Individual differences in the influence of phonological characteristics on expressive vocabulary development by young children

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Abstract

The current study attempts to differentiate effects of phonotactic probability (i.e., the likelihood of occurrence of a sound sequence), neighborhood density (i.e., the number of phonologically similar words), word frequency, and word length on expressive vocabulary development by young children. Naturalistic conversational samples for three children (age 16-37 months) were obtained from CHILDES. In a backward regression analysis, phonotactic probability, neighborhood density, word frequency, and word length were entered as possible predictors of ages of first production of words for each child. Results showed that the factors affecting first production of words varied across children and across word types. Specifically, word length affected ages of first production for all three children, whereas the other three variables affected only one child each. The implications of these findings for models of expressive vocabulary development are discussed.

Introduction

Young children learn new words rapidly and effortlessly. For example, children can form an initial mental representation of a novel word after only a single exposure (Carey, 1978). In addition, young children with normal language development can accurately recognize and, in some cases, produce novel words following only limited exposure (e.g., Dollaghan, 1985). Recently, attention has been focused on the aspects of language structure that may facilitate this rapid acquisition. In particular, the influence of phonological characteristics, such as phonotactic probability and neighborhood density, on expressive vocabulary development has been examined. Phonotactic probability refers to the frequency of occurrence of a phoneme sequence in a given language. Neighborhood density refers to the number of words that are phonologically similar to a given word (Luce & Pisoni, 1998). A neighborhood often has been defined as the words that differ from a given word by one phoneme. For example, neighbors of the word kit /kɪt/ include sit /sɪt/, coat /koʊt/, king /kiŋ/, it /ɪt/, and skit /skɪt/. Both variables have been shown to influence production of known words as well as the acquisition of expressive vocabulary.

High phonotactic probability appears to facilitate production and acquisition of expressive vocabulary by children. For example, children between 3 and 8 years of age repeat nonwords composed of high probability sound sequences more fluently and accurately than nonwords composed of low probability sequences (e.g., Edwards, Beckman, & Munson, 2004). This facilitory effect of high probability appears to change with expressive vocabulary size such that children with smaller vocabularies show a larger effect of phonotactic probability on repetition than children with larger vocabularies (Edwards et al., 2004). This implies that the influence of phonotactic probability on production may change over the course of expressive vocabulary development. Regarding acquisition, children from 3 to 13 years of age learn novel words composed of high probability sound sequences faster than novel words composed of low probability sound sequences (e.g., Storkel, 2001). Thus, the effect of phonotactic probability on production and expressive vocabulary is similar.

Previous studies also have shown that high density facilitates production and acquisition of spoken words by children. German and Newman (2004) found that 7- to 12-year-old children named words with many neighbors more accurately than words with few neighbors. Turning to acquisition, Storkel (2004a) examined the relationship between density and age-of-acquisition of words, using a naturalistic database of the expressive vocabularies of infants and toddlers (ages from 8 to 30 months). The results showed that young children learned words with many neighbors at earlier ages than words with few neighbors. Again, similarities are observed between production and acquisition.

Given this similarity between the effects of phonotactic probability and neighborhood density on production of known words and acquisition of expressive vocabulary, it is important to consider the relationship between production constraints, stemming from the phonological system, and vocabulary acquisition effects, attributable to the lexical system. It has been argued that children build a mental lexicon based on templates of known phonological structures (e.g., Velleman & Vihman, 2002). Moreover, there is clear evidence that children’s phonotactic constraints influence their acquisition of expressive vocabulary during the earliest stages of word learning. For example, children produce new words containing sounds that they produce (IN sounds) more readily than those containing sounds that they do not produce (OUT sounds; e.g., Schwartz & Leonard, 1982). At the core of this issue is whether language input and output share a common representation or have distinct separate representations (e.g., Monsell, 1987). If input and output share a common underlying representation, then variables that affect acquisition of expressive vocabulary should also affect acquisition of receptive vocabulary. On the other hand, if input and output representations are distinct, then different variables may affect expressive versus receptive vocabulary acquisition. Importantly, the effects of phonotactic probability and neighborhood density on expressive vocabulary also have been shown for receptive vocabulary (Storkel & Rogers, 2000; Storkel, 2001). This is consistent with the idea that expressive and receptive vocabulary share a common representation and that the effects of phonotactic probability and neighborhood density can not be solely attributable to production constraints. Thus, we tentatively assume that production evidence can be studied to infer the mechanisms that underlie acquisition of expressive vocabulary.

