J. Child Lang. **38** (2011), 1–34.
doi:10.1017/S0305000910000425

Relationships between lexical and phonological development in young children*

CAROL STOEL-GAMMON
University of Washington

(*Received* 8 *August* 2009 – *Revised* 26 *January* 2010 – *Accepted* 2 *April* 2010 – *First published online* 18 *October* 2010)

ABSTRACT

Our understanding of the relationships between lexical and phonological development has been enhanced in recent years by increased interest in this area from language scientists, psychologists and phonologists. This review article provides a summary of research, highlighting similarities and differences across studies. It is suggested that the research falls into two categories with different goals and different methodological approaches: (1) child-centered studies that examine the influences active in the prelinguistic and early-word period, emphasizing individual developmental patterns and the active role played by the child; and (2) studies inspired by research on word processing in adults; these focus on the effects of the phonological and lexical characteristics of the ambient language on underlying representations and word learning in children. The article concludes with suggestions for integrating the findings from the two approaches and for future research.

INTRODUCTION

Research in linguistics is typically focused on one of the 'subdomains' in the field with relatively little attention to the interactions between domains. Thus, some researchers specialize exclusively in syntax while others publish only in the area of phonology or semantics. Specialized journals have reinforced the separation between the various domains. A similar trend is evident in studies of language acquisition, where the division into domains has predominated, leading to a wealth of knowledge about the ways in which children acquire, e.g., the morphological aspects of their verb system or the phonological patterns of their language. This focus on specialization has led to a lack of attention to the areas of overlap. In the domains of phonological and lexical development, important interactions between

[*] Address for correspondence: Carol Stoel-Gammon, Department of Speech and Hearing Sciences, University of Washington, 1417 N. E. 42nd Street, Seattle, WA 98195, USA. e-mail: csg@u.washington.edu

phonological and lexical development have been identified, and these interactions have been shown to be bi-directional. That is, phonological ability has been shown to influence lexical acquisition and the nature and structure of the lexicon has been shown in turn to influence phonological knowledge.

This purpose of this article is to examine the interactions between lexical and phonological development from infancy to age 4;0, i.e. the prereading period. The focus is primarily on children with typical speech and language development and on production rather than perception; although studies of a variety of languages will be cited, the focus is on investigations of children acquiring American English. The article is structured as follows: (1) a summary of general patterns of phonological and lexical development, as independent phenomena; this summary is intended to provide a general framework for the subsequent discussion and does not include detailed commentary on specific studies; (2) a set of postulates about the relationships between lexical and phonological development across the designated age period; (3) the identification and discussion of several hypotheses which, in the author's view, need further study before they can be fully understood and evaluated; and (4) a summary of lexical–phonological relationships highlighted in the article and suggestions for future research.

Phonological development: a brief summary

In order to produce meaningful speech, children must learn the movements (articulatory and phonatory) necessary to produce words in an adult-like manner, and must have knowledge of the phonological forms of words of their native language. Thus, phonological development has two basic components: (1) a biologically based component associated with the development of the speech–motor skills needed for the adult-like pronunciation of words; and (2) a cognitive–linguistic component associated with learning the phonological system of the ambient language; this component includes processes of memory and pattern recognition associated with the storage and retrieval of words in a child's 'mental lexicon' (Stoel-Gammon & Sosa, 2007).

The beginnings of phonological development appear prior to words with the cries, gestures and vocalizations of the prespeech period; although they are non-meaningful, prespeech vocalizations can be used to regulate the behaviors of others. With the emergence of words, symbolic communication takes on the functions of presymbolic signals, and babbled vocalizations yield to verbalizations. Studies of phonological development tend to focus on vocalizations that have identifiable referents, thus allowing for comparisons between the child's production and the target form. There are, however, vocalizations that meet the criteria of being a word in that they have stable sound–meaning relationships, but do not appear to be based on the adult form. Rather, the child has created his or her own word form, sometimes referred to as a proto-word. For example, one of the children studied by Stoel-Gammon & Cooper (1984) used the form [di] to mean something like 'look at that', while another child in the study produced [ma] or [na] as an all-purpose request form.

Identifying, and analyzing, early word productions is not easy, as the form of a babbled (i.e. non-meaningful) vocalization may be identical to the form of a word. To be judged a word, the child's phonetic form(s) must be systematically linked with the context(s). It is generally assumed that the child's form will bear some resemblance to the adult target in terms of syllable shape and/or segmental patterning. In many cases, the child and adult forms differ substantially, but a pattern of correspondences between child and adult form can be identified. For example, the form [di] for the target 'cheese' would be acceptable if the form appears to be used in the appropriate contexts (e.g. when asking for cheese; when labeling a picture of cheese, etc.) and is relatively stable.

As noted above, phonological development involves both biological and cognitive factors that interact with one another during the period of acquisition. Babies must learn to produce movement patterns that yield sound sequences similar to those of the adult speakers in their environment. They must learn to do this in spite of differences in vocal tract configuration and speed and precision of motor movements, especially movements involving the tongue. Thus, anatomical and neurophysiological constraints in the human infant place natural limits on the range of variation that can occur in early vocalizations.

Although early word productions are marked by extensive individual differences in pronunciation patterns, children aged 2;0 acquiring American English, who typically have a productive vocabulary of about 300 words (Fenson, Marchman, Thal, Dale, Reznick & Bates, 2007), exhibit more consistent patterns, characterized by simple word and syllable shapes (e.g. CV, CVC, CVCV) and by sound classes that are thought to be 'easier' to produce (stops, nasals, glides). It is interesting to note that the size of productive vocabularies of children aged 2;0 in different languages, as measured by adaptations of the MacArthur-Bates Communicative Developmental Inventories (Bleses *et al.*, 2008a), varies considerably, and different dialects of the same language, such as British and American English, have also shown differences (see Bleses *et al.* (2008a) for comparisons). For two-year-olds, the size of productive vocabulary can vary substantially, with a mean of about 550 words for children acquiring Mandarin (Tardif, Fletcher, Liang & Kaciroti, 2009) compared with 307 words (*SD* 162·4) for American children (Fenson *et al.*, 2007) and 261·9 words (*SD* 162) for Australian children (Bavin *et al.*, 2008). Possible associations between the

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

phonological system of a language and the growth of early vocabulary across languages are discussed later.

Even though the phonological system is far from complete by age 2;0, studies of the acquisition of American English show that the basic word structures, syllable shapes and sound classes are present at that age (Stoel-Gammon, 1987), and about half of what a typical two-year-old says can be understood by a stranger (Coplan & Gleason, 1988). On average, a two-year-old has a phonetic inventory containing voiced and voiceless labial, alveolar and (usually) velar stop consonants; labial and alveolar nasals; glides and some fricatives, usually [f] and [s]. In terms of syllable and word shapes, the repertoire includes open and closed syllables that can combine to form disyllabic words. In addition, the typical two-year-old can produce some words with consonant clusters in initial and final position (Stoel-Gammon, 1985; 1987). By age 3;0, the phonetic inventory of an American child with typical development has expanded considerably to include consonants of all place, manner and voice classes and a variety of syllable and word shapes. In their study of children aged 2;0–4;0, Prather and colleagues (Prather, Hedrick & Kern, 1975) reported that all phonemes except voiced fricatives and the voiced affricate were produced correctly in at least one of the word positions tested by at least half the subjects at age 3;0.

It is relatively easy to trace phonological development in terms of accuracy of production and to describe error patterns, but more difficult to determine the processes underlying the course of development. While it is beyond the scope of this article to present a full-blown account of theoretical perspectives, a very brief overview is offered as a framework for the discussion of phonological acquisition. Most theories of phonological development are derived from (adult-based) phonological theories, which have evolved considerably over the past sixty years.

