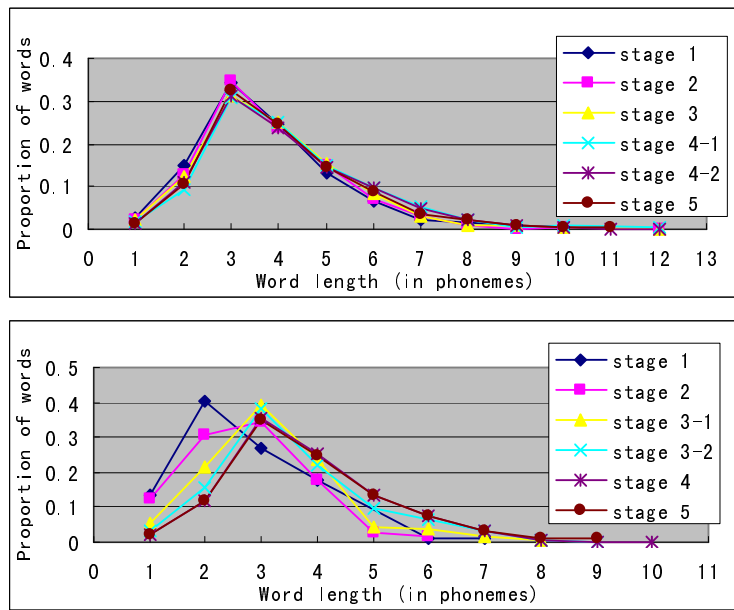


Figure 4 Proportion of words at each length in Joel's stage lexicons (on top panel) and Ruth's stage lexicons (on the bottom). X-axis is word length in phonemes. Y-axis is the proportion of words in the lexicon.

Figure 5 below shows the average neighbourhood density as a function of word length. There is clearly a negative correlation between word length and number of neighbours. One phoneme words have the highest number of neighbours (>10), because in theory they are all neighbours of each other. 2 phoneme words (~10 neighbours) and 3 phoneme words (~5 neighbours) follow in the rank.

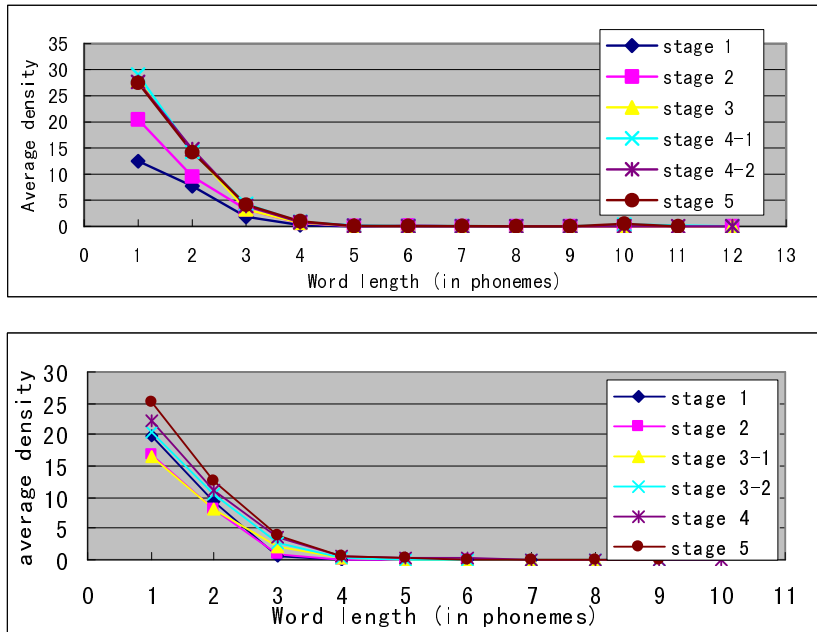


Figure 5 Average neighbourhood density as a function of word length in Joel's (on top) and Ruth's (on bottom) stage lexicons

Next we look at the density distribution in 3, 4, and 5 phoneme words, respectively. In both children's networks, even at the last stage, most of the 4 phoneme words (48% for Joel; 55% for Ruth) and almost all the 5 phoneme words (91% for Joel 84% for Ruth) have zero neighbours. As for 3 phoneme words, the distribution is more spread out. However, in Ruth's networks, the distribution is significantly skewed toward the lower number of neighbours in the early stages. It is only in the last stage that the proportion of words with two neighbours exceed that of words with one

neighbour. Contrarily, Joel's networks have more 3 phoneme words with two neighbours than those with one neighbour after the second stage (with the exception of early stage 4). For comparison, 3 phoneme words have on average more than 15 neighbours in adult lexicon. Figure 6 below shows the density distribution in 3 phoneme words in Joel's and Ruth's lexicons respectively.