Few studies have attempted to disentangle the influence of phonotactic probability from that of neighborhood density in the acquisition of expressive vocabulary. This is important because phonotactic probability is positively correlated with density (e.g., Storkel, 2004b). Because of this natural correlation between phonotactic probability and neighborhood density, it is not clear whether both of these variables contribute independently or interactively to expressive vocabulary development. The current study aims to differentiate the effects of phonotactic probability and neighborhood density in expressive vocabulary development by examining both variables in parallel. In examining the effect of phonotactic probability and density, it is also important to consider their correlation with other phonological variables such as word frequency and length. Word frequency is positively correlated with density (Landauer & Steeter, 1973), and length is negatively correlated with density (e.g., Bard & Shillcock, 1993).

Both word frequency and length influence expressive vocabulary development and also interact with neighborhood density in acquisition. Specifically, word frequency facilitates children's production (Newman and German, 2002) and acquisition of spoken words (Storkel, 2004a), with a high frequency advantage. Moreover, Storkel (2004a) found an interaction between word frequency and neighborhood density in expressive vocabulary development. Specifically, the density effect was observed in low frequency words but not in high frequency words, suggesting that high frequency might overshadow the density effect in expressive vocabulary development. For word length, shorter words are acquired at earlier ages than longer words (Coady & Aslin, 2003; Storkel, 2004a). As with word frequency, word length appears to interact with density in expressive vocabulary development (Storkel, 2004a). In particular, the density effect was observed for short words but not long words, possibly due to the lack of variation in density for long words in English.

The goal of this study is to explore the individual effects of each of these phonological variables on expressive vocabulary development and to explore the generalizability of these effects to more naturalistic contexts. In addition, we seek to examine individual differences in the effect of these phonological characteristics on expressive vocabulary development across children. To date, studies of the influence of phonological characteristics on expressive vocabulary development have focused on groups of children (e.g., Storkel, 2001; Storkel, 2004a). It is especially important to examine individual cases in expressive vocabulary development to highlight similarities as well as differences in the pattern of these effects across children to provide a more detailed picture of typical acquisition. Specifically, the study will explore which types of words are learned earlier versus later in children's expressive vocabulary development by determining the age of first production and the phonological characteristics of each new word produced over a period of one year or more. With this in mind, we pose the following two questions: (1) do phonotactic probability, density, word frequency, and/or word length predict the age when words are first produced spontaneously by young children, and (2) are there similarities and differences across children in the patterns of significant predictors?

Method

Child Samples

Language samples of three children's spontaneous speech (Bloom, 1973; Bloom, Hood, & Lightbown, 1974; Bloom, Lightbown, & Hood, 1975; Higginson, 1985) were obtained from the CHILDES database (MacWhinney, 2000). CHILDES was chosen because it contains naturalistic conversation between children and adults. The selection of these three children, April, Peter, and Allison, was based on the following criteria. First, the children were native speakers of American English with typical language development. Second, the observation took place between the ages of 1 and 3 years to afford comparisons with a previous naturalistic group study by Storkel (2004a). Third, the observations took place at multiple time points over a 1 year period or greater to allow for the exploration of expressive vocabulary development. Fourth, the samples consisted of comprehensive transcriptions of naturalistic conversations between children and their parents or adult examiners. This provides sufficient information to determine whether specific words were produced spontaneously by the child. Finally, data were collected from free play sessions that contained a minimal amount of structured activities in an attempt to guard against biasing the children to use certain types of words. The observations took place at the participants' home for April and Peter. Allison's sessions were held in the Audio-Visual Studio at Teachers College, Columbia University, for which a set of furniture, toys, and snacks were provided. The conversational samples for all children were audio and/or video recorded, and transcribed orthographically by the examiners. Although phonetic transcription was available for April's sample, only gloss forms were used for the analysis.

April's data included 6 conversational samples at 0 to 8 month intervals between the ages of 22 and 35 months. Peter's data included 20 samples at 0 to 3 month intervals between the ages of 21 and 37 months. Allison's data included 6 samples at 1 to 6 month intervals between the ages of 16 and 34 months. All children were in the one-word stage at the first sample point.

Procedure

Children's spontaneous productions of words were identified by excluding imitations or repetitions of words that were produced by an adult immediately prior to the child's utterance. For example, in the following conversation, the word milk in the child's utterance would not be counted as a spontaneous production because it appears in the adult's utterance preceding the child's utterance. As a result milk would be excluded from the analysis.

Adult: 'Do you want to drink milk, or orange juice?'

Child: 'I want milk.'

In order to correspond to the methodology of previous studies (e.g., Storkel, 2004a), only root nouns were used in the analysis, excluding the words of other parts of speech as well as nouns with morphological affixes. In addition, the rules on the inclusion of words were adapted from a previous study by Moe, Hopkins, and Rush (1982) with the additional rules listed below:

(1) Proper names were counted separately from common names (e.g., Cookie Monster was counted separately from cookie and monster).

(2) Children's productions were counted regardless of the contexts. For example, if a child says that's my juice for the context where it seems more appropriate to say where's my juice, the child's original utterance was counted.

