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Children's Abstraction and Generalization of English Lexical Stress Patterns

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Abstract

The current study investigated school-aged children's internalization of the distributional patterns of English lexical stress as a function of vocabulary size. Sixty children (5;3 to 8;3) participated in the study. The children were asked to blend 2 individually-presented, equally-stressed syllables to produce disyllabic nonwords with different resulting structures in one of two frame sentences. The frame sentences were designed to elicit either a noun or verb interpretation of the nonword. Children's receptive vocabulary was also assessed. The results indicated that children more readily blended syllable pairs that resulted in trochaic-compatible word structures than in iambic-compatible structures. This effect was strongest in young children with large vocabularies. As for stress placement, all children were sensitive to the effect of word structure, but only children with the largest vocabularies were sensitive to the biasing effect of grammatical category (noun = trochee; verb = iamb). The study results are discussed with reference to the observation that speech motor skills develop in tandem with lexical acquisition and the hypothesis that phonological knowledge emerges in part from abstraction across lexical representations.

1. INTRODUCTION

Pattern abstraction over speech input may occur without reference to specific linguistic representations. For example, statistical learning studies demonstrate that infants as young as 8 months of age abstract the transitional probability between equally stressed CV syllables after just 2 minutes of exposure to a continuously looped syllable stream (Saffran, Aslin & Newport, 1996; Aslin, Saffran & Newport, 1998). An innate ability to abstract sound patterns, such as that described in statistical learning studies, likely provides an explanation for infants' very early sensitivity to native language rhythm and to the predominant stress patterns of the ambient language (e.g., Mehler, Jusczyk, Lambertz, Halsted, Bertoncini & Amiel-Tison, 1988; Jusczyk, Cutler & Redanz, 1993). Whereas this kind of pattern abstraction may provide a foundation for the acquisition of phonology, a linguistic analysis of sorts is clearly required for children to gain adult-like phonological knowledge. Consider, for example, the relationship between lexical stress and grammatical category in English: disyllabic nouns are typically stressed on the first syllable (a trochaic pattern), disyllabic verbs on the second (an iambic pattern), as in the minimal pair *insight* /ˈɪnsaɪt/ versus *incite* /ɪnˈsaɪt/. To acquire knowledge about grammatically-linked stress patterns in English, a language learner must first identify word forms and their associated semantic content. From disyllabic word forms, the learner must recognize and abstract the stress pattern (trochaic or iambic). From the semantic content, she must abstract the categories noun and verb. The abstract stress pattern must then be linked to the abstract grammatical category. Only then can the pattern be generalized to new instances, which is what adult English speakers do (Kelly & Bock, 1988; Sereno & Jongman, 1993; Guion, Clark, Harada & Wayland, 2003). Because pattern abstraction will increase in robustness with the number of stored instances over which the pattern occurs (see, e.g., Bybee 2001), phonological knowledge is said to emerge from those instances. If the relevant instances are word forms, as in the case of lexical stress patterns, then the knowledge can be said to emerge from the lexicon.

The hypothesis that phonological knowledge emerges in some part from abstractions across the lexicon has implications for child language acquisition. In particular, it suggests that such knowledge will continue to change and develop as a child's lexicon expands. The current study was designed to test this hypothesis as it pertains to the acquisition of English lexical stress patterns. School-aged children were tested on their access to abstract metrical frames for novel word production and on the type of frames selected. The stimuli and sentential context were manipulated to bias the selection of trochaic frames in some instances and iambic frames in others according to the distributional facts of English stress. The extent to which different selection biases held was predicted to vary as a function of vocabulary size.

1.1 Vocabulary Acquisition and Phonological Development

To date, there is limited evidence for the hypothesis that phonological knowledge changes with vocabulary acquisition. Computational modeling studies demonstrate only that the hypothesis is plausible (e.g., Metsala & Walley, 1998; Redford & Miikkulainen, 2007), and results from empirical studies are subject to alternative interpretations. With respect to the empirical studies, these have largely investigated the relationship between vocabulary size and phonological complexity (Stoel-Gammon & Dale, 1988; Paul & Jennings, 1992; Rescorla & Ratner, 1996) and the relationship between vocabulary size and nonword repetition or learning (Gathercole, Willis, Emslie & Baddeley, 1992; Werker, Fennell, Corcoran & Stager, 2002; Edwards, Beckman & Munson, 2004; Munson, Edwards & Beckman, 2005; Munson, Kurtz & Windsor, 2005; Fernald, Perfors & Marchman, 2006). The relationship between vocabulary size and the abstraction or generalization of phonological patterns per se has not been investigated, but is nonetheless assumed. For example, Edwards et al. (2004) investigated the effects of vocabulary size on repetition accuracy of low and high frequency phoneme sequences and found that all preschool and school-aged children in their large sample reproduced high frequency sequences more accurately and fluently than low frequency sequences. They also found that the effect was largest in the youngest children and in children with smaller vocabularies for their age. The authors argued that children with larger vocabularies experienced smaller effects of frequency on repetition and were more accurate in their productions overall because they have abstracted more robust phonological representations from the lexicon than children with smaller vocabularies. They reasoned that more robust representations allow for better and faster mappings across the auditory-articulatory realms.

In a review article that examines the hypothesis of emergent phonological knowledge as a process of abstraction across the lexicon, Stoel-Gammon (2011:2) argues for the importance of both "a biologically based component associated with the development of speech-motor skills" and "a cognitive-linguistic component" associated with the representation (defined as recognition and retrieval) of phonological form. She sees phonological development as beginning with pre-speech vocalizations and the concurrent mapping between the auditory-articulatory realms. The mapping drives speech motor skill development, which later supports the acquisition of lexical items (see also Vihman, 1996). Once acquired, production of lexical items also extends speech practice, and thus the continued development of basic speech motor skills. With this interrelationship between motor skill development and lexical acquisition in mind, Stoel-Gammon questions whether the finding of better nonword repetition abilities in children with larger vocabularies provides unequivocal support for the hypothesis that phonological patterns are abstracted from the lexicon. In her view, the finding might instead represent the effects of practice: children with larger vocabularies would have produced more different sequences than children with smaller vocabularies, so their speech motor skills will be better developed and repetition more accurate. Stoel-Gammon thus observes that the relationship between vocabulary size and nonword repetition accuracy need not entail differences in phonemic and/or phonotactic knowledge; it could instead represent differences in practice resulting in different levels of speech motor skill development. We agree with this conclusion, and so sought to test the hypothesis using a task that more obviously requires generalization.

There is a long history in linguistics and psychology of using generalization to infer representation. Consider, for example, the famous "wug test" devised by Berko (1958) to test children's abstraction of English plural morphology. A preschool aged child is shown a picture of a single "wug," then asked to name a picture that contains two of the same. Knowledge of plural morphology and the associated phonology is demonstrated when the child correctly generates "wugs" /wʌgz/ as the answer. Retrieval, storage, abstraction, and generalization are all clearly involved in this task. First, "wug" must be remembered in association with the picture, which involves storing the perceptual form and generating a perceptual-motor routine for its production[1]. These input and output forms are both linked to whatever concept has been generated to represent the meaning "wug." The stored *wug* forms are likely situated with similar forms in memory; that is, in a phonological neighborhood (Vitevitch, Luce, Pisoni & Auer, 1999). Since there is good evidence to suggest that children store "whole words" (see, e.g., MacWhinney, 1985; Tomasello, 2003), we assume that the neighborhood would contain other, morphologically unanalyzed input and output forms. Thus, when the child is asked to generate a plural response, the "wug" perceptual-motor routine is activated and the child abstracts the appropriate phonological form of the plural with reference to the nearest whole word phonological neighbors that are themselves linked to a plural concept. In this way, the morpho-phonological knowledge associated with plural

[1]The assumption that a perceptual-motor routine is established immediately as part of the remembering process is supported by Berko's (1958) description of the procedure. She notes that "(i)t was not uncommon for a child to repeat the nonsense word immediately upon hearing it and before being asked any questions. Often, for example, when the experimenter said 'This is a gutch', the child repeated, 'Gutch' (p.153)."

marking in English can be described as emerging from abstraction across similar items within the lexicon.