One of the earliest child-based theories stemmed from Jakobson's structuralist approach (1968); Jakobson proposed that children adhered to a universal order of acquisition of phonemic contrasts, regardless of their language. With the appearance of Chomsky & Halle's seminal book (1968) laying out the premises of generative phonology, the focus of phonological theory turned to relationships between abstract and surface forms: one of the basic tenets is that spoken productions result from the application of a set of phonological 'rules' applied to abstract underlying forms similar to those of adults. Researchers interested in phonological acquisition used these constructs to create a set of rules that could capture differences between the adult pronunciations and the child's (mis-)pronunciations (e.g. Grunwell, 1981). Stampe's (1969) theory of natural phonology proposed a set of universal and innate 'phonological processes' that applied to adult and child speech. In acquiring an adult-like phonology, a child must learn to suppress those processes that do not occur in their language. For example, a child learning Hawaiian does not have to suppress the process of final consonant deletion as there are no word-final consonants in that language, whereas a child learning English must learn to produce final consonants. Stampe's theory has been highly influential in studies of phonological acquisition and phonological disorders.

In the 1970s, there was a shift in phonological theories from linear, segment-based perspectives to non-linear, hierarchical approaches in which phonological representations were described not as strings of segments but as a hierarchy of phonological 'levels', each containing a different type of information. In brief, these models include levels of the phrase and prosodic word, moving down to the levels of foot and syllable structure, and then to a hierarchy of features (for a historical overview, see Bernhardt & Stemberger, 1998). Optimality Theory (Prince & Smolensky, 2004) is among the most recent approaches that have been applied to phonological development and disorders. The premise of this approach is that there is a universal set of conflicting 'constraints' of two basic types: markedness constraints which disallow the presence of marked structures in the output (e.g. a constraint on final consonants) and faithfulness constraints which require a match between the input and output. Phonological acquisition is viewed as a process of ranking and re-ranking of constraints to conform to the constraint patterns of the ambient language (see Dinnsen & Gierut (2008) for an overview).

Differences among these theories have implications for our understanding of the associations between lexical and phonological development. Among these are their views regarding: (1) innateness; (2) the role of prelinguistic development; (3) the influence of input; (4) the effects of language use, including frequency of occurrence; and (5) the nature and number of underlying phonological representations that form part of the 'mental lexicon'.

Lexical development: a brief summary

Word learning is one of the major accomplishments of the first years of life. Infants enter the world with the biological capacity for understanding and producing speech, and social interactions between infants and their caregivers create a world in which language becomes the primary means of communication. By the end of the first year, babies with typical development are able to produce a few words; these early words often resemble prelinguistic, non-meaningful vocalizations such as [baba] or [mama], which can gain word status by associating sound with meaning. American children aged 2;0 have a productive vocabulary of 250–350 words (mean of 307) and, by age 2;6, their productive vocabulary has increased to about

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

570 words. Around the age of 6;0, children learning English have a receptive vocabulary of several thousand words, with estimates varying from 6,000 to 14,000. The wide range of estimations of vocabulary size can be related, in part, to methodological differences in determining a child's vocabulary; in addition, it has been documented that environmental and educational differences associated with social class impact vocabulary size (see Hart & Risley, 1995).

Longitudinal research shows that the rate of vocabulary growth tends to be quite slow in the first few months after the onset of words, with many children taking about six months to acquire a 50-word vocabulary; after that, vocabulary growth accelerates significantly, leading many researchers to argue that there is an identifiable 'vocabulary spurt' or 'naming explosion' at around age 1;6. Various factors have been proposed for the increase in vocabulary; it has been linked to cognitive changes related to the infant's understanding of object permanence leading to the 'naming insight' (Corrigan, 1978), to the ability to represent objects symbolically (Lifter & Bloom, 1989), to the ability to form categories of objects (Gopnik & Meltzoff, 1992) and to changes in lexical memory and/or articulatory abilities (Woodward, Markman & Fitzsimmons, 1994). Some researchers have questioned the notion of a vocabulary spurt, noting that the rate of word learning in the second year of life exhibits considerable variation: whereas some children undergo a dramatic increase in vocabulary growth around age 1;6–1;8, many, perhaps most, exhibit a more gradual increase in rate of acquisition rather than distinct periods of slow vs. fast learning (Bloom, 2000; Ganger & Brent, 2004). The presence (or not) of a vocabulary spurt will be addressed later, as it relates to changes in the developing phonological system.

Investigations of lexical development have identified a number of factors that influence which words children acquiring English are likely to learn. First, there is grammatical class: the vocabularies of young children contain a high proportion of commons nouns. When the average number of words in the vocabulary is 50, common nouns account for 40% of the forms. It is generally assumed that these words are acquired in the context of labeling and or requesting objects. Studies of children acquiring American English show that adults tend to provide labels for objects more often than for actions or relations (Goldfield, 1993). Interestingly, when the vocabulary has grown to over 600 words, the same percentage holds: 40% of the words are common nouns (Bates *et al.*, 1994). Other early-acquired forms include a small set of words commonly used in social contexts such as *mommy*, *daddy*, *hi*, *bye-bye*, *uh-oh* and *no*.

A second factor is frequency of input, with the effects varying according to a word's lexical category (Goodman, Dale & Li, 2008). Although closed-class words (e.g. pronouns, articles, prepositions, quantifiers) are the most frequent in the input, they are not acquired earliest; in fact, they tend to be learned relatively late. Common nouns appear early and, as noted above, account for approximately 40% of a child's words; within this class, frequency of input correlates strongly with order of acquisition: the more often children hear a particular noun, the earlier that noun will become part of their productive vocabulary. A third important influence on vocabulary acquisition is social class as measured by socioeconomic status (SES): children from families with higher SES have larger vocabularies than children from lower SES families, a finding that is presumably linked to the fact that parents in higher SES families spend more time talking to their children (Hart & Risley, 1995; Hoff, 2003). Finally, the phonology of target words has been shown to affect early vocabulary acquisition. Early words acquired by children learning English tend to be short (one or two syllables) and have consonants that are acquired relatively early in the course of phonological acquisition. This factor is explored in greater detail in the remainder of this article.

The next sections provide an overview and discussion of the associations between lexical and phonological acquisition. Specifically, the first sections focus on research indicating that phonology affects the lexicon, for example, that the a child's phonological system, or the phonological features of a word, influences the likelihood of a word being incorporated into a child's productive vocabulary. The later sections examine the influences of vocabulary on productive phonology.

THE PRELINGUISTIC PERIOD: ESTABLISHING THE FOUNDATION FOR LEARNING WORDS

The postulates below provide a summary of research relating vocal behaviors of the prelinguistic period to early lexical and phonological development. As noted in the 'Introduction', the emphasis is on infants/toddlers with typical development and on studies of the acquisition of American English.

Postulate I: lexical acquisition is influenced by a child's prelinguistic vocalizations

During the first year of life, babies pass through predictable and universal stages of vocal development, beginning with 'coos' that appear around age 0;2–0;3 and moving on to more speech-like consonant–vowel (CV) syllables (canonical babble) around age 0;6–0;7. Longitudinal studies have shown correlations between the following pairs of factors: the amount of vocalization at age 0;3 and vocabulary size at age 2;3; the age of onset of canonical babble and the age of onset of meaningful speech; the number of CV syllables at age 1;0 and age at use of first words; use of consonants at age 1;0 and phonological skills at age 3;0; and diversity of syllable and sound types at ages 0;6–1;2 and performance on speech and language tests at age 5;0 (see Stoel-Gammon (1992) for a more detailed summary). In each case, infants who produced more in the prelinguistic period (i.e. more vocalizations at age 0;3; more CV syllables at age 1;0) had superior performance on subsequent speech and language measures during childhood. The links between babble and speech have been interpreted as evidence that infants who produce a greater number of prelinguistic vocalizations, particularly a greater number of canonical utterances with a variety of consonants and vowels, have acquired a greater inventory of 'building blocks' that can be recruited for the production of words. This finding holds for children with typical speech and language development, and even more strongly for those with speech–language disorders. Of course, these are correlations and not causal factors. The sections below show that the correlations appear to be attributed to a number of interrelated factors.