(3) Onomatopoeia were counted as words.

These criteria for the inclusion of spontaneous productions of the words yielded 340 different root nouns for April's sample, 767 different root nouns for Peter's sample, and 174 different root nouns for Allison's sample. The discrepancy in the number of different nouns across children was expected since the number of utterances produced varied for each child across samples. The number of new nouns produced in each month is shown in Table 1. Note that the number of months for April and Peter in this table does not match the number of samples described above. This is because in some cases there were two samples obtained in a particular age and these samples were collapsed into one in the table. Age appeared to be a relatively good index of language development across children. Specifically, April and Peter were observed over a relatively similar age range (22-35 months for April vs. 21-37 months for Peter) and their expressive vocabulary development appeared similar. Specifically, the total number of different words at the first sample point was comparable: 101 different words for April vs. 122 for Peter. In addition, the majority of words at the first sample point were nouns: 58% nouns for April vs. 62% nouns for Peter. Finally, the size of the expressive noun vocabulary was relatively similar at the first sample point: 59 nouns for April vs. 76 nouns for Peter. On the other hand, Allison's observations begin at an earlier age (i.e., 16 months), and her language development also appears to be at an earlier stage than either April's or Peter's. Allison only produces 30 different words at her first sample point. Her noun percentage is somewhat lower than April and Peter (i.e., 43% nouns), and her raw number of nouns at the first sample also is much lower than April's and Peter's (i.e., 13 nouns). Thus, comparisons across children suggest that Allison represents an earlier stage of development than April or Peter, who are relatively similar to one another.

Insert Table 1 About Here

Variables

Age of first production, phonotactic probability, density, frequency, and length were included as the variables of interest. Each variable was computed using a method specific to the variable. In addition, two types of measures were computed for each variable. The first measure was a continuous standardized score, either a median transformation score or a z-score. These normalized scores were used to center the skewness in the distribution for each variable and adjust the relative range across variables to afford comparisons across variables and children. These measures were used in the primary analysis for each child's data. The second measure was a binary coding of the continuous measure (e.g., high vs. low; short vs. long). This binary coding was used to examine the effect of the continuous measure on different types of words (e.g., the effect of neighborhood density on short vs. long words). These measures were used in follow-up analyses for children with multiple significant predictors of age of first production.

Phonotactic probability and density were computed using the Hoosier Mental Lexicon (HML, Nusbaum, Pisoni, & Davis, 1984) database. The HML is an on-line dictionary of adult American English pronunciations of over 19,000 words. The HML also contains adult familiarity ratings (Nusbaum et al., 1984) and word frequency counts from Kučera & Francis (1967). Although the HML is an adult database, it has been used in previous studies of language development (e.g., Storkel & Rogers, 2000; Newman & German, 2002; Storkel, 2001, 2004a). In addition, previous studies have shown that adult-based counts and child-based counts yield similar results (Jusczyk, Luce, & Charles-Luce, 1994).

Outcome Variable

Age of first production. Age of first production was assigned to each word based on the earliest age when the child spontaneously produced the word in the conversational sample. The obtained age was converted to a z-score to allow for comparison across children, Z = (obtained each - M age for that child)/SD for that child.

Predictor Variables

Phonotactic probability. Two measures of phonotactic probability were computed: positional segment frequency and biphone frequency. Positional segment frequency refers to the likelihood that a phoneme occurs in a given position in a given language, and biphone frequency refers to likelihood that a pair of phonemes co-occur in a given position in a given language (Storkel, 2004b). Following the methods described in Storkel (2004b), positional segment frequency for each sound in a word was computed by dividing the sum of the log frequency of the words in the HML containing the target sound in the target position by the sum of the log frequency of the words in the HML containing any sound in the target position. Biphone frequency was obtained by dividing the sum of the log frequency of the words in the HML containing the target pair of sounds in the target position by the sum of the log frequency of the words in the HML containing any pair of sounds in the target position. These sums were then divided by the number of phonemes or the number of biphones in the word to yield a positional segment average and a biphone average. It has been reported that these averages are correlated with word length and that this correlation can be reduced or eliminated by computing median transformation scores based on length (Storkel, 2004b). A median transformation score was obtained by subtracting the median segment or biphone average for words of a given length in the HML from the obtained value and dividing it by half the interquartile range of the words of a given length in the HML (see Storkel, 2004b for an example). This continuous measure was used in regression analyses. As previously indicated, this continuous measure was used to create a dichotomously coded variable so that the effect of lexical variables on high versus low probability words could be examined. Words with median transformation scores at or below zero were categorized as low probability words, whereas words with median transformation scores above zero were categorized as high probability words.