In the current study, we assess the abstraction and generalization of English lexical stress patterns using a syllable blending task borrowed from Guion and colleagues (2003). Children were presented with two individual syllables and asked to blend them into word-like units, and to produce these nonword units in a given sentential context. This task entailed that isolated syllables be inserted into a metrical frame, with stress produced accordingly. The relevant frames were a trochaic or iambic foot, resulting in main stress occurring on either the first or second syllable and so in a strong-weak (trochaic) or weak-strong (iambic) stress pattern. To investigate the hypothesis of emergent phonological knowledge, we tested whether frame selection varied in a systematic way with vocabulary size and the distributional facts of English stress. Specific background on English lexical stress and its acquisition is presented next to further motivate the study design and the predictions made.

1.2 Lexical Stress Patterns in English

English is a stress-timed language. All content words of an utterance are produced with main stress; determiners, auxiliaries, and the like are typically unstressed. When words are comprised of more than one syllable, main stress occurs on just one of these. Thus, in disyllabic words, stress either occurs on the first syllable or on the second and so these words are produced with either a trochaic or iambic stress pattern. That said, the most frequent location for word stress in English is on the first syllable (Cutler & Carter, 1987). The pattern of first syllable stress is especially robust in spoken language. For example, Cutler and Carter (1987) investigated lexical stress patterns in a corpus of British English with 20,000 words and found that 69% of the multisyllabic content words were realized with first syllable stress. When monosyllabic words were considered in the count, then the occurrence rose to 90%. The patterns of American English appear to parallel those of British English. Clopper (2002) investigated stress patterns of multisyllabic words in a large American English corpus (Hoosier Mental Lexicon; Luce & Pisoni, 1998) and found that the trochaic pattern is 3.4 times more frequent than the iambic pattern in disyllabic words. In the current study, we investigated whether children were more likely to blend isolated syllables using a trochaic frame than an iambic frame and whether preference for one or the other frames could be predicted by vocabulary size.

English is also a quantity sensitive language, meaning that lexical stress is correlated with syllable structure. So-called heavy syllables, which have either long vowel nuclei (tense vowels or diphthongs) or final consonants, are more likely to have stress than light syllables, which have a short vowel nuclei (i.e., lax vowels; Hayes, 1995). English speakers have clearly abstracted this distributional fact. For example, Guion and colleagues (2003) presented adult English speakers with individual syllables that varied in structure, and asked them to blend these into word-like units. Some of the syllables were open with monopthongal vowel nuclei, and so were “light.” Others had diphthongal nuclei or consonantal offsets or both, and so were “heavy” and even “super heavy.” In addition, super heavy syllables of the type CVVC were compared to those of the type CVCC in order to assess the relative contribution of vowel length and codas to stress placement. The results were that stress placement correlated with syllable weight in general, and vowel length in particular. We used a subset of the syllable shapes from Guion et al. in the present study to investigate whether English-speaking children generalize the association between stress and syllable structure in a syllable blending task, and whether quantity sensitivity for stress is predicted by vocabulary size.

Finally, there are the grammatically-linked lexical stress patterns of English. As previously noted, disyllabic nouns are usually stressed on the first syllable, while disyllabic verbs are more often stressed on the second. Whereas this pattern is usually illustrated with reference to noun/verb homographs like *récord* and *recórd*, it generalizes across the lexicon. For example, Kelly and Bock (1988) investigated the dictionary stress for all pure disyllabic nouns and verbs in the Francis and Kučera (1982) corpus and reported that 94% of nouns were produced with trochaic stress compared to just 31% of verbs. Further, Sereno and Jongman (1993) found that the basic trochaic noun and iambic verb pattern extends even to noun/verb homophones such as *answer*. Although stress does not perceptibly shift as a function of grammatical category in these words, they are nonetheless produced with small but consistent differences depending on their function in a sentence. In particular, when a word like *answer* is used as a noun it is produced with a somewhat longer and louder first syllable than when it is used as a verb.

The trochaic noun and iambic verb pattern also generalizes to nonwords. Kelly and Bock (1988) presented adults with disyllabic nonwords that were stressed either on the first or second syllable and asked them to create novel sentences using these words. The results were that trochaically stressed nonwords were more often used as nouns than as verbs, and iambically stressed nonwords as verbs rather than as nouns. Similarly, Guion and colleagues (Guion et al., 2003) showed that adults used a trochaic pattern to blend independent syllables into a single word-like structure when producing these in a frame sentence designed to elicit a noun interpretation ("I'd like a ____."), but they used an iambic pattern when producing the syllables as words in a frame sentence designed to elicit a verb interpretation ("I'd like to _____."). We used the same design as Guion and colleagues in the current study to test whether the acquisition of grammatically-linked lexical stress patterns in children's speech varied as a function of vocabulary size.

1.3 The Acquisition of English Lexical Stress

As noted at the outset of this report, very young infants are sensitive to the rhythm patterns of their native language (e.g., Mehler et al., 1988; Jusczyk et al., 1993). These same patterns are repeated in infants' early nonlinguistic vocalizations (e.g., Levitt & Wang, 1991; Davis, MacNeilage, Matyear, & Powell, 2000; Vihman, Nakai, & DePaolis, 2006); for example, Vihman and colleagues (Vihman et al., 2006) showed clear cross-linguistic differences in the durational correlates of prosodic patterns in babbling produced by infants exposed to stress-, syllable- and mora-timed languages. English-learning children also produce lexical stress patterns very early on, using duration to contrast unstressed and stressed syllables by 2 years of age (Pollock, Brammer, & Hageman, 1993; Kehoe, Stoel-Gamon, & Buder, 1995; Schwartz, Petinou, Goffman, Lazowski, & Cartusciello, 1996). English-learning children also appear to be sensitive to the high frequency of word-initial stress in English. Take, for example, the so-called trochaic bias that is evident in both listening preferences (Jusczyk et al., 1993) and in patterns of weak syllable deletion (Allen & Hawkins, 1980; Echols & Newport, 1992; Gerken, 1994; 1996; Kehoe & Stoel-Gammon, 1997). Two year old children are more likely to delete a weak syllable in a lexical item or prosodic word if it occurs before a strong syllable than if it occurs after a strong syllable (e.g., "*ba<u>nána</u>*" → "*nána*" and "*púshes the dóg*" → "*púshes dóg*"). The pattern is attributed to a production preference for trochaic feet (strong-weak) over iambic feet (weak-strong).