Postulate I-A: the sounds of babble underlie the phonological patterns of early word productions. Around the age of 0;6–0;7, most infants begin to produce consonant–vowel syllables that resemble the syllables or words of adult languages. The consonants in CV babble are not random, but tend to follow predictable patterns in terms of place and manner of articulation. Most are articulated with the lips or the front of the tongue and are produced with full oral closure (stops or nasals) or with an open mouth posture (glides). The most frequent consonants include [m], [b] and [d], which occur in one- and two-syllable vocalizations like [baba] or [di]. Between age 0;6 and 1;0, the consonantal repertoire expands considerably, but claims that babies produce all the sounds of all languages of the world have not been substantiated (Jakobson, 1968). In fact, a limited set of consonants, primarily stops, nasals and glides, as noted above, accounts for the great majority of consonant productions (Vihman, 1996).

Although non-meaningful, prelinguistic vocalizations may be phonetically identical to children's later pronunciations of real words. Thus, the babble [mama] at age 0;7 can become the word *mama* at age 0;10, and non-meaningful [ba] at age 0;8 can later signal the word *ball*. In first words, as in babble, there is a predominance of CV syllables, consonants produced in the front of the mouth, and a high proportion of stops, nasals and glides (Oller, Wieman, Doyle & Ross, 1976). In a study of the first ten words of fifty-two children, Bernhardt & Stoel-Gammon (1996) reported that 90% of the children produced CVCV words among their first ten words, and all children produced words with stop consonants. As in babble, words with final consonants at this stage were infrequent and words with fricatives and liquids were very rare.

Early words such as *mommy*, *daddy* and *byebye* conform closely to the patterns of babble and appear early in the receptive vocabulary; for production, moving from a non-meaningful to a meaningful vocalization is a matter of adding meaning to sound. In addition to common preferences

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

evident in babble and words, individual differences have been documented; here again, findings support the notion of continuity between babble and speech: child-specific prelinguistic vocal patterns in place and manner of articulation of consonants, syllable shape, and vocalization length are carried forward to the production patterns observed in first words (Stoel-Gammon & Cooper, 1984; Vihman, Macken, Miller, Simmons & Miller, 1985).

The effects of babble are also apparent in children with atypical development. As one might expect, young children with hearing loss exhibit a delay in the use of words; however, correlations between frequency and complexity of CV syllables in non-meaningful vocalizations and the appearance and use of spoken words in the period of meaningful speech have been documented for this group as well (Moeller *et al.*, 2007). Among children with cleft palate, another population with atypical vocal development, increased use of CV syllables and syllables with stops consonants in the prelinguistic (and pre-surgery) period predicts the earlier appearance of words and faster vocabulary development after surgical repair of the cleft (Chapman, Hardin-Jones & Halter, 2003).

Postulate I-B: babble provides motor practice for the spoken forms of early words and for the formation of an auditory–articulatory loop. Speech production has a skill component and, as with any skilled activity, practice increases the control and precision with which a movement is performed. The more often the baby produces the movements that shape the vocal tract to produce particular sounds and sound sequences (e.g. the syllable [ba]), the more automatic those movements become and ultimately the easier it is to execute them in producing meaningful speech. Vihman (1992) reported that individual patterns of frequently occurring consonant–vowel syllables in babble ('practiced' syllables) formed the basis of child-specific patterns found in word productions. Vihman argued that babies who have a large stock of practiced syllables have an advantage in early word acquisition because they have a larger repertoire of phonetic forms to which meaning can be attached.

As they vocalize, babies hear (and feel) their productions, and thus can link their own articulatory movements with the resulting acoustic signal, a link that is essential for the production of words. The baby who repeatedly produces the non-meaningful forms [ba] and [mama] at age 0;7 becomes aware of the tactual and kinesthetic sensations associated with these productions and hears the acoustic output, creating an auditory–articulatory 'feedback loop' that is fundamental to speech production throughout life (Fry, 1966; Stoel-Gammon, 1998a). At the same time, babies begin to recognize similarities between their own production of [ba] or [mama] and the adult production of *ball* or *mommy*; awareness of this auditory–articulatory link draws attention to adult words that are phonetically similar to the baby's output and provides the basis for the stored representations needed for the

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

comprehension and production of words of the ambient language (Locke, 1993; Stoel-Gammon, 1998a; Vihman, 1996).

Postulate I-C: reduced use of canonical babble is associated with delays in lexical development. For most American children, the first words are produced by age 1;3 and a productive vocabulary of 300 words is in place by age 2;0. There are, however, children who fail to achieve these language milestones at the expected ages. For example, 'late talkers' are described as having hearing and cognitive abilities within the normal range, but a vocabulary of fewer than ten words at age 1;6 and fewer than fifty words at age 2;0. The prespeech development of these children is characterized by a delay in the onset of CV syllable use, and vocalizations that are composed of smaller consonantal inventories and simpler syllable structures than children with typical development (Paul & Jennings, 1992; Rescorla & Ratner, 1996; Stoel-Gammon, 1991).

Postulate I-D: adult–child vocal interactions influence infant babble and provide support for word learning. Goldstein, King & West (2003) reported that adult feedback in the form of 'interactive proximate responses', such as imitations, was associated with higher use of more advanced vocalizations such as CV syllables, thus increasing the likelihood of the occurrence of this type of babble. In a subsequent study, Gros-Louis, West, Goldstein & King (2006) found that mothers' responses to vowel-like vocalizations differed from those to CV vocalizations: in general, mothers tended to respond to CV productions with 'language-expectant' responses such as acknowledging (e.g. *oh really?*), naming (e.g. *it's a cup*) or imitating/expanding (e.g. imitation: *Mama*; expansion: *Mama. Yes, and dada is working*); in contrast, the highest response rates for vowel vocalizations were acknowledging, vocal play (e.g. use of a sound effect like 'vroom') and questions. Notably, the rate of imitation of CV vocalizations was eight times the rate of imitation of vowel-like vocalizations. Gros-Louis *et al.* (2006) concluded that the differential responses encouraged the use of particular sounds and syllable types in the infant vocal output.

The mutual reinforcement of caregiver verbalizations and infant vocalization continues into the second year of life. Tamis-LeMonda, Bornstein & Baumwell (2001) reported that caregiver responsiveness at ages 0;9 and 1;1 predicted the timing of several language milestones; of particular interest for the relationship between phonological and lexical development is the finding that maternal imitations and expansions of children's vocalizations at age 1;1 (a time when most of the vocalizations are non-meaningful) predicted the age of acquisition of a productive vocabulary of fifty words. These findings are consistent with those of Velleman, Mangipudi & Locke (1989), who examined maternal contingent responding and found that higher levels of phonetic contingency, but not semantic contingency, were associated with greater increases in language development over twelve months.

Adult input and child output are mutually reinforcing: maternal imitations tend to cause an increase in infant vocalizations and these vocalizations, in turn, are likely to elicit maternal imitations that, once again, increase the rate of infant vocalizations (Veneziano, 1988). Thus, prelinguistic vocalizations provide a starting point for social–communicative interactions between caretaker and child. Routines of conversational turn-taking occur when infants are as young as age 0;3; these 'proto-conversations' are characterized by alternation of speaking and listening, with appropriate pauses after a vocalization/verbalization. Initially, caregivers accept almost any behavior, even vegetative noises, as the baby's 'turn' in the conversation. Later, they become more selective, responding to speech-like babbles, but not to burps or coughs (Snow, 1977). Even later, adult feedback is directed toward productions that resemble words: in response to a vocalization that sounds like [mama] or [dædæ], English-speaking parents are likely to imitate the form, providing the infant the context needed to relate sound and meaning. As a consequence, the infant's non-meaningful productions have a good chance of becoming early-acquired words.