Density. Density was computed for each word by counting the number of words in the HML that differed by one phoneme from each target word. The obtained value for each word was used to compute a median transformation score, as described in the previous section on phonotactic probability and in Storkel (2004b). Words with median transformation scores at or below zero were categorized as having sparse neighborhoods, while words with median transformation scores above zero were categorized as having dense neighborhoods.

Frequency. Frequency was defined as the number of times a word occurs in a given language. For this study, log frequency from Kučera and Francis (1967) was converted to a z-score, based on the means and standard deviations for each child. Words were then coded into categories of low frequency words (i.e., words with a z-score lower than zero) and high frequency words (i.e., words with a z-score higher than zero). To examine the comparability between the adult-based frequency counts and child counts, we determined the frequency of occurrence of each word for each child across samples and correlated this child count with the adult count. The correlation was significant for each child, $p < 0.05$ and $r^2 = 0.04\text{-}0.14$, indicating that the child and adult counts were relatively comparable. We chose to use the adult counts because the child counts are inherently tied to age of first production. That is, a word that first appears in an earlier sample will have more opportunities to occur across samples, leading to a higher frequency. Use of the child counts would confound frequency with age-of-acquisition.

Length. Length for each word was obtained by counting the number of phonemes in the phonemic transcription given in the HML. The obtained values were converted to a z-score based on the means and standard deviations for each child. Words were further categorized as short (i.e., words with z-score at or below zero) and long (i.e., words with z-score above zero).

Sample variability. To explore the influence of variability across samples on our results, the words produced across the three children were combined, and the proportion of words known by one versus two versus all three children was computed.

Phonological development. To explore the potential contribution of phonological development to our results, normative data for phonological development were obtained from independent (Stoel-Gammon, 1985; Dyson, 1988) and relational approaches to phonological analysis (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). For each word, the independent and relational age of acquisition was determined for both the initial and final consonant. For the independent age of acquisition, the earliest age when 50% of 15- to 39-month-old children's phonetic inventories included the sound was determined from Stoel-Gammon (1985) and Dyson (1988). For the relational age of acquisition, the proportion of 3-year old children who correctly articulated each consonant was obtained from the data by Smit, et al (1990).

Results

Primary Analysis

The continuous measures described above were submitted to a backward regression analysis to determine which variables were significant predictors of expressive vocabulary development for each child. Age of first production was entered as an outcome variable. Measures of phonotactic probability (segment average and biphone average), density, frequency, and length were entered as predictor variables. Non-significant predictor variables were removed from this first model in successive steps to arrive at a final regression model that included all the variables that accounted for a significant portion of the variance in age of first production. The final regression model for each child is shown in Table 2.

Insert Table 2 About Here

April. For April, segment average was removed as a non-significant predictor in the first step of the backward regression analysis, $t = -0.08$, $p > 0.90$, $r^2 < 0.01$. Biphone average was removed in the second step, $t = -0.47$, $p > 0.60$, $r^2 < 0.01$. Density was removed in the third step, $t = 0.95$, $p > 0.30$, $r^2 = 0.01$. Frequency was removed in the fourth step, $t = -0.97$, $p > 0.30$, $r^2 = 0.02$. The remaining predictor was length, $t = 4.22$, $p < 0.001$, $r^2 = 0.07$. This final model was statistically significant, F (1, 232) = 17.82, $p < 0.001$, $r^2 = 0.07$. Length showed a positive slope, $B = 0.27$, indicating that as word length increased, the age of first production also increased. Thus, April produced shorter words at an earlier age than longer words, similar to previously reported group results (Storkel, 2004a).

Peter. For Peter, biphone average was removed as a non-significant predictor in the first step of the backward regression analysis, $t = 0.48$, $p > 0.60$, $r^2 < 0.01$. Segment average was removed in the second step, $t = 0.97$, $p > 0.30$, $r^2 = 0.01$. The remaining predictors were density, frequency, and length (see Table 2). This final model was statistically significant, F (3, 515) = 8.74, $p < 0.001$, $r^2 = 0.05$. The slope for density was positive, $B = 0.11$, meaning that words from sparse neighborhoods were produced at earlier ages than words from dense neighborhoods. This finding is counter to previous group studies where an advantage for dense neighborhoods has been found (Storkel, 2004a). For the frequency effect, the slope was negative, $B = -0.14$, meaning that high frequency words were produced at earlier ages than low frequency words. For the length effect, the slope was positive, $B = 0.11$ indicating that short words were produced at earlier ages than long words. The frequency and length effects parallel those of previous group studies (Storkel, 2004a).