Somewhat surprisingly, the trochaic bias may be less evident in very early productions compared to later child language. With respect to early word production, Vihman and colleagues (Vihman, DePaolis, & Davis, 1998) showed substantial individual differences in the preferred disyllabic stress pattern used by 9 English learning children at the 25 word stage (1;1 to 1;8 in the sample). Multi-rater perceptual judgments indicated that 5 of the 9 children produced most of their disyllables with a trochaic pattern, consistent with the predominant language pattern; however, 3 of the children produced most of their words with an iambic pattern and 1 produced a roughly equal number of disyllables with a trochaic and iambic pattern.

By 2 years of age, children are producing more language overall and are manifesting the pattern of weak syllable deletion described above. Even so, McGregor and Johnson (1997) showed that children at this age still practice iambic patterns in some words, and that children with more advanced language skills are less likely to delete weak initial syllables in any iambically stressed words. In spite of the early practice with iambic patterns, kinematic and acoustic-phonetic evidence indicates that the production of iambic stress is immature at age 7 (Goffman & Malin, 1999; Ballard, Djaja, Arciulil, James, & van Doorn, 2012). In contrast, children's production of trochaic patterns is adult-like by age 3 years (Ballard et al., 2012). Whereas Ballard and colleagues suggested that the slow acquisition of iambic stress patterns in English-speaking children might be due to a physiological constraint related to the production of rising intensity or increasing duration, this does not explain the child who initially favors iambic patterns at age 1 (see Vihman et al., 1998), assuming continuity in the production of stress. Instead, the slow acquisition of iambic stress may have more to do with how the distributional patterns in the language are mirrored in the child's lexicon. Even the child who produces mainly iambs at age 1, will soon have trochaic patterns as their dominant language target. The larger their vocabulary becomes, the more asymmetric the practice with trochaic and iambic forms will become. It is perhaps this asymmetry of practice, rather than physiology, that accounts for older children's immature production of iambic patterns.

The extensive discussions of a so-called trochaic bias in early child language acquisition stand in contrast to work on the acquisition of other distributional patterns related to lexical stress in English, which is minimal. The work that exists on quantity sensitivity suggests that the correlation between syllable structure and lexical stress is acquired easily and early in perception from input patterns (Turk, Jusczyk, & Gerken, 1995; Pons & Bosch, 2010), but that this is not reflected in production. In production, the correlation between syllable structure and stress placement is delayed, as demonstrated in studies of minimal word production (Fikkert, 1994; Kehoe, 1998). For example, Fikkert's (1994) data showed that Dutch-learning children first acquire a default, quantity insensitive, bounded foot that is left-headed (i.e., a trochaic pattern). Early on, these children correctly produce disyllabic words that receive initial stress, but truncate those that receive final stress. Quantity sensitivity is acquired later, which suggests that the correlation between syllable structure and stress placement may be less robust in production than the default stress pattern of the language.

Kehoe (1998) found that many of the patterns described by Fikkert (1994) held also for English-speaking children. She did find, however, that even the youngest children in her sample (22 months) produced iambic-like forms, a finding that she attributed to the super-heavy final syllable in these words. Older children in her sample (36 months) showed an even stronger tendency towards final stress in words with super-heavy final syllables. Kehoe suggested that the findings may indicate either the earlier acquisition of quantity sensitivity in English than in Dutch, or the possibility that stress is lexicalized/memorized (p. 15). The latter suggestion is of course compatible with the current hypothesis of emergent phonological knowledge; but our hypothesis also predicts what Fikkert's stages of metrical acquisition suggest, namely, that quantity sensitivity is less robust in production than might be predicted from the default stress pattern of the language. Of course, in English, early disyllabic words include many diminutive constructions like *kitty*, *bunny*, or *teddy* (see, e.g., Saxton, 2010:137) that contravene the typical relationship between weight and stress[2]: assuming onset syllabification of the medial C, they have a CV.CVV word structure and are trochaically stressed. Repeated production of disyllables such as these may privilege the production of trochaic patterns while undermining an association between weight and stress for multisyllabic words. Thus, true quantity sensitivity for stress may only emerge in production when the child acquires a critical mass of iambically stressed words such as *balloon*, *guitar*, or *afraid*, which have light initial syllables and super-heavy final syllables.

As for the grammatically-linked stress patterns of English, we found only one study by Curtin and colleagues (Curtin, Campbell, & Hufnagle, 2012) relevant to acquisition. In this study, Curtin and colleagues tested 16-month-old infants' ability to map iambically-stressed and trochaically-stressed labels onto path actions and objects using a habituation paradigm. The results were consistent with the ambient language pattern: iambically-stressed labels were associated with path action, but trochaically-stressed labels were not. Of significant relevance to the present study, Curtin et al. found no relationship between receptive vocabulary size and performance in their critical experiment. They note, however, that this may have been due to the vocabulary measure chosen—the short form of the MacArthur Communicative Development Inventory (CDI, Fenson et al., 1994), which uses parental report and tests only for knowledge of concrete nouns. It could also be that the association between (the language dominant) trochaic pattern and nouns is learned early in perception given the strong noun bias exhibited in English-learning infants early word productions and the finding that English-speaking mothers' speech is also heavily biased towards noun production in a labeling context (Tardif, Gelman, & Xu, 1999). The prediction for

[2]Fikkert (1994) argues that vowel length does not contribute to syllable weight in Dutch, but this is not true of English where tense vowels like /i/ are treated as heavy (e.g., Halle, 1977).

production is less clear, but the presumed late acquisition of disyllabic verbs would suggest that the pattern may not be acquired as early as in perception (see below).

1.4 Current Study Predictions

The current study investigated whether school-aged children's performance in a syllable blending task varied with vocabulary size. Our focus was on school-aged children, as opposed to infants and toddlers, for two reasons. First, we assumed that the relationship between the lexicon and abstract phonological knowledge would be more amenable to test when vocabulary sizes were large and variable enough for individual differences to emerge. Second, we wanted to minimize effects that could be attributed solely to immature motor skills. Although acoustic and kinematic studies indicate that iambic stress may not be fully acquired until sometime after 7 years of age (Goffman & Malin, 1999; Ballard et al., 2012), children use duration to create contrastive lexical stress patterns from at least age 2 onwards (Pollock et al, 1993; Kehoe et al., 1995; Schwartz et al., 1996). Transcription studies also indicate that children control vowel length and reliably produce coda consonants by age 2 (Kehoe & Stoel-Gammon, 2001). We expected therefore that by age 5 any effects observed would be best attributed to lexical representations and vocabulary-based practice rather than to independent immaturities in speech motor control. The study predictions were as follows.

1. Children with larger vocabularies should exhibit a stronger tendency to produce nonwords with a trochaic stress pattern than children with smaller vocabularies all other things being equal—Our review of lexical stress patterns in English established that trochiac stress is the dominant pattern provided in the input, leading to its early acquisition. Early acquisition could mean that children with smaller vocabularies —that is those who have acquired less diverse forms—will show a stronger tendency to produce nonwords with trochaic stress patterns than children with larger vocabularies. However, the current prediction assumes both Stoel-Gammon's (2011) argument that vocabulary size correlates with speech practice and the hypothesis of emergent phonological knowledge. With regard to speech practice, the prediction assumes that children with larger vocabularies, who have more trochaically-stressed disyllabic items in their lexicon than children with smaller vocabularies, will use more disyllabic words in spontaneous speech. As more practice leads to greater entrenchment, the pattern will more likely be selected during production.