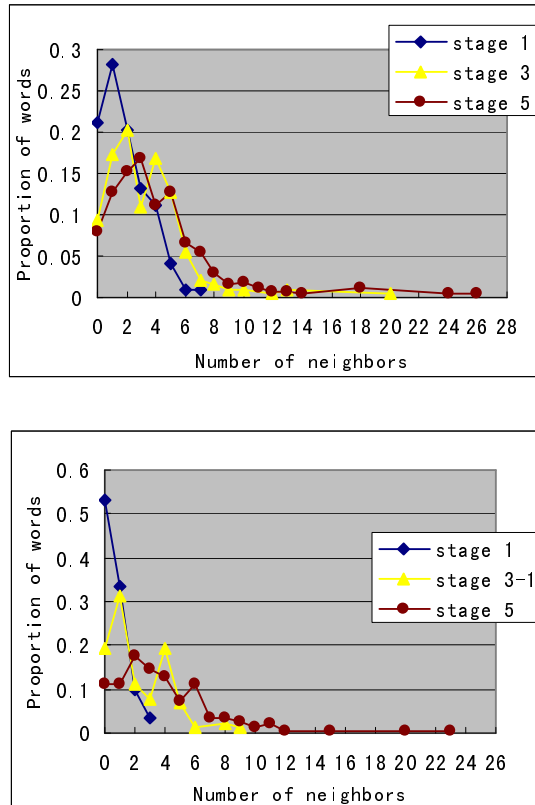


Figure 6 Proportion of 3 phoneme words in Joel's (top) and Ruth's(bottom) lexicons as function of number of neighbours. X-axis shows number of neighbours. Y-axis shows the percentage of words. Only three stages, stage 1, 3 and 5 are shown in the figure for a good intelligibility.

3.3. Phonological network development

Coady & Aslin (2003) proposed that words with more frequent sounds are acquired early while words with less frequent sounds are acquired late. Storkel's (2004) study using the data in MacArthur communicative development inventories (CDI) confirms that neighbourhood density, word frequency and word length all predict the age of acquisition. In this study, we are interested in using spontaneous production data to test whether neighbourhood density affects the order of acquisition in early stages. We assume that lexical development is a dynamic process, as children both acquire new words and lose existing words. Therefore, there are two possible operations on the lexicon, addition and deletion. Our hypothesis considering the sequence of addition and deletion is as follows.

***Hypothesis** Words that are newly added to the lexicon have fewer neighbours than existing words and similarly. Words that remain in the network from stage to stage have more neighbours than words that lost later.*

If this hypothesis is proved to be true, it will support Storkel's (2004) finding that words with more phonological neighbours are acquired earlier than words with fewer neighbours.

3.3.1. New vs. old words

We partition the lexicon in a non-initial stage lexicon into "new" words (i.e. words that don't exist in the previous stage lexicon) and "old" words (i.e. words that already exist in the previous stage lexicon). We then plot the neighbourhood density of 3-, 4- and 5- phoneme words in both the "new" category and the "old" category. A Welch's two sample t test is performed for each combination of word length and stage to see if the neighbourhood density distribution is significantly different between the "new" words and the "old" word. Table 1 below show the results of statistical analysis for Joel's and Ruth's data. As shown below, in stage 3 and early stage 4 of Joel's lexicon, the average density of 3 phoneme old words is significantly higher than the density of 3 phoneme new words. In late stage 4, the average density of 4 phoneme old words is significantly higher than the density of 4 phoneme new words. No other statistical significance is observed.