Allison. For Allison, biphone average was removed as a non-significant predictor of age of first production in the first step of the backward regression, $t = -0.36$, $p > 0.70$, $r^2 = 0.02$. Density was removed in the second step, $t = 0.75$, $p > 0.40$, $r^2 < 0.01$. The remaining predictors were segment average, frequency, and length (see Table 2), and this final model was significant, $F(3, 136) = 4.81$, $p = 0.003$, $r^2 = 0.10$. Although the frequency effect was not significant, it was retained in the final model because it did not reach the criteria for exclusion from the backward regression. The segment average slope was negative, $B = -0.12$, meaning that words composed of high probability sound sequences were produced at earlier ages than words composed of low probability sound sequences. This mirrors the effect of phonotactic probability in group studies (e.g., Storkel & Rogers, 2000; Storkel, 2001). For the length effect, the slope was positive, $B = 0.24$, indicating that short words were produced at earlier ages than long words, paralleling past findings from group studies (e.g., Storkel, 2004a).

Follow-up analyses

For the children with multiple significant predictors of age of first production, namely Peter and Allison, additional analyses were conducted to explore the significant predictors for different types of words to determine the consistency in the predictors of age of first production across words. The significant factors for each child were coded into dichotomous word types, such as low and high for phonotactic probability, sparse and dense for density, low and high for frequency, and short and long for length, as previously described. Regression analyses were then performed for each type of word using the remaining significant predictors.

Peter. The results for the follow-up analyses for Peter are summarized in Table 3. Each of the three significant predictors from the primary analysis, specifically density, frequency, and length, was analyzed for each word type. In the first follow-up analysis, frequency and length were entered as possible predictors of age of first production for both sparse and dense words. For words from sparse neighborhoods, the overall model was significant, F (2, 328) = 5.92, p = 0.003, r^2 = 0.04. Frequency was a significant predictor of age of first production of sparse words. The negative slope indicates that high frequency sparse words were produced at earlier ages than low frequency sparse words. Length was not a significant predictor of age of first production of sparse words. The overall analysis of words from dense neighborhoods also was significant, F (2, 185) = 6.47, p = 0.002, r^2 = 0.07. Frequency and length were both significant predictors of age of first production of dense words. The slopes indicate that high frequency and short dense words were produced at earlier ages than low frequency and long dense words. To summarize, frequency predicted age of first production of both sparse and dense words, whereas length only predicted age of first production of dense words.

Insert Table 3 About Here

In the second follow-up analysis for Peter, density and length were entered as possible predictors of age of first production for both low and high frequency words. For low frequency words, the overall model was not significant, F (2, 264) = 2.15, p = 0.12, r^2 = 0.02. In contrast, the overall model for high frequency words was significant, F (2, 249) = 6.67, p = 0.002, r^2 = 0.05. In this model, length was a significant predictor of age of first production of high frequency words. Short high frequency words were produced at earlier ages than long high frequency words. For Peter, the predictors of age of first production varied across low versus high frequency words.

In the third follow-up analysis for Peter, density and frequency were entered as possible predictors of age of first production for both short and long words. For short words, the overall model was significant, F (2, 354) = 9.21, $p < 0.001$, $r^2 = 0.05$. Both density and frequency were significant predictors of age of first production of short words. Specifically, sparse and high frequency short words were produced at earlier ages than dense and low frequency short words. For long words, the overall model was not significant, F (2, 159) = 0.38, $p > 0.60$, $r^2 < 0.01$. The predictors of age of first production varied across short versus long words for Peter.

Allison. Like Peter, two follow-up analyses were performed for Allison focusing on her two significant predictors of age of first production, specifically segment average and length. The results of these follow-up analyses are shown in Table 4. In the first follow-up analysis, length was entered as possible predictors of age of first production of low probability and high probability words. The overall analysis for low probability words was not significant, F (1, 72) = 3.37, $p > 0.07$, $r^2 = 0.05$. In contrast, the overall analysis for high probability words was significant, F (1, 98) = 9.66, $p = 0.002$, $r^2 = 0.09$. Length was a significant predictor of age of first production of high probability words with short words being produced at earlier ages than long words. Thus, the predictors of age of first production varied across low probability versus high probability words.

Insert Table 4 About Here

In the second follow-up analysis, segment average was entered as a predictor of short versus long words. The overall models for short words and long words were not significant, F (1, 78) = 2.84, $p > 0.09$, $r^2 = 0.04$ and F (1, 92) = 0.30, $p > 0.50$, $r^2 < 0.01$ respectively.

Sample variability. The predictors of expressive vocabulary development varied across children. Can this variability be attributed to differences in the words produced? That is, did the three children produce the same words but differ in the age of first production of these words or did the children produce different words? Among the 952 different words combined for all children, 702 words (74%) were produced by only one of the children, 171 words (18%) were produced by two children, and 79 words (8%) were produced by all children. Thus, there was minimal overlap in the words produced by each child; however, it is possible that even though children did not produce the same words, they may have produced words with similar characteristics but differ in the age when these words were produced. To further explore this, the raw values for each variable were compared across children using a one-way ANOVA and Tukey pairwise comparisons to determine how the characteristics of the words produced differed by child. The raw values for each variable for each child are summarized in Table 5.