2. Children with larger vocabularies should exhibit a stronger tendency to produce nonwords with iambic stress than children with smaller vocabularies when the initial syllable is light and the final one is super heavy—Given the preponderance of monosyllabic items in English, and that trochaic stress is 3.4 times more likely than iambic stress in disyllabic words (Clopper, 2002), a strong bias towards weight sensitivity may depend on regular practice with iambically stressed disyllabic words that have light initial syllables and super heavy final syllables (i.e., CV.CVVC as in "balloon" /bə'luːn/ and "guitar" /gɪ'tɑɹ/). Given the rarity of these forms in English, we assume that only children with larger vocabularies will have acquired a sufficient number of such words to have engaged in the relevant practice.

3. Children with larger vocabularies will be more sensitive to the trochaic noun / iambic verb pattern of English than children with smaller vocabularies

—Assuming a practice-based disjunction between perception and production, acquisition of the grammatically-linked stress pattern in English will depend on the acquisition of an especially large vocabulary. This is because disyllabic verbs with second syllable stress are far less frequent and familiar than monosyllabic verbs in English. The relative frequency of monosyllabic versus disyllabic verbs is evident from the Peabody Picture Vocabulary Test (PPVT-4; Dunn & Dunn, 2007), which is what we used to measure vocabulary size in the school-aged children who participated in the present study. This test includes 17 verbs in the first 100 items on Form A and 19 on Form B. A majority of these (31 out of 36) are monosyllabic in their base form, and 3 are disyllabic (*juggle*, *annoy*, *measure*). Note that 2 of the 3 disyllabic verbs on the PPVT that we would expect a child to encounter early on are actually produced with a trochaic stress pattern (*juggle*, *measure*). Note also that to learn the trochaic noun / iambic verb pattern, a child will have to ignore that monosyllabic verbs are produced with a trochaic pattern when in the gerund (e.g., *eating*, *drinking*, *swimming*) and sometimes in the preterit (e.g., *wanted*, *painted*).

2. METHODS

2.1 Participants

Sixty American-English speaking children participated in the study. The children ranged in age from 5;3 to 8;3 (M = 6;10; SD = 10 months). All were native speakers of the West Coast variety of American English, and all were free of speech and hearing problems as determined by parental report and a pure-tone hearing screen. Vocabulary size was assessed for all children using the PPVT-4 (Dunn & Dunn, 2007). Raw scores ranged from 99 to 194 (M = 139.42; SD = 16.61). Not surprisingly, the scores were highly correlated with age-in-months, $r(60) = .59$, $p < .001$.

2.2 Materials

The materials consisted of 16 pairings of 16 monosyllables that had been recorded with a high quality microphone in digital format by a native English-speaking adult female in the frame sentence “Now I say _______.” Each syllable was produced separately in this frame in order to ensure “equal” stress; that is, every syllable received stress and a nuclear pitch accent. The syllables were then excised from the frame sentences, normalized to 50% peak intensity, and recombined to create the 16 pairings of the monosyllables shown in Table 1. Eight of the pairings yielded stimuli of the type CVV+CVC; that is, an ordered pair with the long vowel or diphthong in initial position. Another eight pairings yielded stimuli of the type CV+CVVC; that is, an ordered pair with the long vowel or diphthong in second position. Note that the first pairing results in a sequence of two heavy syllables, whereas the second results in a light, then heavy syllable sequence. Both forms are legal in English, but CVCVVC forms are much less frequent. Lexical class was manipulated through the use of a frame sentence, as described below under procedure.

The ordered pair of syllables was presented to child listeners with an intervening 500 millisecond pause. Pilot work suggested that shorter inter-syllabic intervals resulted in more strictly imitative productions, perhaps because the child heard the stimulus as a single, hyper-articulated word. The longer inter-syllabic intervals seemed to better enable children to recognize the syllables as individual units that then needed to be brought together under a single lexical stress pattern.

2.3 Procedure

The experiment took place in a child-friendly experiment room in the Speech and Language Laboratory at the University of Oregon. The experimenter introduced the production task as an "alien word" game. A paraphrased version of the instructions given to children is as follows: "You will be hearing 'alien words' each of which sounds like 2 words. Your job is to smoosh the two pieces of the word together so that it sounds more like one real word." "Smooshing" was demonstrated by the experimenter, who said two different CV syllables individually associating each with one of her fists, and then, with the gesture of bringing two fists together, said the same two syllables as a single CVCV word-like entity. Several practice items were then used to ensure that participants were able to blend syllables into a single word-like structure. After this, the notion of a frame sentence was introduced. Children were told that they were to put the blended word into one of two sentences. These were designed to elicit either a noun-like production, which had been shown to bias adults towards a trochaic stress pattern, or a verb-like production, which had been shown to bias adults towards an iambic stress pattern (Guion et al., 2003). As in Guion et al., the noun-inducing frame was "I'd like a ____"; the verb-inducing frame was "I'd like to ___." The decision was made to NOT reduce the determiner or preposition during frame sentence presentation so that the cue to noun- or verb-ness would remain highlighted. Again, practice was given to ensure that children could do the task. Once it was clear that the child understood the task, the experiment began.

On each trial, the experimenter provided one of the frame sentences and then played a syllable pair. The child blended the syllables then said the word in the frame sentence. If the experimenter felt that the child did not sufficiently "smoosh" the syllables together, the child was given two other opportunities to do so (i.e., the trial was repeated). If the child did not succeed after 3 tries, the experimenter continued onto the next item. Each pair was presented in the context of either a noun or verb frame sentence in one of three predetermined randomized orders for a total of 32 trials per child. Children's productions were digitally recorded using a wireless microphone that was clipped to a baseball cap or headband and located in the center of the child's forehead.

2.4 Coding

The procedure resulted in 1920 words (60 children × 16 words × 2 frame sentences). It immediately became clear that children did not always manage to blend the syllables into a single word-like unit; some were produced as a sequence of monosyllables with obvious equal stress. The decision was therefore taken to code items as blended (1) or not blended (0). To do this in a rigorous way, the acoustic waveform for each item was examined in Praat (Boersma & Weenink, 2009). Unsuccessfully blended items were defined as those with inter-syllabic pauses. Pauses were identified on the waveform as any silent interval that intervened between a medial sonorant or fricative consonant and its adjacent vowel. When the medial consonant was a stop, pauses were identified only when closure duration exceeded 100 milliseconds. This criterion was chosen because it corresponded to an audible boundary. Previous studies have also taken pauses longer than 100 milliseconds to indicate hesitancy between speech units (see Lounsbery, 1954; Goldman-Eisler, 1958). A total of 215 items were produced with pauses and coded as not blended.

In addition to pausing, items were coded as not blended (0) if the child modified the target vowel quality in a way that impacted its length (e.g., /deɪtus/ for /dɛtus/) or introduced a medial coda consonant (e.g., /dɛstus/ for /dɛtus/). A total of 152 items were produced in a way that changed the target structure and so were coded as not blended.