Joel's neighbourhood density of "old" words vs. "new" words at each stage

	s2		s3		s4-1		s4-2		s5	
	old	new	old	new	old	new	old	new	old	new
3	59	124	116	87	148	127	158	79	192	68
phoneme	3.59	3.06	3.70*	2.67*	4.64*	3.90*	4.08	3.55	4.13	3.80
4	30	96	67	94	94	130	94	87	135	62
phoneme	0.66	0.65	0.71	0.68	0.96	0.78	0.98*	0.62*	1.03	0.87
5	14	64	40	61	45	90	46	64	68	49
phoneme	0.07	0.07	0.05	0.11	0.2	0.2	0.10	0.07	0.10	0.06

Ruth's neighbourhood density of "old" words vs. "new" words at each stage

	s2		s3-1		s3-2		s4		s5	
	old	new	old	new	old	new	old	new	old	new
3	15	22	22	67	59	83	88	85	124	76
phoneme	0.53*	1*	1.72	2.38	2.98	2.73	3.89	3.29	4.18*	3.18*
4	11	8	15	38	38	44	48	77	71	71
phoneme	0	0	0.26	0.23	0.23	0.20	0.54	0.55	0.67	0.57
5	/	3	1	9	6	31	16	49	33	43
phoneme	/	0	0	0	0	0.03	0.12	0.20	0.18	0.13

Table 1. Comparing the phonological neighbourhood density of words that are 3, 4, and 5 phonemes long between new words and old words at each non-initial stage lexicon of Joel (on top) and Ruth (on bottom). For each word length (3, 4 or 5) × stage × word category (old or new) combination, two values are provided: number of cases (on the first row) are average neighbourhood density (on the second row). Statistical significance is marked by the presence of * on the third row beside the average neighbourhood density in both word categories. A significant level of $p = 0.1$ is used. *As shown in Table 1a, in stage 3 and early stage 4 of Joel's lexicon, the average density of 3 phoneme old words is significantly higher than the density of 3 phoneme new words. In late stage 4, the average density of 4 phoneme old words is significantly higher than the density of 4 phoneme new words. No other statistical significance is observed.*

In Ruth's lexicon, in stage 2, the density of 3 phoneme old words is significantly lower than that of new words of the same length; in the final stage, stage 5, the density of 3 phoneme old words is significantly higher than that of new words of the same length. No other statistical significance is observed.

In summary, the results are more complicated than the null hypothesis has predicted. In both children's lexicon, only 2 or 3 out of 18 cases (6 * 3) show a statistically significant difference in the number of neighbours between old words and new words of same length. In Ruth's lexicon, there is even a reversed case in the second stage, in that new 3 phoneme words have more phonological neighbours than old 3 phoneme words. There are at least two things that can be observed from the tables above. First, the effect of order of acquisition (old vs. new) on phonological neighbourhood density is a function of word length. It is more robust in 3 phoneme words compared to 4 or 5 phoneme words. Second, there is an interaction with order of acquisition and sample size. As shown above, the expected correlation (i.e. old words having more neighbours than new words) only start to show in the lexicon in later stages in both children. The fact that it shows up in 3 phoneme words before 4 or 5 phoneme words can also (at least partly) be explained by the difference in sample size, as 3 phoneme words always outnumber the other two categories.

3.3.2. Lost vs. retained words

We examined the second half of the hypothesis in a similar way. Words in each non-final stage lexicon are partitioned into lost words (i.e. words that only exist in the previous stage but not the current one) and retained words (words that are common to the previous and the current lexicon). Neighbourhood density of lexical items of same length are compared across the lists using Welch's two sample t test. The results are shown below.

In stage 3 and early stage 4 of Joel's lexicons, the density of 3 phoneme retained words is significantly higher than the density of 3 phoneme lost words. In late stage 4, a similar trend is observed for 4 phoneme words. No other significance is observed.

Similarly, in late stage 3 and stage 4 of Ruth's lexicon, the density of 3 phoneme retained words is significantly higher than the density of 3 phoneme lost words. No other significance is observed.

Joel's neighbourhood density of "lost" words vs. "retained" words at each stage

	s1		s2		s3		s4-1		s4-2	
	lost	retain	lost	retain	lost	retain	lost	retain	lost	retain
3 phoneme	40	59	67	116	55	148	117	158	45	192
	1.87	1.84	2.97	3.38	2.65*	3.49*	3.82*	4.65*	4	3.89
4 phoneme	42	30	59	67	67	94	130	94	46	135
	0.21	0.23	0.72	0.59	0.61	0.75	0.76	1	0.52*	0.91*
5 phoneme	24	14	38	40	56	45	88	47	42	68
	0	0	0.07	0.07	0.10	0.06	0.20	0.19	0.11	0.07