In summary, the investigations of prespeech development yield a picture of interacting elements that contribute to the prespeech repertoire and ultimately to the productions of words. First, we have physiological bases that allow infants to hear and to vocalize. As they mature, infants establish a repertoire of speech-like vocalizations ('building blocks') that become practiced CV syllables, the units that form the basis of spoken words. Second we have the vocal/verbal interactions between caregiver and child. The caregivers imitate and encourage the speech-like vocalizations they hear, and highlight the similarities between the infant output and words of the target language. Third, we have the feedback loop that serves two functions: (a) upon hearing their own vocalizations, babies can determine the associations between oral motor movements and sound and begin to establish an articulatory–auditory loop; and (b) the feedback loop allows babies to compare their productions with those of their caregivers, noting the similarity between their babbled form, e.g. [mama] and the word *mama*. The role of caregiver feedback in this scenario varies across socioeconomic class, language and cultures; the expectations of middle-class American parents tend to be high-end, a factor that may be associated with relatively rapid vocabulary growth (see Bleses *et al.*, 2008a).

EARLY MEANINGFUL SPEECH: THE INTERPLAY OF PHONOLOGY AND LEXICAL ACQUISITION

During the period of early meaningful speech, children move from non-meaningful vocalizations to words, with several months of overlap between babble and speech. The postulates below summarize investigations of early

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

lexical and phonological development, once again focusing primarily on children with typical development and the acquisition of American English.

Postulate II: early lexical development is influenced by the phonological form of the adult word and by the child's productive phonology

There is considerable variation in the age of appearance of the first words: some children with typical development produce the first adult-based form as early age 0;9; others may not have identifiable words until around age 1;3. Once a child has moved into the stage of meaningful speech (often defined as the stage at which a child's productive vocabulary has 5–10 words), the lexicon grows to 50–60 words by age 1;6, rising to about 300 words by age 2;0, and 2,500–3,000 words at age 4;0 (Anglin, 1989). As noted previously, in order to produce an adult-based word, children must be aware of the link between a particular sequence of speech sounds and a particular meaning; they must also have some knowledge of the articulatory movements needed to produce the sequence of sounds in the target word. For some words, the sequence of speech sounds may have occurred in the child's babble, as in the case of the non-meaningful [ba] used subsequently for the word *ball*. Other target words, such as *cheese* or *caterpillar* involve learning not only the link between sound and meaning, but also a new set of articulatory movements to produce a form that resembles the target. The disparity in the amount of learning involved in acquiring words such as *ball* and *cheese* leads to the prediction that, other things being equal (e.g. input frequency, part of speech), target words with phonetic properties that mirror a child's prelinguistic vocalizations will be acquired earlier than words with features (e.g. speech sounds, syllable shapes) that are not present in the prespeech repertoire. As shown in the preceding postulates, development in the prelinguistic period affects multiple areas of subsequent language development, including the age of onset of meaningful speech and rate of vocabulary growth (see *Postulate I*), as well as the selection of words for inclusion in the early lexicon.

Postulate II-A: some children exhibit preferences for words with particular sounds and sound classes. The words that comprise the child's early vocabulary are determined not only by semantic and pragmatic factors, but also by the child's productive phonological abilities. Observational studies show that individual children display patterns of 'lexical selection and avoidance' that reflect their own phonological abilities and preferences. In their seminal study, Ferguson & Farwell (1975) analyzed longitudinal data from three young children and identified phonological influences on lexical acquisition. Notably, one child's vocabulary included the words *shoe*, *cheese*, *cereal*, *ice* and *eyes*. These words are interesting for two reasons: (1) they are relatively uncommon in the vocabularies of young children acquiring

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

English; and (2) they all contain sibilant fricatives and affricates. The presence of words with sibilants was surprising in that consonants in this sound class are not common in babbling and are rarely produced correctly in child speech. Although the child's pronunciation of the words was not entirely accurate, she was able to produce each with a sibilant consonant. Ferguson & Farwell used the term 'lexical selection' to describe the child's preference for words with a particular type of consonant. Stoel-Gammon & Cooper (1984) reported on the first fifty words of three children, one of whom, Daniel, had a high proportion of words ending in velar stops [k] or [g], e.g. *quack*, *rock*, *clock*, *sock*, *whack*, *milk*, *frog*, *yuk*, *block* and *walk*, with many of these words produced as [gak]. Of Daniel's first fifty words, 22% ended in a velar stop compared with 8% and 4% of velar-final words for the other two children. Stoel-Gammon & Cooper noted that the presence of lexical selection and a preferred articulatory routine such as [gak], often resulting in many homophonous forms, was associated with a relatively fast rate of lexical acquisition compared to the children who did not display lexical selection or a preferred vocal motor routine (see the discussion of templates below).

With observational studies, it is not possible to rule out the effects of input – perhaps the child who produced many words with final /k/ acquired these words early because they were among the most common words he heard. To test this possibility, Leonard, Schwartz and colleagues (Leonard, Schwartz, Morris & Chapman, 1981; Schwartz & Leonard, 1982) designed a set of experiments examining children's ability to learn novel words with phonological characteristics that were either part of the individual child's productive repertoire or were not. In two studies with children aged 1;2–1;10, the researchers first determined the phonological characteristics of each child's speech and then constructed a set of 'test' words that were paired with objects and actions. Half of the test words were phonologically 'IN', defined as having consonants that the child had been observed to produce accurately in over 50% of the attempts at adult words, and half were phonologically 'OUT': words that contained consonants not produced by the child during the speech sample. An experimenter introduced the new word to the children, controlling the number of times each word was heard. After ten biweekly training sessions, the children were tested on the words. Overall, the children in both studies attempted to produce more words with consonants that were IN their phonological repertoires than words with consonants that were OUT of their repertoires. In terms of comprehension, however, there were no differences between IN and OUT words. The experimental studies provide strong evidence that children's productive phonologies influence the words that are present in their early vocabularies. They also suggest that children have tacit knowledge of their own phonological abilities.

Postulate II-B: some children build their early vocabulary around 'whole-word' phonological patterns of adult words. The notion of lexical selection introduced by Ferguson & Farwell (1975) focused primarily on preferences for words with a particular sound or sound class; similarly, Leonard and colleagues designed their experimental word lists around consonants that were IN or OUT of a child's phonological system. Rather than selecting words with particular sounds or sound classes, some children appear to focus on 'whole-word patterns' or 'templates' derived from words that share a set of phonological features including the suprasegmental feature of stress and number of syllables as well as sound types. Using their own well-practiced output patterns, children then create a production pattern for a set of words that conform to the template. For example, Waterson (1971) reported that, at age 1;6, her son's pronunciations of the words *another*, *finger*, *Randall* and *window* was very similar: each target was produced as a CVCV form wherein the consonants were palatal nasals (a consonant that is not a phoneme of English). Waterson noted that it was difficult to relate the child's form of the words to the adult target using an analysis based on segment-by-segment matching; the pronunciations did, however, conform to a whole-word pattern. Waterson argued that her son noticed certain similarities in the target words, namely presence of a nasal consonant and stress on the antepenultimate syllable, and then replicated these features using an articulatory routine he was capable of producing.

The use of production templates appears to provide the child with a means of producing a range of adult targets with a relatively simple output form. Vihman & Croft (2007; see also Macken, 1996; Velleman & Vihman, 2002) highlight many cross-language examples of children using templates in the early stages of acquisition, arguing that children build upon their individual phonological preferences and then select adult words that conform to these preferences. Once again, the child appears to choose adult words on the basis of the interplay between the phonological features of the target and the child's own production patterns. Initially, the words selected are relatively close to the child's output patterns and thus tend to be quite accurate, whereas later-acquired forms may be 'adapted' to fit into the child's preferred output and consequently may show less accuracy than earlier forms (Velleman & Vihman, 2002). In some cases a production template yields forms that bear little resemblance to the target words. For example, Leonard & McGregor (1991) described a child who developed a template that required fricative elements of the target word to appear in final position. Thus, the child pronounced *zoo* as [uz], *fine* as [aɪnf], *soap* as [ops], *Snoopy* as [nupis] and *stop* as [taps]. In cases like this, the apparent idiosyncratic productions can be seen as systematic once the template becomes evident. Further discussion and examples of templates can be found in Macken (1996) and Vihman (1996).