Lexical stress patterns were coded only for the 1553 items that were blended renditions of the order syllable pair. These items were excised from the frame sentences in which they were produced and presented over headphones in random order to 5 native English-speaking listeners, who made perceptual stress judgments. All 5 listeners were upper-division linguistics majors who had a clear understanding of lexical stress as a linguistic phenomenon. All also had extensive experience working with children, and so were very familiar with children's speech. Listeners identified main stress as occurring either on the first or second syllable. Listeners were also given the option of coding the item as having equal stress—a category used to distinguish true word-likeness from blending at the phrase-level. Three out of 5 judges agreed on stress placement for 1398 out of the 1553 items. Only these items with high inter-listener agreement were included in the analyses on lexical stress.

In order to confirm that items were actually produced in a manner consistent with the main stress judgments, just over 10% of the items judged by a majority of listeners as trochaically or iambically stressed were randomly selected for acoustic measurement; 50% of those judged to have equal stress were measured since there were relatively few of these (N = 137). Duration, intensity at vowel midpoint, and mean F0 were recorded for the first and second vowels, and then expressed as ratios with values from the first syllable divided by those from the second. A mixed effects model with stress judgment (trochaic, iambic, equal), word structure (CVV.CVC versus CV.CVVC), and grammatical category (noun versus verb) as fixed factors and child and age as random factors showed a significant effect of stress judgment on the duration ratio, $F(2, 144.05) = 11.45$, $p < .001$, the intensity ratio, $F(2, 305.14) = 42.06$, $p < .001$, and the F0 ratio, $F(2, 133.82) = 53.40$, $p < .001$. Not surprisingly, the effect of word structure was also significant for the duration ratio, $F(1, 176.04) = 49.42$, $p < .001$, as was the interaction between word structure and grammatical category, $F(1, 188.18) = 5.18$, $p = .024$. Finally, the interaction between stress judgment and grammatical category was significant for the intensity ratio, $F(1, 217.08)$, $p = .038$. In spite of these other effects, post hoc mean comparisons over all the data indicated that each pairwise comparison (trochaic vs. iambic, trochaic vs. equal, iambic vs. equal) was significantly different on every measure taken.

Table 2 shows the mean (and standard deviation) values for each measure by each stress pattern. These values show that, as expected, tokens judged to have main stress on the first syllable (trochaic pattern) were associated with larger duration, intensity, and F0 ratios than those judged to have main stress on the second syllable (iambic pattern). Tokens judged to have equal stress fell somewhere between the perceived trochees and iambs.

2.5 Analyses

The coding scheme yielded two dependent variables for analysis: blending ability (blended versus not blended) and lexical stress pattern (trochaic, iambic, equal). Given the categorical nature of these variables, logistic regression analyses were used to investigate the effect of vocabulary size, word structure (CV.CVVC versus CVV.CVC), and grammatical category (noun versus verb) on the dependent variables. Three levels of vocabulary size—small, medium, and large—were created by dividing the participating children into 3 groups according to their raw PPVT scores. Children with small vocabularies had a mean PPVT score of 122 (*SD* = 8.5), those with medium vocabularies a score of 138 (*SD* = 4.1), and those with large vocabularies a score of 157 (*SD* = 11.2). While the use of raw PPVT scores to define vocabulary size is consistent with the hypothesis that phonological knowledge regarding lexical stress emerges from the lexicon, it is confounded with age. The mean age of children with small vocabularies was 6;4 (*SD* = 9.1 months), that of children with medium and large vocabularies was 6;7 (*SD* = 9.1 months) and 7;6 (*SD* = 6.4 months), respectively. Accordingly, age-in-months was entered as a control variable in all analyses.

3. RESULTS and DISCUSION

3.1 Blending Ability

Blending ability among all participants ranged from 31% word-like productions to 100% word-like productions. Vocabulary size, word structure, grammatical category, and age in months were used to predict blending ability in a binary logistic regression model. A backward elimination procedure was used to keep only those interactions that contributed significantly to explaining the variance in blending ability. The final model was significant, $X^2(4, N = 1920) = 122.02$, $p < .001$, but accounted for only a small proportion of the variance, Nagelkerke $R^2 = .10$. Since our interest is in the behavior of the predictors in the model, the results are nonetheless instructive. Vocabulary size, word structure and age were all significant predictors of blending ability. Grammatical category was not a significant predictor, nor were any of the interactions. Table 3 provides the detailed results from the model, and Figure 1 the predicted probability of blending as a function of the significant predictor variables.

Figure 1 shows that older children were better able to blend ordered syllable pairs into word-like units than younger children. In addition, children with smaller vocabularies for their age appeared to be better able to blend syllables into word-like units than children with larger vocabularies for their age. The raw frequency data are given in Table 4 to illustrate this point more completely.

The effect of word structure on blending ability was due to children’s greater success in blending CVV+CVC syllable pairs into word-like units than CV+CVVC syllable pairs. The overall average predicted probability that a CVV+CVC syllable pair would be blended into a single word-like unit was .86 (*SD* = .07) and .76 (*SD* = .10) for a CV+CVVC syllable pair.

Since Figure 1 suggests that younger children with larger vocabularies for their ages may have had more trouble blending syllable pairs than other children, we split the data into terciles by age in months and used vocabulary size and word structure to predict blending ability within each subset of data. Age-in-months within the tercile was entered as a control variable. The results were that vocabulary size was a significant predictor of blending ability in the two younger age groups with the Wald statistic equal to 12.70, $p < .001$, for the youngest group ($N = 21$) and 8.53, $p = .004$, for the next older group ($N = 19$). Vocabulary size did not predict blending ability in the oldest age group ($N = 20$). By contrast, word structure predicted blending ability in all age groups with the Wald statistic equal to 15.11, $p < .001$, in the youngest group, 10.69, $p = .001$, in the next older group, and 4.86, $p = .027$, in the oldest group of children.

We conclude from these results that younger children blended fewer of the ordered stimuli into word-like units than older children, but that all children were selective in what they failed to blend: children were less likely to blend the ordered syllable pairs that would result in word structures with a light initial syllable and super heavy second syllable (CV.CVVC). This word structure is precisely the one that should bias children to produce an iambic stress pattern. The finding that children produced CVV.CVC word shapes more readily than CV.CVVC might be attributed to the lower frequency of words with CV.CVVC forms. The effect of vocabulary size on word blending in the youngest children might also indicate a particular resistance to producing iambic patterns, assuming that children with smaller vocabularies produced the blended versions of these with a trochaic stress pattern.

3.2 Lexical Stress Patterns

Recall that high inter-listener agreement for lexical stress placement was obtained for 1,398 blended items. The number of items for which agreement was high ranged from 5 to 32 per child, but the majority of children ($N = 55$) each produced at least 17 items (more than half) in such a way that stress could be reliably coded. The 5 children who did not were treated as outliers, and their data were excluded from further analysis. In all, the analyses reported below were based on 1,350 blended items produced by 55 children.

The percentage of items perceived as trochaically stressed was higher than the percentage perceived as iambically stressed (56.4% versus 34.4%). A smaller percentage of items were perceived as equally stressed (9.2%). The relative frequencies of different stress patterns suggests a preference for a trochaic pattern that was nonetheless somewhat weaker than would be expected based on the distributional facts for English alone. The weakness of the preference is consistent with the experimental design, which favored a much higher proportion of iambically stressed items than is typical for English. With respect to the items perceived as equally stressed, these were produced by a subset of 39 children, who ranged in age from 5;3 to 8;3 with a mean age of 6;10 (SD = 9.8 months) and had vocabulary sizes ranging from small (PPVT = 99) to large (PPVT = 194) with a mean score of 140.8 (SD = 17.8 points).