First, there was a significant effect of child for age of first production, F (2, 1278) = 33.23, $p < 0.001$, $r^2 = 0.05$. Tukey pair-wise comparisons showed that Allison's age of first production was significantly younger than April's and Peter's age of first production, as previously noted. Second, there was a significant effect of child for density, F (2, 1278) = 6.00, $p = 0.003$, $r^2 = 0.01$. The density of Peter's words was significantly lower than that of Allison's words. Third, there was a significant effect of child for frequency, F (2, 890) = 5.35, $p = 0.005$, $r^2 = 0.01$. The frequency of Peter's words was significantly lower than that of Allison's words. Fourth, there was a significant effect of child for length, F (2, 1278) = 10.07, $p < 0.001$, $r^2 = 0.02$. Peter's words were significantly longer than April's or Allison's words. Finally, there was no significant effect of child for segment average and biphone average, F (2, 1278) = 2.12, $p = 0.12$, $r^2 < 0.01$ and F (2, 1273) = 2.33, $p = 0.10$, $r^2 < 0.01$ respectively. Generally, Allison's age of first production was younger than the other two children, and the lexical characteristics of Peter's words appeared to differ from the other two children.

Insert Table 5 About Here

Phonological development. Another possible account of the variability across children is the influence of phonological development. The backward regression analyses described in the primary analysis section were repeated twice: once with an independent measure of phonological development (Stoel-Gammon, 1985; Dyson, 1988) added as a potential predictor of age-of-acquisition of words, and once with a relative measure of phonological development (Smit, et al., 1990) added as a potential predictor. The result revealed that only April showed a significant effect of phonological development on age of first production of words. Specifically, the relative measure of final consonant acquisition was a significant predictor of age of first production of words, $t = -2.04$, $p = 0.043$, $r^2 = 0.03$, with early acquired words being composed of sounds that many 3-year-old children produced accurately and later acquired words being composed of sounds that few 3-year-old children produced accurately. This is in line with past findings (e.g., Schwartz & Leonard, 1982). Importantly, length remained as a significant predictor of age of first production of words for April, and the direction of the effect of length was unchanged. Thus, production constraints did not appear to explain or alter the results of the primary analysis.

Discussion

This study examined how phonotactic probability, density, frequency, and length affect the age of first production of words by young children in naturalistic conversations. A summary of results is shown in Table 6. Across children, the predictors of age of first production varied. All children showed a significant effect of length with short words being produced at earlier ages than long words. This finding mirrors that of previous group research (Storkel, 2004a). Only one child, Peter, showed a significant effect of density and the direction of the effect was opposite of that reported in past group studies (Storkel, 2004a), with sparse words being produced at an earlier age than dense words. Only one child, Peter, showed a significant effect of frequency, and the effect paralleled past groups findings (Storkel, 2004a), with high frequency words being produced at earlier ages than low frequency words. Only one child, Allison, showed a significant effect of phonotactic probability, and the effect mirrored the previous group results (Storkel & Rogers, 2000; Storkel, 2001), with a high probability advantage.

Insert Table 6 About Here

The comparison across word types in the follow-up analyses showed variability in the predictors for each type of word. For example, for Peter, frequency was the only predictor of age of first production for sparse words, but both frequency and length were predictors for dense words. For Peter, there were no significant predictors for low frequency words (counter to past group studies, Storkel, 2004a), but length was a predictor for high frequency words (similar to past group studies, Storkel, 2004a). For Allison, there were no significant predictors for low probability words, but length was a predictor for high probability words. For short words, frequency and density were significant predictors for Peter and past groups of children (Storkel, 2004a), whereas there were no significant predictors for Allison. For long words, there were no significant predictors for Peter, Allison, or past groups of children (Storkel, 2004a).

Sample Variability

One possible explanation for the observed variability in the predictors of expressive vocabulary development across children may be due to differences in the words sampled across children. That is, naturalistic sampling may have lead to differences in the topics chosen and corresponding differences in the words used. In this way, the observed variability may be thought of as an artifact of naturalistic sampling. Indeed, there was minimal overlap in the words produced by the children, and there were significant differences across children in the characteristics of the words produced. Although it is possible that differences in the words produced because of sampling procedures may account for some of the variability in the results, it can not account for all of the variability. In support of this, the lexical characteristics of Peter's words appeared to differ from those of April's and Allison's words. Likewise, the significant predictors of age of first production differed between Peter and April and Peter and Allison. In contrast, the lexical characteristics of April's and Allison's words were similar, but the significant predictors of age of first production differed. Thus, variability between April's and Allison's predictors can not be attributed to sample differences. Moreover, the phonotactic probability of the words produced was similar across all three children, yet phonotactic probability was a significant predictor for only Allison. Thus, the variability in phonotactic probability as a predictor across children can not be attributed to differences in the words produced. Finally, length also differed across children with Peter's words being longer than April's words and longer than Allison's words, but all three children showed significant effects of length on expressive vocabulary development. Taken together, it seems unlikely that the pattern of results can be solely attributed to differences in the words sampled, although examination of a larger group of children would allow for further exploration of this hypothesis.