Postulate II-C: patterns of lexical selection are evident beyond the first-50-word period. Although individual differences have been highlighted in the studies of lexical selection described above, general patterns of selection are also apparent across children with larger vocabularies. Stoel-Gammon's phonological analysis (1998b) of 596 words from the MacArthur Communicative Development Inventories (CDI; Fenson *et al.*, 1993) showed that the CDI words tend to be short, either monosyllables (60% of words) or disyllables (35%). The most common word shapes are CVC and CVCV and consonant clusters are relatively rare, occurring in 19% of the words in initial position and 13% in final position. Stress placement is extremely uniform across the sample. Of the 242 words of more than one syllable, 90% have stress on the first syllable. These highly frequent patterns provide a general template for the target forms of early-acquired words of American English: they are less than three syllables, are unlikely to have a consonant cluster and, if longer than one syllable, are stressed on the first syllable.

Detailed analyses of the segmental characteristics of the first 100 words acquired by American children (based on Dale & Fenson's age-of-acquisition norms, 1996) revealed a predominance of stops in initial position (57% of the words) and a strikingly high proportion of words beginning with /b/, which accounted for 22% of the initial phonemes of these words (Stoel-Gammon, 1998b). The high proportion of /b/-initial words is a good example of a general lexical selection pattern, as it is not a general characteristic of the phonology of English: words with initial /b/ account for about 5% of the words in the adult lexicon and about 8% of words spoken to children under age 2;6 (Stoel-Gammon & Peter, 2008). Further analysis of the age-of-acquisition data from the CDI showed that the proportion of /b/-initial words exceeds 22% when the average lexicon size is less than 100 words (Stoel-Gammon, 2008).

Postulate III: lexical development and phonological development tend to be commensurate

Studies of individual differences in the rate of lexical development provide a good test of the association between lexical and phonological development: children with large vocabularies have more advanced phonological systems than those with small vocabularies. This relationship is very apparent among late talkers, for whom a limited phonological system goes hand-in-hand with a small productive vocabulary (Stoel-Gammon, 1991), even when the phonetic analysis includes non-meaningful (i.e. uninterpretable) utterances as well as identifiable word productions. Paul & Jennings (1992) compared the phonologies of late talkers and control subjects matched for age, sex and socioeconomic status, and reported that all of the late talkers were phonologically less advanced than their age-matched peers with regard to the number of different consonants produced, complexity of syllable structures, and accuracy of consonants in word productions. In a later study involving late talkers and a control group of age-matched peers with typical development, Rescorla & Ratner (1996) reported that late talkers, aged 2;0–2;7, displayed significantly smaller inventories of consonants and vowels and greater proportional use of open syllables (vowel only or consonant–vowel) and vocalized less frequently than the controls. As in the study by Paul & Jennings (1992), the phonological systems of the late talker group resembled the systems of younger children with typical development. Rescorla & Ratner hypothesized that the low rates of vocalization and phonological delay are interdependent for the late talkers, indicating a bidirectional relationship between child vocalization and lexical development. Specifically, they claim that some children may have underlying phonemic inadequacies, causing them to vocalize less than typically developing children (consistent with *Postulate I-B*). This paucity of vocalization reduces their opportunities for the vocal practice that is thought to facilitate phonological development. Moreover, these quiet infants and toddlers may miss out on important conversational interactions with caregivers that can promote language acquisition (see *Postulate I-D* above).

The phonological development of young children with unusually large vocabularies has received relatively little attention, but can also shed light on the relations between lexical and phonological development. Stoel-Gammon & Dale (1988) examined the phonological patterns of a group of 'precocious' talkers, that is, children who had productive vocabularies of 400–600 words at age 1;6, far exceeding the average vocabulary of 50–60 words. Comparisons of the phonetic inventories of the precocious talkers at age 1;8 with a group children aged 1;9–2;0 with typical development revealed differences in both the size and nature of the consonantal repertoire. At age 1;9, the inventories of the typically developing children contained, on average, 6·7 consonants in word-initial position and 3·6 consonants in final position. By age 2;0, the inventories had increased to 9·5 consonants in initial position and 5·7 consonants in final position. For the precocious talkers, the average phonetic inventory at age 1;8 included 11·7 word-initial consonants and 7·4 word-final consonants. Thus, precocious talkers at age 1;8 had larger phonetic inventories than the typically developing children at age 2;0. Smith, McGregor & Demille (2006) reported similar findings in their study of pronunciation accuracy in productions of 'lexically precocious' two-year-olds compared with a group of age-matched peers and an older group matched for lexicon size. Finally, in a study of slightly older children with typical development, Schwarz, Burnham & Bowey (2006) found that articulation accuracy, based on an articulation test, predicted vocabulary size at ages 2;6 and 2;9.

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

In sum, studies of the phonological development of children with exceptionally large or exceptionally small vocabularies, i.e. precocious talkers and late talkers, as well as children with typical development, yield the same findings. Lexicon size and phonological skills are commensurate: precocious talkers are advanced in both domains and late talkers are delayed in both; among children with typical development, vocabulary size and articulation abilities are correlated. Although the association between the two is apparent, it is difficult to determine the causal factor(s), and the influence is undoubtedly bidirectional to some extent. For late talkers, it would seem reasonable that phonological development is a limiting factor that inhibits lexical growth as the small repertoire of sounds and syllable types cannot support the production of a large set of words. For precocious talkers, in contrast, the large vocabulary may create a demand for a more advanced phonological system.

POSTULATE IV: underlying representations change as the vocabulary increases

Underlying representations (URs) are part of the mental lexicon that stores the information needed to recognize and produce words. Word recognition involves the ability to extract and store auditory phonetic information and link it to meaning, while word production requires linking a stored form (or forms) with articulatory details. Despite of decades of discussion and debate on the topic, there is little agreement about the number and nature of URs in the adult mental lexicon and even less agreement about URs in children. N. Smith (1973), among others, argued that there is a single, adult-like UR for both the recognition and production of words by young children. Others have hypothesized the existence of two URs, an auditory representation for recognition of the adult word and an articulatory representation for production (see Menn & Matthei (1992) for a discussion of two-lexicon models). More recently, Beckman, Munson & Edwards (2007; Munson, Edwards & Beckman, in press) have posited two levels of representations, based on a different set of parameters: an item-based level involving a 'fine-grained' representation of the patterns associated with hearing or producing a word, and a coarser, more abstract level with information about recurring sublexical phonological patterns. Finally, in contrast to the single- or dual-entry models of lexical representation, Sosa and Bybee (2008) propose a usage-based account of phonology in which representations are not fixed entities but emerge 'by generalizing over existing forms and extracting patterns of similarity' (p. 484). Within this perspective, a single word may have multiple representations.

Postulate IV-A: when the vocabulary is small, underlying representations are stored as single, unanalyzed units. It has been suggested, even assumed, that children's early URs contain relatively little detail: a word is stored and retrieved not as a sequence of phonemes, but as a single unit (e.g. Metsala & Walley, 1998; Walley, 1993). Initial support for this notion came from Ferguson & Farwell's (1975) observation that the children in their study often produced the same sound (phoneme) differently across different words and that some words were more variable than others. For example, one child produced the word *pen* ten different ways in a 30-minute period with pronunciations ranging from [hɪn] to [^{m}bo] to [ba^{h}]. Although none of the versions was accurate, each included one or more features of the word *pen*, such as nasality, a labial or alveolar consonant, or a CVC word shape. The authors hypothesized that the child was aware of the phonetic features of the word and produced a subset of these in her output forms, but did not store and retrieve the word as a sequence of phonemes. Building on their observations of intra- and inter-word variability, Ferguson & Farwell (1975) suggested that the minimal unit of lexical representation in the early stages of word acquisition was the word or phrase, rather than the segment; children may be sensitive to featural properties of a word, but lack knowledge of the way features are organized into sequences of phonemes. A change in the form of URs was postulated to occur when the vocabulary reached a critical mass, perhaps 50–100 words; at this point, the number of holistic forms becomes too large to be kept in memory and the child begins to move towards a more segmental representation (e.g. Vihman, 1996; Vihman & Velleman, 1989; Walley, 1993). Studies of speech perception, however, raise questions about the holistic nature of URs and the single-lexicon models, as there is evidence of attention to fine-grained phonetic detail in speech perception tasks by children even in the earliest stages of word learning (Swingley & Aslin, 2002) and evidence of sensitivity to the probabilistic phonotactic patterns of the ambient language in infants and toddlers (Jusczyk, 1997).