Vocabulary size, word structure, grammatical category, and age-in-months were entered into a multinomial logistic regression model to predict stress placement. Again, a backwards elimination procedure was used to keep only significant interactions in the model. The final model accurately classified 87.6% of the trochaically stressed items, 20.9% of the iambically stressed items, and 0% of the equally stressed items. This performance was a significant improvement over the null model, $X^2(20, N = 1350) = 119.20$, $p < .001$, which classified all items as trochaically stressed. The predictors that contributed to explaining variance in the final best-fit model were word structure, −2LL = 1338.71, $X^2(2, N = 1350) = 23.96$, $p < .001$, an interaction between vocabulary size and grammatical category, −2LL = 1325.06, $X^2(4, N = 1350) = 10.30$, $p = .036$, an interaction between vocabulary size and age, −2LL = 1325.06, $X^2(4, N = 1350) = 16.49$, $p = .002$, and an interaction between grammatical category and age, −2LL = 1320.40, $X^2(2, N = 1350) = 5.64$, $p = .060$. Neither vocabulary size nor grammatical category nor age were significant predictors on their own.

Roughly the same overall fit of the data was achieved in the absence of interactions, $X^2(10, N = 1350) = 90.40$, $p < .001$. In this model, which also had fewer degrees of freedom, 89.6% of the trochaically stressed items and 19.4% of the iambically stressed items were correctly classified, and all the variables were significant predictors of stress placement: vocabulary size, −2LL = 1377.82, $X^2(4, N = 1350) = 34.26$, $p < .001$, word structure, −2LL = 1366.63, $X^2(2, N = 1350) = 23.07$, $p < .001$, grammatical category, −2LL = 1352.08, $X^2(2, N = 1350) = 8.52$, $p = .014$, and age, −2LL = 1369.36, $X^2(2, N = 1350) = 25.80$, $p < .001$.

Figure 2 provides a clearer sense of the patterns in the data. In this figure, the relative proportions of trochaic and iambic productions, calculated within speaker, are displayed as a function of vocabulary size, word structure, and grammatical category. A reference line is placed at the .5 mark so that the reader is able to better visualize the significant effects of each predictor variable. With respect to prediction #1, children with larger vocabularies had a somewhat stronger preference for producing trochaic stress (bars) than iambic stress (lines) than children with smaller vocabularies: 69.9% of the items produced by children with large vocabularies were trochaically stressed versus 43.8% and 57.8% of the items produced by children with medium and smaller vocabularies respectively. Keep in mind that children with the smallest vocabularies also tended to be the youngest children in the sample, and so those least likely to have blended all syllable pairs. It is likely that the stronger preference for trochaic stress in children with smaller vocabularies compared to those with medium vocabularies reflects the finding that these children also produced far fewer CV.CVVC nonwords.

In keeping with the distributional patterns of English, the relative proportion of trochaically stressed items was also higher on average for the disyllabic nonwords with a CVV.CVC structure than for those with a CV.CVVC structure (60.3% vs. 47.3%). Similarly, the relative proportion of trochaically stressed items was higher for nonwords produced in a noun context than for those produced in a verb context (56.7% vs. 51.0%), and vice versa for the relative proportion of iambically stressed items. Equally stressed items patterned with iambically stressed items: more CV.CVVC nonwords were perceived as equally stressed compared to CVV.CVC nonwords (69 versus 55), and more items were perceived as equally stressed when they were produced in a verb context than when they were produced in a noun context (68 versus 56).

Recall that the effects of word structure and grammatical category were predicted to vary with vocabulary size. In particular, prediction #2 was that children with larger vocabulary sizes would exhibit a stronger tendency to produce CV.CVVC nonwords with iambic stress than children with smaller vocabularies, and prediction #3 was that children with larger vocabularies would be more sensitive to the correlation between grammatical category and lexical stress than children with smaller vocabularies. The data shown in Figure 2 are compatible with both predictions, even though the omnibus analysis presented earlier showed only an interaction between vocabulary size and grammatical category. To test whether the effects of word structure and grammatical category really held equally across all vocabulary sizes, as suggested in the omnibus analysis, new logistic regression analyses were conducted on the data split by vocabulary size. In these analyses, word structure and grammatical category were used to predict trochaic stress (presence versus absence) and iambic stress (presence versus absence). Age was entered as a control variable. The results on trochaic stress, presented in Table 5, were that word structure was a significant predictor of stress placement for items produced by all children regardless of vocabulary size, but grammatical category was only a significant predictor of stress placement for items produced by children with the largest vocabularies. The results on iambic stress, presented in Table 6, were that word structure was a significant predictor of stress placement for items produced by children with medium and large vocabularies; grammatical category was not a significant predictor of stress placement.

Overall, the results show that stress placement on nonwords varied with vocabulary size, and in the expected direction. The main effect of vocabulary size was consistent with the prediction that children with larger vocabularies would produce more items with trochaic stress than iambic stress. The main effect of word structure demonstrated that children were sensitive to the correlation between weight and stress. The finding that this effect was partially modulated by vocabulary size (see Table 6 above) provides some support for the prediction that children with larger vocabularies would be more sensitive to quantity for stress than children with smaller vocabularies, but this result may also reflect the previously reported differences in blending ability. The predicted effect of vocabulary size on the acquisition of grammatically-linked stress patterns was upheld by an interaction between vocabulary size and grammatical category on stress placement, coupled with the result that grammatical category only predicted stress placement on items produced by children with the largest vocabularies.

4. GENERAL DISCUSSION

The current study was motivated by the hypothesis that mature phonological knowledge includes patterns abstracted across stored lexical items. The hypothesis implies that phonological knowledge will vary with the structure of the lexicon that is stored. We assessed this hypothesis for the acquisition of English stress patterns. Three predictions were advanced: (1) children with larger vocabularies should exhibit a stronger tendency to produce nonwords with a trochaic stress pattern than children with smaller vocabularies, all other things being equal; (2) children with larger vocabularies should exhibit a stronger tendency to produce nonwords with iambic stress than children with smaller vocabularies when the initial syllable is light and the final one is super heavy; and (3) children with larger vocabularies will be more sensitive to the trochaic noun / iambic verb pattern of English than children with smaller vocabularies. The first and third prediction were clearly supported by the results. Consistent with prediction #1, young children with larger vocabularies for their age were less likely than their peers with smaller vocabularies to blend syllable pairs, especially when the blended forms would result in an iambic-compatible word structure. In addition, children with the largest vocabularies overall were more likely than their peers to produce blended items with a trochaic stress pattern than an iambic one. Consistent with prediction #3, only children with the largest absolute vocabulary sizes showed the predicted effect of grammatical category on the production of blended items.

In contrast to predictions #1 and #3, prediction #2 received less support in that the effect of word structure on blending ability and stress placement was fairly robust across different vocabulary sizes. This result suggests that all children were sensitive to syllable weight, which is consistent with Kehoe's (1998) conclusion that quantity sensitivity for stress may be acquired early in English; perhaps because it is memorized with the lexical items where it occurs. It may also be worth noting that, although disyllabic CV.CVVC lexical items are relatively rare in English, children have extensive practice with this form in normal speech because of the overwhelming preponderance of heavy monosyllabic nouns in English and the frequency with which these are rendered in determiner noun phrases as iambically-stressed prosodic words (e.g., "the dog" /ðə'dɑːg/). In the remainder of this section, we leave aside further discussion of quantity sensitivity and instead discuss the results pertaining to predictions #1 and #3 with reference to speech practice and emergent phonological knowledge.