Phonological Development

We examined normative data of phonological development to determine whether phonological constraints would predict age of first production of words. The results showed that normative measures only predicted expressive vocabulary development for one child, April. Importantly, the influence of phonological development did not eradicate the influence of other factors, namely word length. Thus, we tentatively conclude that our results reflect the factors affecting expressive vocabulary development rather than phonological constraints on production.

We predict that receptive vocabulary would provide converging evidence with this study of expressive vocabulary. This hypothesis warrants further investigation.

Multiple Constraints on Expressive Vocabulary Development

If one assumes that the variability in the predictors of expressive vocabulary development is not an artifact of using a naturalistic sample, then we must explore possible theoretical explanations for this observed variability. One model that allows for variability across expressive vocabulary development is the Emergentist Coalition Model (Hirsh-Pasek, Golinkoff, & Hollich, 2000). This model assumes that a range of cues are available to the child to learn words but that how these cues are used varies over time. That is, children may begin learning words by using a subset of the available cues and then may appeal to a wider range of cues or a different set of cues as they gain experience learning words and hone in on the cues that are most relevant or useful. We extend this model to account for our data.

Because of the consistency in the effect of word length across our three children and past group studies, we propose that one of the earliest cues is word length. Word length may not be a cue in the sense defined by Hirsh-Pasek, et al (2000), but rather word length may place constraints on processing that affect expressive vocabulary development from the very beginning. That is, when learning a new word, a child must hold the phonological form in working memory, identify the referent and extract the relevant characteristics, and create a lexical and semantic representation in long-term memory. Word length influences working memory such that shorter words are remembered more accurately than longer words (e.g., Hulme & Tordoff, 1989). Thus, word length may be a basic constraint on expressive vocabulary development that is operative at the onset as well as throughout expressive vocabulary development.

According to the Emergentist Coalition Model, once a child has learned a number of words, cues are extracted from those words to further promote expressive vocabulary development. We suggest that the relevant cues vary across development and that each of the children studied represents a different developmental point. In particular, Allison may represent an earlier stage than April and Peter, and Peter may represent a slightly later stage than April.

Taking Allison as the earliest stage of development, phonotactic probability appears to be an early cue that may diminish across development. To use phonotactic probability as a cue, a child must have learned the phonological regularities of the language. In fact, previous studies show that children as young as 9 months have learned the phonotactic probability of their native language (Jusczyk et al., 1994). Once this cue has been extracted, phonotactic probability may influence phonological processing of a novel word, facilitating learning of high probability words by very young children.

Taking April as the next stage of development, we could infer that the importance of phonotactic probability decreases across development. However, April has yet to extract other relevant cues, relying solely on length. April also was the only child to show an influence of phonological development on expressive vocabulary development. Therefore, April may have been undergoing significant change in her phonological system that may have drawn resources from expressive vocabulary development, affecting her ability to extract or apply additional cues.

Turning to Peter as the most advanced stage of development, we see that two additional cues have emerged: density and frequency. Of these, frequency accounted for a greater proportion of variance than density (see Table 2). Likewise, frequency predicted age of first production of three types of words, sparse, dense, and short, whereas density predicted age of first production for only one type of word, short. Therefore, we suggest that Peter was consistently using frequency and was just beginning to use density as a cue for expressive vocabulary development. Children must have experience with the language to have evidence that words differ in their frequency of occurrence, thus accounting for this later emergence of frequency as a relevant cue. Greater frequency of exposure to a word may strengthen the newly formed lexical representation. Density appears to emerge even later than frequency. The child must have already learned words and organized these words into neighborhoods in long-term memory to extract density as a relevant cue. This may promote expressive vocabulary development because new lexical representations will be connected to existing representations in long-term memory, strengthening the new representation. Interestingly, Peter did not show the same density effect on expressive vocabulary development as observed in previous group studies. It may be that children have difficulty using a cue correctly when the cue first emerges. Thus, we predict that Peter would show a consistent advantage for dense words at future sample points.

This study of three children suggests that the use of phonotactic probability, density, and frequency change across development. This hypothesis is contingent upon inter-individual comparisons. Future longitudinal research is needed to provide better support for this account of the observed variability.