Ruth's neighbourhood density of "lost" words vs. "retained" words at each stage

	s1		s2		s3-1		s3-2		s4	
	lost	retain	lost	retain	lost	retain	lost	retain	lost	retain
3 phoneme	15	15	15	22	30	59	54	88	49	124
	0.8	0.46	1.066	0.63	2.2	2.23	2.31*	3.15*	2.93*	3.86*
4 phoneme	9	11	4	15	15	38	34	48	54	71
	0.22	0	0	0	0.33	0.21	0.17	0.25	0.5	0.54
5 phoneme			2	1	4	6	21	16	32	33
			0	0	0	0	0.04	0	0.15	0.21

Table 2a. Comparing the phonological neighbourhood density of words that are 3, 4, and 5 phonemes long between "lost" words and "retained" words at each non-initial stage lexicon of Joel (on top) and Ruth (on bottom). Table presented in the same fashion as Table 1a, except that the two category names are different.

The findings with lost vs. retained word comparison reveal a similar tendency as the new vs. old comparison. In other words, predicted difference doesn't really show up, and when it does, it only shows up in 3 phoneme words in later stages of the lexicon.

3.3.3. General trend

One potential problem of the analyses in 3.3.1 and 3.3.2 has to do with the sampling rate of the corpus. In this study, we generally assume that the stage lexicons built based on data from the recording sessions are a good

enough approximation of the child's mental lexicon at that time. It is certainly true that they cannot reflect 100% of the child's actual lexicon since the sampling rate is only one hour per 10 days. However, it is not a big problem when we are comparing quantitative measures such as size and degree across networks, because if sampling rate has an effect, it should affect all networks equally (see more discussion on this topic in the discussion section below). But it does become a potential problem in the study of words that are acquired or lost from one stage to the next. It is possible that a word form is miscounted as newly acquired (in the next stage) or lost (in the current stage) just because it happens not to show up in the recording sessions. The seriousness of this problem depends on the probability of words being accidentally missing from all five hours of recording spread out in a time span of 40 days.

In view of this problem, we design a separate study, in which the first three stage lexicons are merged as the lexicon for the first half of the year, and the final three stages are merged as the the second half of the year. Similar analyses as in 3.3.1 and 3.3.2 are performed on the two half-year lexicons. The results are presented in the tables below.

The results show that in Joel's lexicons, 3 and 4 phoneme words that stay throughout the year have more neighbours than words of same length that only appear in the second half of the year. Similarly, 3 phoneme words that exist in both lexicons have more neighbours than those that disappear later. A reversed trend is observed for 5 phoneme words, in that words that later disappear from the lexicon have more neighbours than those stay in. Interestingly, a slightly different observation is also made in Ruth's lexicons, as 5 phoneme words that only appear later seem to have more neighbours than those that show up first. No other pattern is observed for Ruth's lexicons.

In summary, the results from the half-year lexicons are consistent with our findings from stage lexicons, in that in most cases, there is no significant difference in terms of neighbourhood density between newly-acquired and old words, as well as between lost and remaining words. If a neighbourhood density difference does show up, it is more obvious in 3 phoneme words. However, it is also possible for the density effect to show up in the opposite direction of the hypothesis would predict (as in the case of 5 phoneme words here), which can probably be explained by the small sample size.

Joel's network density between "retained" and "lost" words in the 1st half of the lexicon, and between "old" and "new" words in the 2nd half

	1 st half lexicon		2 nd half lexicon	
	retain	lost	old	new
3 phoneme	234	58	234	158
	4.62*	3.84*	6.12*	5.36*
4 phoneme	159	89	159	191
	1.17	1.13	1.54	1.17
5 phoneme	84	75	84	154
	0.13*	0.30*	0.29	0.35

Ruth's network density between "retained" and "lost" words in the 1st half of the lexicon, and between "old" and "new" words in the 2nd half

	1 st half lexicon		2 nd half lexicon	
	retain	lost	old	new
3 phoneme	93	18	93	191
	2.33	2.61	5.21	4.89
4 phoneme	53	13	53	168
	0.30	0.53	0.90	0.96
5 phoneme	11	1	11	114
	0	0	0.09*	0.29*

Table 3. Comparing the phonological neighbourhood density of words that are 3, 4, and 5 phonemes long between the "lost" words and "retained" words in the first half of the lexicon of Joel (top) / Ruth (bottom), and between "old" words and "new" words in the second half of the lexicon of Joel (top) / Ruth (bottom). Other conventions are the same as in Table 1a.