The rationale behind the prediction that children with larger vocabularies would exhibit a stronger preference for producing trochaic patterns than children with smaller vocabularies followed from Stoel-Gammon's (2011) observation that vocabulary size and speech motor skills co-develop. Children with larger vocabularies have acquired more trochaically-stressed lexical items overall, and so presumably have more lifetime practice producing trochaic foot structures across numerous items than children with smaller vocabularies. Assuming that practice results in entrenchment and that entrenched patterns result in production biases, there should be a relationship between vocabulary size and the strength of a bias. Again, this was the present finding: children with the largest vocabularies produced more nonwords with a trochaic stress pattern than children with smaller vocabularies.

The proposed relationship between vocabulary size and entrenchment has broad implications for understanding first and second language acquisition. For example, the relationship could account for the finding that nonword repetition is more accurate in children with larger vocabularies than in children with smaller vocabularies (Gathercole, et al., 1992; Werker, et al., 2002; Edwards, et al., 2004; Munson, Edwards, et al., 2005; Munson, Kurtz, et al., 2005; Fernald, et al., 2006). Let us assume that production accuracy increases during development because speech practice is motivated by achieving the closest link possible between the stored perceptual forms of words extracted from the input and the abstract perceptual-motor routines that guide production. Let us further assume that better self-generated approximations of target patterns are repeated with greater frequency than poorer approximations. What then about entrenchment and nonword repetition accuracy? It may be that larger vocabularies allow for the development and entrenchment of routines that are more generalizable; that is, routines that better reflect shared characteristics between groups of words rather than simply the characteristics specific to a single word. This is because the child with a larger vocabulary will have the chance to practice a diversity of words with similar sound shapes. By contrast, the child with a small vocabulary may achieve production accuracy on the items she has represented, but the entrenched routines will be more specific in nature—pertaining as they do to fewer lexical items—and so less generalizable. The child with access to more generalizable routines can call on these to produce nonword stimuli. The child with more specific routines must try to adapt these online to approximate the nonword target.

As for second language acquisition, a relationship between entrenchment and vocabulary size could account for the effect of age of acquisition on foreign accent. Specifically, foreign accent might be explained by the relative sizes of the first and second language vocabularies that a speaker has acquired. In younger children, the relative sizes of the two vocabularies are likely to be more equal than in older children and adults; thus, the routines that emerge from lexical practice will be equally weighted across languages, instead of weighted heavily in favor of one language or another.

The prediction that children with large vocabularies would be more sensitive to the trochaic noun / iambic verb pattern of English than children with smaller vocabularies was motivated in part by the fact that disyllabic verbs are rarer in English than disyllabic nouns, and are likely acquired quite late and only after more common vocabulary items. Given this aspect of the rationale, the more specific prediction could have been that children with larger vocabularies would exhibit a stronger association between verbs and the iambic pattern than children with smaller vocabularies. We found instead that sensitivity varied more with the association between nouns and the trochaic pattern than between verbs and the iambic pattern (see Tables 5 & 6). Then again, if we assume that more lexical items leads to greater generalization of the pattern, this finding remains consistent with the overall hypothesis.

Note that regardless of any interaction with vocabulary size, the hypothesis of emergent phonological knowledge is supported just by the main effect of grammatical category on stress pattern production. In order for the trochaic noun / iambic verb pattern to be generalized to novel instances, one has to have abstracted a phonological contrast between lexical items that behave as nouns and those that behave as verbs. Such an abstraction depends on the acquisition of disyllabic words that can be categorized as nouns and verbs. Of course, the explicit representation of a phonological contrast is not required. What is necessary, however, is some kind of analysis of noun- and verb-ness that is tied closely enough to stored lexical forms for the association between grammatical category and lexical stress pattern to be abstracted.

Although we found that the effect of grammatical category was only significant for those items produced by children with the largest absolute vocabulary sizes, the absence of a significant interaction between vocabulary size and grammatical category in the overall analysis suggests limited differences in children's phonological knowledge as a function of differences in vocabulary size. Under the hypothesis of emergent phonological knowledge, this could suggest that the observed differences in vocabulary size across individuals in the present study were too small to result in robust behavioral differences. Such a suggestion is at least compatible with differences between the present results on children's production of lexical stress and those obtained by Guion et al. (2003) in their similar study of adult behavior. Whereas we found an overall stronger effect of word structure than grammatical category in children's productions, Guion et al. found the opposite in adults: the biasing effect of grammatical category on adult production of lexical stress was almost twice as strong as the biasing effect of word structure on production. Thus, it could be that adults have a more robust representation of the trochaic noun / iambic verb pattern than children because they have stored substantially more items over which to abstract this pattern.

An alternative explanation for the different relative weightings of structure and grammatical factors in child and adult production is that, by adulthood, a lifetime of practice with speech results in productions that are more modulated by semantics (i.e., sentence meaning) than by phonological structure. Attention to grammatical category, cued by a determiner versus infinitival particle, also reflects attention to phrase-level form-meaning pairings. Elsewhere, we have suggested that children are more influenced by word-level structure than by phrase-level structure compared to adults (Shport & Redford, 2014). Thus, a final explanation for the difference between children and adults that we see here when comparing the current results to those obtained by Guion et al. (2003) is a stronger influence of word- over phrase-level factors in children's productions. In particular, compared to adults, children may have less robust representations and therefore more minimal influences from the constructions referenced by the frame sentences ("construction" is used here in the sense of Construction Grammar; e.g., Goldberg, 2006).

It is possible that all the effects reported here would have been stronger had we sought to identify children who exhibited an even wider range of vocabulary sizes to participate in our study. The problem with doing this, however, is that we would have had to make further compromises regarding either the children's age or their developmental status. The basic fact is that, barring developmental disabilities or delay, vocabulary grows mainly as a function of time. For this reason, it is difficult to decouple effects of vocabulary from other developmental effects. This is why evidence for the hypothesis of emergent phonological knowledge is most compelling when a lexical-grammatical analysis is a pre-requisite for the abstraction of the phonological pattern. In the present study, we find effects on lexical stress that can only be attributed to this kind of analysis. But we also find effects that speak to a relationship between vocabulary size and speech practice. Based on these findings, we conclude that a comprehensive theory of emergent phonology should assume a developmental trajectory that begins with statistical learning in early development, and quickly moves on to the entrenchment of particularly well-represented patterns through babbling and lexical practice, and then finally on to implicit representations of lexical frequency and grammatical meaning. It is just this latter type of phonological knowledge that is emergent from abstraction over the lexicon. Such a theory captures the empirical results presented here and elsewhere in the literature, and thus provides a strong conceptual framework for understanding the development of a mature phonological grammar.