Conclusion

This study provided evidence that examination of the factors that predict expressive vocabulary development in individual children can provide new insights into the mechanisms that underlie expressive vocabulary development. We identified length as a consistent predictor of expressive vocabulary development across three individual children, with the results converging with those of past group studies. In addition, phonotactic probability, density, and frequency appeared to predict expressive vocabulary development but with individual variation across children. We attributed this inter-child variability to developmental differences across children and suggest that the Emergentist Coalition Model provides one possible mechanism to account for developmental differences. Greater longitudinal exploration over a larger developmental period is needed to provide insights into why these differences exist.

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Table 1. Number of new nouns produced in each month (hypothesized total number of different nouns across time)

Age in months	April	Peter	Allison
16			13 (13)
19			25 (38)
20			32 (70)
21		76 (76)	
22	59 (59)	56 (132)	21 (91)
23		46 (178)	
24		37 (215)	
25	126 (185)	46 (261)	
26		36 (297)	
27		61 (358)	
28		60 (418)	47 (138)
29		82 (500)	
30		53 (553)	
31		55 (608)	
32		27 (635)	
33	71 (256)	33 (668)	
34	60 (316)	51 (719)	36 (174)
35	24 (340)		
37		48 (767)	

Table 2. Results of the primary backward regression analysis for each child

		β estimate	Standard Error	r^2	t	p
April						
	Length	0.27	0.06	0.07	4.22	<0.001
Peter						
	Density	0.11	0.05	0.01	2.11	0.04
	Frequency	-0.14	0.05	0.03	-3.06	0.002
	Length	0.11	0.05	0.02	2.43	0.02
Allison						
	Segment average	-0.12	0.06	0.03	-2.02	0.05
	Frequency	0.15	0.08	0.01	1.77	0.08
	Length	0.24	0.08	0.05	2.89	0.005

Table 3. Results of the follow-up regression analyses by word types for Peter

	β estimate	Standard Error	r^2	t	p
Sparse words					
Frequency	-0.13	0.06	0.03	-2.33	0.02
Length	0.10	0.05	0.02	1.82	0.07
Dense words					
Frequency	-0.15	0.08	0.04	-1.96	0.05
Length	0.20	0.08	0.05	2.44	0.02
Low frequency words					
Density	0.11	0.07	0.01	1.64	0.10
Length	0.06	0.06	0.01	0.98	0.33
High frequency words					
Density	0.09	0.07	0.01	1.20	0.23
Length	0.23	0.07	0.05	3.30	0.001
Short words					
Density	0.14	0.06	0.01	2.14	0.03
Frequency	-0.21	0.05	0.04	-3.87	<0.001
Long words					
Density	0.07	0.08	<0.01	0.87	0.39
Frequency	-0.01	0.08	<0.01	-0.09	0.93

Table 4. Results of the follow-up regression analyses by word types for Allison

	β estimate	Standard Error	r^2	t	p
Low probability words					
Length	0.15	0.08	0.04	1.84	0.07
High probability words					
Length	0.28	0.09	0.09	3.11	0.002
Short words					
Segment average	-0.12	0.07	0.03	-1.69	0.10
Long words					
Segment average	-0.04	0.08	<0.01	-0.55	0.59

Table 5. Mean, standard deviation, and range for each variable

		April	Peter	Allison
Age	M	29	27	25
	SD	5	4	6
	Range	22-35	21-37	16-34
Density	M	10	8	10
	SD	8	8	8
	Range	0-31	0-33	0-32
Frequency	M	2.68	2.55	2.80
	SD	0.94	0.80	0.96
	Range	1.00-5.03	1.00-5.00	1.00-5.03
Length	M	3.94	4.16	3.71
	SD	1.45	1.36	1.22
	Range	2-10	2-10	2-9
Segment average	M	0.048	0.048	0.046
	SD	0.015	0.015	0.015
	Range	0.007-0.084	0.007-0.085	0.007-0.092
Biphone average	M	0.0038	0.0041	0.0038
	SD	0.0028	0.0028	0.0027
	Range	0.0001-0.0164	0.0001-0.0164	0.0001-0.0164
Number of tokens		2,184	26,234	1,752

Table 6. Summary of predictors for each child (with early acquired word types noted in parentheses) and of differences across children

	April	Peter	Allison
Overall analysis	Length (short)	Density (sparse) Frequency (high) Length (short)	Segment average (high) Length (short)
Follow-up analyses			
Low probability	NA	NA	No significant predictors
High probability	NA	NA	Length (short)
Sparse	NA	Frequency (high)	NA
Dense	NA	Frequency (high) Length (short)	NA
Low frequency	NA	No significant predictors	NA
High frequency	NA	Length (short)	NA
Short	NA	Density (sparse) Frequency (high)	No significant predictors
Long	NA	No significant predictors	No significant predictors
Sample variability		Lowest density Lowest frequency Longest words	Youngest
Phonological development	Significant (early sounds)	No significant effect	No significant effect