A major difficulty with attempting to study URs is that our knowledge is only indirect, based on observations of behavior. In light of Ferguson & Farwell's findings regarding variability, Sosa & Stoel-Gammon (2006) examined longitudinal production data from four children with typical development, aged 1;0–2;0, to determine if changes in intra-word variability could serve as an indicator of a transition from whole-word to segmental production patterns. They found that variability over the 12-month period showed peaks and valleys rather than steady decreases as one might expect. Two children displayed a U-shaped learning curve with considerable variability at the beginning of the study, followed by a decline and then an increase in variability. There was no linear relationship between productive lexicon size and rates of variability, and no evidence of a general decline in variability across the children. These findings are not compatible with the notion that attainment of a vocabulary of 50–100 words is associated with phonological reorganization and the emergence of phonemic representation.

There is, of course, the possibility that intra-word variability is not a valid index of phonological reorganization; if there is a link, however, the study of Sosa & Stoel-Gammon (2006) suggests that the influence only becomes apparent when the productive vocabulary exceeds 150–200 words. An alternative interpretation of these findings is that increases in variability, rather than decreases, indicate a transition between developmental stages. On this view, increased variability is interpreted as a marker of emergent systematicity (Vihman, 1996). If this is the case, the findings of Sosa & Stoel-Gammon suggest that the onset of phonemic representation occurs after a child has a productive vocabulary of 150–200 words.

Postulate IV-B: an increase in vocabulary size results in greater detail in underlying representations and affects expressive phonology. During early and middle childhood, children with typical development exhibit tremendous growth in the size of vocabulary and in the development and refinement of their expressive phonological systems. By age 8;0, American children have achieved a receptive vocabulary of about 10,000 words (Anglin, 1989) and a productive phonology that is nearly adult-like. These developmental changes can be attributed to bidirectional influences between the phonological system and vocabulary (e.g. Beckman, Munson & Edwards, 2007; Edwards, Beckman & Munson, 2004; Hoff, Core & Bridges, 2008; Metsala & Walley, 1998; Vihman, 1996; Walley, 1993). As children learn new words, they begin to recognize similarities across phonological forms and add sublexical information (about phonemes, phoneme sequences, syllables) to their URs. Metsala & Walley claim that growth in vocabulary leads to changes in the phonological structure of URs, a phenomenon that they refer to as the 'lexical restructuring hypothesis' (1998). As before, the difficulty in assessing this hypothesis lies in the fact that URs can only be inferred from measurable behaviors, although experimental approaches to determining the nature of URs, summarized below, support the view of changes in representations with vocabulary growth.

EFFECTS OF FREQUENCY, PHONOLOGICAL SIMILARITY AND AGE OF ACQUISITION ON LEXICAL AND PHONOLOGICAL DEVELOPMENT

The set of postulates listed above stem from 'child-centered' perspectives of the associations between phonological and lexical development. Researchers have performed detailed phonological analyses of children's productions, or of target words, and linked them to the developing lexicon. Taken together, the findings support the view that children are active participants in acquiring their phonological system, relating their own output to adult input, recognizing phonological similarities across target words, and choosing words for their productive vocabularies that conform to their individual phonological skills. An alternative approach to examining associations between lexical and phonological development is derived from findings of language processing in adults, which highlight the role played by the lexical and sublexical patterns of the ambient language. This area of study is newer than the child-centered studies and, to date, the research has yielded both areas of general agreement and pockets of conflicting findings. The conflicts are likely related to differences in methodology, populations and underlying theoretical views. Given the lack of uniformity in the findings, the summaries below are presented as hypotheses or observations rather than postulates.

Three constructs related to lexical processing in adults have significant potential for our understanding of lexical and phonological development in children: (1) FREQUENCY of words, phonemes and phoneme sequences in the adult language; (2) PHONOLOGICAL SIMILARITIES across words; and (3) AGE OF ACQUISITION of words. In adults, word frequency affects processing in both perception and production: high-frequency words are associated with faster word recognition and are produced more quickly and more accurately (see Ellis, 2002). Regarding phonological similarities across words, Luce & Pisoni (1998), among others, proposed that words in the mental lexicon are grouped into 'phonological neighborhoods' based on shared properties; words are 'neighbors' if they differ from each other by the substitution, deletion or addition of one phoneme in any position. Words with many neighbors reside in 'high-density' neighborhoods, while words that have few or no neighbors reside in low-density neighborhoods. In general, high-density neighborhoods are associated with inhibition in tasks of word recognition and production by adults, presumably due to competition effects among phonologically similar forms (Luce & Pisoni, 1998). Finally, studies indicate that the factor of age of acquisition, defined as the length of time a word has been in an individual's lexicon, affects word processing. According to Garlock, Walley & Metsala (2001), word frequency and subjective reports of the age of acquisition contribute to the overall familiarity of a word, which may in turn influence the specificity and stability of the phonological representation in the mental lexicon. Due to potential confounds between age of acquisition and word frequency (high-frequency words tend to be early-acquired), it is difficult to tease out the independent effects of each of these factors.

Application of the constructs of frequency, neighborhood density and age of acquisition to developmental patterns in children is not straightforward. For example, measures of word frequency vary from one database to another. For adult investigations of English, these measures are often taken from the database of Kucera & Francis (1967), who used several sets of written corpora as the basis of their word-frequency calculations. Although many investigations of the effects of frequency on the language development of American children have used this database, it seems reasonable to ask if this is appropriate, especially for children under the age of 3;0. Adult-based counts derived from written corpora will be different from counts based on child-directed speech; for example, Goodman *et al.* (2008) showed that parent input frequency predicted age of acquisition substantially better than Kucera & Francis's adult norms. The same concern occurs with the notion of neighborhood density: with a productive vocabulary of less than 500 words, it is likely that the neighborhood density of a child's lexicon will differ substantially from that of a mature speaker. An additional concern is that the definition of phonological neighbors is based on the segmental properties of target words. If children's early word representations are holistic and adults' are segmental (as discussed above), defining neighbors as words that differ by a single phoneme may be inappropriate for studies of children. Lastly, the factor of age of acquisition can be reliably determined for young children using checklists like the CDI. For adult studies, this factor is highly subjective, typically determined by asking adults to estimate the age at which they learned a particular word. These estimates are likely to be influenced by their familiarity with the word. Once again, the outcomes of these two approaches may yield different findings for the two groups.

While the effects of frequency, neighborhood density and age of acquisition have been documented for adults (e.g. Garlock *et al.*, 2001), the role they play in the acquisition of expressive phonology is still being established. Most studies of children have examined the effects of these variables on children older than 4;0 (beyond the age range of the focus of this article) and have examined aspects of speech perception or word recognition rather than production. The sections below present findings regarding possible relationships between these variables and phonological and lexical acquisition in young typically developing children. As before, the focus is on production rather than perception, on studies of children acquiring American English, and on preschool children with typical development. The first section discusses findings from experimental studies using a non-word repetition task while the second focuses on studies of real words.