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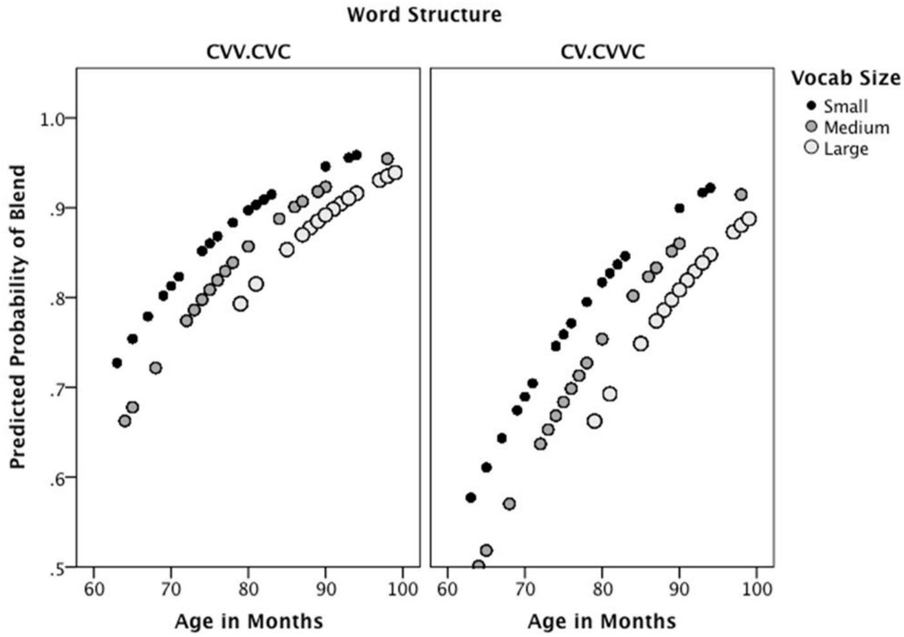

Figure 1.
The predicted probability of a successfully blended production of order syllable pairs as a function of vocabulary size, word structure, and age in months.

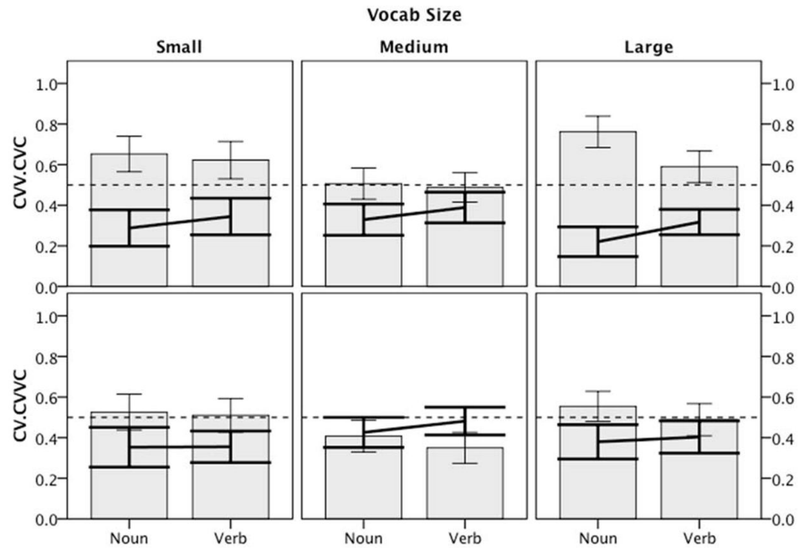

Figure 2.

Lexical stress patterns as a function grammatical category, target word structure, and vocabulary size. The bar graph represents the proportion of items with trochaic stress, the line graph the proportion of items with iambic stress. Error bars show + and − 1 Standard Error.

Table 1

Stimuli were ordered syllable pairs that either had syllable shapes with equal weight (CVV+CVC) or a light, then super heavy syllable (CV+CVVC).

CVV+CVC		**CV+CVVC**	
beɪ + lɛt	beɪ + tɛs	bɪ + tus	kɪ + gin
pu + lɛt	pu + tɛs	dɛ + tus	sɛ + gin
taɪ + lɪn	taɪ + sɪn	kɪ + teɪs	nɪ + lit
tu + lɪn	tu + sɪn	dɛ + teɪs	sɛ + lit

Table 2

Mean duration (milliseconds), intensity (dB), and F0 (Hz) ratios (vowel 1 divided by vowel 2) as a function of perceived stress pattern.

Ratios	Trochaic	Iambic	Equal
Duration	1.401 (.727)	0.851 (.463)	1.081 (.374)
Intensity	1.111 (.087)	0.994 (.063)	1.034 (.044)
F0	1.323 (.280)	0.903 (.196)	1.049 (.149)

Table 3

Coefficients in the final binary logistic regression model of blending ability.

Predictor variables	**B (*S.E.*)**	**Wald (*df* = 1)**	***p* =**	**Odds Ratio**
Vocabulary size	−.38 (.09)	15.83	.001	0.67
Word structure	−.67 (.12)	30.02	.000	0.51
Gramm. category	−.15 (.12)	1.59	.208	0.86
Age	.07 (.01)	81.13	.000	1.07
Constant	−2.96 (.53)	31.35	.000	0.05

Table 4

Average percentage of word-like items blended as a function of vocabulary size and different terciles of age.

Vocabulary size	Tercile of age group	% blended	*N* (items)
Small	Youngest (*M* = 5;9)	76.7	352
	Older (*M* = 6;9)	85.4	192
	Oldest (*M* = 7;8)	88.5	96
Medium	Youngest (*M* = 6;0)	68.1	320
	Older (*M* = 6;10)	84.9	192
	Oldest (*M* = 7;8)	88.3	128
Large	Youngest	NA	0
	Older (*M* = 6;11)	76.8	224
	Oldest (*M* = 7;9)	88.5	416

Table 5

Coefficients in the binary logistic regression model of trochaic stress on data split by vocabulary size.

Vocab size	Predictor variables	B (*S.E.*)	Wald (*df* = 1)	*p* =	Odds Ratio
Small	Word structure	−.47 (.19)	5.45	.020	0.64
	Gramm. category	.21 (.19)	1.14	.286	1.23
	Age	.06 (.01)	33.25	.000	1.06
	Constant	−4.07 (.81)	25.37	.000	0.02
Medium	Word structure	−.50 (.20)	6.17	.013	0.61
	Gramm. category	.22 (.20)	1.17	.280	1.24
	Age	.01 (.01)	0.85	.356	1.01
	Constant	−.93 (.98)	0.90	.343	0.40
Large	Word structure	−.72 (.20)	13.05	.000	0.49
	Gramm. category	.57 (.20)	7.94	.005	1.76
	Age	−.00 (.02)	0.00	.965	1.00
	Constant	.58 (1.6)	0.14	.710	1.78

Table 6

Coefficients in the binary logistic regression model of iambic stress on data split by vocabulary size.

Vocab size	Predictor variables	B (*S.E.*)	Wald (*df* = 1)	*p* =	Odds Ratio
Small	Word structure	.20 (.20)	1.02	.312	1.22
	Gramm. category	−.28 (.20)	1.92	.166	0.80
	Age	−.05 (.01)	26.50	.000	0.95
	Constant	3.58 (.84)	18.31	.000	35.70
Medium	Word structure	.48 (.21)	5.45	.020	1.61
	Gramm. category	−.32 (.21)	2.37	.124	0.73
	Age	−.02 (.01)	3.69	.055	0.98
	Constant	1.39 (1.0)	1.92	.166	4.02
Large	Word structure	.66 (.21)	10.16	.001	1.93
	Gramm. category	−.33 (.21)	2.55	.110	0.72
	Age	.01 (.02)	0.23	.629	1.01
	Constant	−1.66 (1.6)	1.07	.300	0.19