4. Discussion

4.1. On interpreting phonological network development

In general, our results with regarding to the general features of static stage lexicons are consistent with the findings in other studies on children's phonological neighbourhoods. However, the most interesting finding of this paper is that the hypothesized neighbourhood density effect doesn't show up in the early stage of lexical acquisition. As we have shown

above, in most cases, words that are acquired first don't seem to have more phonological neighbours than words that are acquired later of same length. Similarly, words that are removed from the lexicon don't seem to have fewer neighbours than those that stay (of same length). In the few cases that neighbourhood density effect does show, (a) it happens more often in 3 phoneme words than in 4 or 5 phoneme words; (a) it tends to happen later in the acquisition process; and (c) when the sample size is small, as in the case of 3 phoneme words in the early stages and 5 phoneme words in general, there might be a reversed neighbourhood density effect, in that words acquired later (or removed from the lexicon) have more neighbours than those acquired earlier (or remain in the lexicon). These findings all suggest that children only start to show a preference for acquiring and keeping words with more neighbours when their lexical acquisition passes a certain level. At least in early stage of lexical development, neighbourhood density is either not the major factor that decides whether a words should be added to or removed from the lexicon, or predicts in the opposite direction.

Let's consider two different scenarios with respect to word acquisition and neighbourhood density. In scenario A, words that are newly acquired are generally lower in number of neighbours than words that are acquired earlier. This means that at any give point, words that already exist in the lexicon are structurally more important (by having more connections) than words that are newly added. In other words, old words eventually form the backbone of the network. (Note that under this scenario, it is not necessarily the case that average number of neighbours would decrease over time because all words may benefit from the addition. It is just that after the addition, old words have more neighbours than new words) Such a growing pattern would entail that words that eventually have more neighbours in the adult lexicon will be added earlier.

In scenario B, words that are newly acquired are generally higher in number of neighbours than words that are acquired earlier. This means that structurally important words (judging from the resultant network) are acquired later. That is to say, before these words are added, there already exist a number of words that are remotely similar, but haven't formed a neighbourhood yet. After the new word is added, previously disconnected words are drawn together because they are all connected to the new word now. This would be the case that Charles-Luce & Luce (1998) predicted, that children start with sparse phonological neighbourhoods and later new words fill in the gaps.

Similar implications can be drawn with regard to the removal of words from the lexicon. Our results show that both scenario A and B exist in Joel's and Ruth's phonological neighbourhoods development. More specifically, scenario B is more likely to be used early in the process and scenario A later. This is understandable because the strategies in scenario B allow children to start with a small and sparse networks and encode more heavily connected words later, thus it reduces the burden on perceptual and other cognitive abilities to analyse and maintain similar words in the initial stage of lexical acquisition. Later when children are more experienced with acquiring and organizing similar sounding words and have acquired some structurally important words, they tend to use more the strategies in scenario A because adding words to existing neighbourhoods requires less effort than adding words that form new neighbourhoods. Notice that the shift occurs during the time where the acquisition of vocabulary and grammar is both around critical stages (during the naming explosion; MLU is between 2 and 2.5), therefore it is not surprising if they tend to use an effort-saving strategy for organizing the phonological neighbourhood. In general, our data support the view that children start with a sparse network of words that might not turn out to be structurally important later, and quickly shifts to a denser network with a backbone structure that is more similar to the final network. According to our data, the shift happens in the third year of life, probably when the phonological network reaches a certain level of size and complexity.

4.2. On individual differences

In our previous study (Ke & Yao, 2008), we found that the two children, Joel and Ruth had very different structure in their collocation networks, and that the difference cannot simply be explained by different acquisition rate. In the current study, the two children's network development is significantly different, however, the difference does seem to be mostly in speed. Joel's networks are not only bigger in size (cf. Figure XXX), but also converge to the stable point more quickly (cf. Figure XXX and XXX). In addition, the reversed neighbourhood density effect, which is probably a signal of early stage in lexical acquisition, is more often observed for Ruth's networks whereas the predicted neighbourhood density effect, which signals later stage of lexical acquisition, is more often (and also earlier) observed in Joel's networks. All the above evidence suggest that

Joel is ahead of Ruth in terms of phonological neighbourhood development, although their age and MLU are comparable.

Notes

1. For words with more than one syllables, stress needs to fall in the same position for them to be neighbours of other words (e.g. *pit* and *pity* are still considered as neighbours, but not *'convert* and *con'verter*).

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