Studies involving non-words

The majority of studies investigating the effects of lexical and sublexical properties of the ambient language on phonological production have used a non-word repetition task. Within this approach, productions of a carefully constructed set of non-words are elicited from the child and the accuracy of pronunciation is the single outcome variable. Hypotheses and observations stemming from these studies are summarized below.

Hypothesis: phonotactic probability and neighborhood density influence accuracy of production of non-words in children. Phonotactic probability refers to the relative frequency in a language of a single phoneme in a particular

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

word position or to the frequency of a sequence of phonemes (bi-phones). Studies of infant perception reveal that babies are sensitive to the phonotactic probabilities of their native language: infants aged 0;8 are able to segment non-words from fluent speech based only on cues associated with transitional probabilities between individual syllables (Aslin, Saffran & Newport, 1998); infants aged 0;9 listen significantly longer to high-probability as opposed to low-probability non-words (Jusczyk, Luce & Charles-Luce, 1994). Thus, prior to the acquisition of a productive or receptive lexicon, infants appear to be aware of the sound patterns of their native language.

Phonotactic probability also affects production: studies using non-word repetition tasks have shown that children exhibit greater accuracy in the production of segments and segment sequences with high phonotactic probabilities (e.g. Zamuner, Gerken & Hammond, 2004). For example, Zamuner *et al.* (2004) analyzed repetitions of nonsense words in high- and low-probability CVC syllables and found that children aged 1;8–2;4 were more accurate in their productions of final consonants in high-probability forms. In a study of Dutch children aged 2;2–2;8, Zamuner (2009) created a set of nonsense CVC words controlled for phonotactic probability and neighborhood density; each consonant occurred in initial and final position and, for each position, in a high- and low-frequency environment, based on the bi-phone frequencies of Dutch. Findings showed that both initial and final consonants were produced more accurately in high phonotactic probability sequences. Further examination of the data revealed correlations between vocabulary size and repetition accuracy for initial, but not final, consonants.

With an older group of participants, Beckman & Edwards (2000) investigated the influence of bi-phone frequency on imitations of nonsense words by children aged 3;2–5;0. Accuracy scores were significantly higher for the frequent CV and CC sequences, but there was no advantage for frequent VC sequences. The results suggest that the position of a sound/sound sequence within the syllable affects accuracy, but differ from the investigation of Zamuner *et al.* (2004), who reported that production of final consonants (i.e. consonants in VC sequences) in high probability sequences was more accurate than initial consonants.

Non-word repetition tasks were also used by Edwards, Beckman & Munson (2004) to examine the relationship between bi-phone frequency and production accuracy in children aged 3;0 to 8;0. Consistent with previous work, their findings indicated that low-frequency sequences were produced with less accuracy than high-frequency sequences. In addition to analyzing accuracy, the authors made acoustic measures of segment durations and found that productions of the same target phoneme were longer in low-frequency than in high-frequency sequences. For example, the phoneme /v/ was longer in the non-word /vugim/, where it occurs in a low-frequency environment, than in the high-frequency sequence /vɪ-/ in the form /vɪdæg/. This finding was interpreted as evidence that productions of less-frequent sequences are less 'fluent' than productions of frequent sequences, presumably because they are less practiced. The authors noted that the influence of frequency declined with increases in vocabulary size (and age). In a follow-up study with a different set of stimuli, Munson, Edwards & Beckman (2005) analyzed non-word repetitions in two groups of children aged 3;3–6;4, one group with typical development, the other with phonological disorders. They reported greater accuracy for high-frequency bi-phones (phonotactic frequency) that was independent of speech perception and articulatory ability. The authors concluded that their results 'support a model of phonological ability in which children's flexible control over phonemes emerges gradually as they amass lexical items and develop stable mappings across acoustic, articulatory and semantic characteristics of those items' (p. 76).

In view of the close relationship between neighborhood density and phonotactic probability, it is not surprising that density also appears to influence young children's repetitions: non-words from high density neighborhoods (with high phonotactic probability) are produced more accurately than non-words from low density (and low phonotactic probability) neighborhoods (Beckman & Edwards, 2000; Edwards *et al.*, 2004; Zamuner *et al.*, 2004; Zamuner, 2009). Acknowledging that the phonotactic probability effect they found could be interpreted as a neighborhood density effect, Zamuner and colleagues (2004) reanalyzed the non-words in their study according to neighborhood density; they found that high-probability words were typically high density and low-probability words were low density, making it impossible to determine the relative effects of the two factors. The factor of neighborhood density is discussed further in the section on cross-linguistic studies below.

Taken together, the studies of phonotactic probability indicate that production accuracy in children is linked to frequency of occurrence of a phoneme or phoneme sequence in the ambient language. These findings are consistent with those of Stoel-Gammon (1998b), who showed that frequency of occurrence of initial consonants of real words from the CDI (i.e. real words produced by young American children) was strongly correlated with measures of correct production at age 3;0 ($r=0{\cdot}71$). There was also a relationship between accuracy and frequency of occurrence of final consonants, although the correlation was weaker.

The experimental studies cited above all used the same basic methodology: children were asked to repeat a set of nonsense words, an approach that allows investigators to control phonotactic probability and other confounding variables. Interpretation of findings based on this approach is not straightforward; as noted by Coady & Evans (2008), there is no agreement

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

regarding exactly what non-word repetition tasks tell us about language learning, although most researchers agree that accurate repetition of non-words involves elements of perception, lexical organization and production (see Gathercole (2006) and related commentaries for an extensive discussion of findings from non-word repetition tasks). Specifically, in order to achieve an accurate production of a non-word, a child must be able to: (1) accurately perceive the non-word form; (2) store the form in short-term memory; (3) retrieve the form from memory; (4) create an articulatory plan for producing it; and (5) implement the articulatory plan. The associations between vocabulary size and accuracy on non-word repetition tasks are presumably related to language experience: the more often a child hears or says a known word, the greater that child's familiarity with the sounds and sound sequences of the ambient language. B. Smith (2006), however, provides a cautionary statement regarding interpretation of outcomes, noting that, although we can identify production errors, we do not know the underlying cause; mispronunciations may be due to problems with perception, storage, retrieval or articulation, or to some combination of these.

While the findings from these experimental tasks are quite uniform, it is important to note that production of non-words reflects different processes than those involved in the production of known words. To produce a known word, the child must first retrieve a stored representation from long-term memory and then produce it without benefit of a spoken model. In terms of accuracy, it is likely that productions of known words may differ from those of non-words (see Hoff *et al.*, 2008). As noted in the earlier discussion of underlying representations (*Postulate IV-B*), larger vocabularies presumably facilitate organization of the input into smaller units. One area of conflicting findings relates to vocabulary measures: Coady & Evans (2008) state that the relationship between non-word repetition accuracy and vocabulary size holds only for receptive vocabulary, whereas Munson and colleagues (Munson *et al.*, 2005) present findings indicating that accuracy is related to both receptive and productive vocabulary.

Studies involving real words/known words

At present, there is a clear need for more studies of the effects of frequency, neighborhood density and phonotactic probability based on investigations of the acquisition and production of real words. One hypothesis and two observations from the few available studies are summarized below.

Hypothesis: real words from high-density neighborhoods are produced more accurately than words from low-density neighborhoods. On the basis of findings with non-words, one would expect a link between neighborhood density and accuracy for known words, as the URs for words from dense neighborhoods

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

would presumably contain greater detail in order to differentiate among phonologically similar forms. Sosa collected longitudinal language samples from fifteen children aged 2;0–2;5 (Sosa, 2008) and analyzed a subset of words within the framework of 'usage-based' phonology (Bybee, 2001). Usage-based theory emphasizes the role that language use plays acquiring a language; for phonology, the theory highlights the importance of input and production in the instantiation and ongoing development of the phonological system. The children in Sosa's study showed a facilitative effect of neighborhood density on production: words from dense neighborhoods (as determined by the 20,000-word database of Nusbaum, Pisoni & Davis, 1984) were produced more accurately and with less variability than words from less dense neighborhoods. These findings support the notion of an interaction between the size and structure of the lexicon and the developing phonological system, as posited in the studies using non-words.

Observation 1: influences of phonotactic probability, neighborhood density and word frequency on word acquisition vary across children. Maekawa & Storkel (2006) analyzed nouns occurring in the conversational samples of three children acquiring American English to determine the effects of lexical and sublexical patterns on word acquisition. Multiple samples were analyzed for each of the children, who ranged in age from 1;4 to 1;10 at the beginning of the study and 2;10 to 3;1 at the end; samples contained between 174 and 767 different root nouns. Variables of interest included: (1) age of first production of each noun, a child-specific variable; (2) phonotactic probability and neighborhood density of each noun as determined by analysis of a 20,000-word dictionary (Nusbaum, Pisoni & Davis, 1984), a phonological variable based on the adult lexicon; (3) frequency of occurrence of each noun, based on adult data from Kucera & Francis (1967), a lexical variable based on the adult lexicon; and (4) length of each noun as measured by the number of phonemes, a phonological variable based on the children's lexicons.

Regression analyses indicated that word length (number of phonemes) was the only factor which affected age of first production for all three children; the other variables affected only one child each. The preference for shorter words mirrors Stoel-Gammon's finding (1998b) based on her analysis of 596 words from the CDI, showing that words (not just nouns) of more than two syllables were quite infrequent in the CDI corpus, accounting for about 6% of the words. In discussing their findings, Maekawa & Storkel suggested that the differences observed among the three children might be linked to differences in stages of linguistic development.

Observation 2: relationships among the variables of word frequency, age of acquisition and production accuracy are unclear. In adults, word frequency has a facilitative effect on both perception and production. For children, it would seem logical to predict that words that are produced frequently would be less variable and, perhaps, more accurate due to the influence of motor practice. Findings in this domain are conflicting, however, as different approaches to measuring word frequency have yielded different results. Tyler & Edwards (1993) measured frequency using a child-specific approach, counting the number of times a word was used in speech samples from two young children. With this metric, they found that accurate productions of voiceless stops emerged first in high-frequency words. Velten (1943), in contrast, determined word frequency by diary of his daughter's speech. He reported that the words produced most frequently were the last to change (i.e. remained inaccurate longest) when a new phonemic contrast entered her phonological system. Velten's finding may be related to the observation above (see *Postulate I-B*) that vocal motor patterns that occur frequently may be more 'automatic' and thus resistant to change when new sounds and sound contrasts enter the child's phonological system.

Sosa (2008) used the Kucera & Francis (1967) word counts, based on adult corpora, to examine the relationships among word frequency, age of acquisition, and variability and accuracy of production. They reported that fifteen children, aged 2;0–2;5, produced high-frequency words with less variability than low-frequency words, but did not find a relationship between word frequency and accuracy of production. In terms of effects of age of acquisition, later-acquired words were produced with greater accuracy than early-acquired words at the same age point, perhaps because pronunciation of the early-acquired words had become associated with automatic vocal motor patterns, while later-acquired words entered the lexicon at a time when the child's production abilities were more advanced. Statistical analyses showed no significant relationship between variability of production and age of acquisition. Given the limited number of studies and the disparities in the findings and in the measurements of word frequency, it is not possible to make a definitive statement regarding the role of word frequency and measures of production. In the future, it would be ideal to examine effects of word frequency using a variety of measures including: (1) adult counts (e.g. Kucera & Francis, 1967); (2) general counts of input to children based on corpora from many children; (3) general counts of child output based on corpora from many children; and (4) frequency counts of word input and output in individual children.

In sum, findings from investigations of non-words and real words indicate that children are sensitive to the statistical properties of their language and that these properties influence both accuracy of production and the organization of the mental lexicon. The findings extend our understanding of phonological and lexical development by examining the effects of word frequency, phonotactic probability and neighborhood density and, to some extent, the role of age of acquisition. At present, however, findings in some domains are conflicting; differences in methodology and in the age of participants make it difficult to compare across studies.

SUMMARY AND DISCUSSION

Although both the child-centered investigations and adult-based studies discussed above focus on the relationship between lexical and phonological development, they have used different methodologies, different datasets and different underlying frameworks. The child-centered studies in the first part of this article have mainly focused on the earliest phases of language acquisition and have stressed the foundational role of prelinguistic development in early lexical and phonological development. Taken together, the studies suggest that, from birth to age 2;6, the developing phonological system affects lexical acquisition to a greater degree than lexical factors affect phonological development. The form of an infant's prelinguistic vocalizations shapes the vocal and verbal exchanges with caretakers; infant output is linked to adult input that, in turn, provides the infant with a basis for identifying words, establishing URs and creating auditory–articulatory links. According to this approach, the child is an active learner within the developmental process.

In contrast, the adult-based studies highlight external factors with a focus on lexical and sublexical (phonological) features of the ambient language. These studies rarely consider the role of babbling (but see Beckman *et al.* (2007) and Munson *et al.* (in press), who acknowledge the importance of prelinguistic development) and make no mention of social, interactive influences on early lexical acquisition. Individual differences also receive little attention in the adult-based, ambient language perspective. As shown by the child-centered studies, young children appear to have some knowledge of their own production abilities and choose words for their vocabulary that closely match their production preferences, or words that can be modified to fit with those preferences. For the most part, early patterns of lexical selection are related more to individual production preferences than to characteristics of the ambient language.

At the same time, effects of ambient language properties receive little attention in the child-centered studies. These effects are apparent in the early stages of word learning: neighborhood density plays a role in the age of acquisition of nouns (Storkel, 2009) and in accuracy of production (Sosa, 2008). In both cases, words from denser neighborhoods (with density determined by an adult database) had an advantage (earlier acquisition, increased accuracy). It would be interesting to examine the factor of

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

neighborhood density using a database of children's words or even words from a particular child.

QUESTIONS AND FUTURE DIRECTIONS

Many unanswered questions remain regarding the interactions between lexical and phonological development. Three of these are presented below.

Methodology

Differences in methodological approaches make it difficult to compare findings across studies and determine the relative role of various factors. These differences include: (1) naturalistic vs. experimental investigations; (2) the use of real vs. nonsense words; (3) the use of different databases for determining ambient language effects; and (4) the use of different outcome measures for determining underlying representations. Issues in this domain have been noted above. Systematic studies of the effect of these methodological variations are much needed.

Cross-linguistic studies

The research cited in this review article is based almost exclusively on American English. We must be careful not to assume that all the findings from studies of English will be replicated in investigations of other languages. Importantly, English differs from may other languages in terms of syllable and word structures, as it as characterized by a high proportion of CVC words and a low proportion of words with more than two syllables. Both of these characteristics affect analyses based on neighborhood density, one of the factors shown to influence both age of acquisition and accuracy in children. Languages with a higher proportion of open syllables, such as Spanish, and/or a higher proportion of words of three or more syllables, such as Finnish or Japanese, will generally have less-dense neighborhoods, as longer words tend to have fewer neighbors. Exactly how these, and other, cross-linguistic differences will affect accuracy and/or lexical organization is not known; this issue should be addressed in future studies. A recent cross-linguistic study by Edwards & Beckman (2008) provides a good starting point for this type of research (see also Munson *et al.*, in press).

Investigations of differences in the statistical properties of different languages will shed light on universal and language-specific properties of the interactions between lexical and phonological acquisition. To take one example, Ota (2006) examined truncation patterns in three children acquiring Japanese, seeking to determine the relationships between the frequency of truncation in child speech and lexical and structural frequency in maternal input. He found that words occurring more frequently in the input (i.e. lexical frequency) were less likely to truncate in the children's productions, but that there was no relationship between truncation rate and the overall frequencies of prosodic word structures in the input. Ota cautions that researchers must be careful to separate lexical factors from structural effects in determining effects of frequency.

As noted earlier, rate of vocabulary acquisition varies across languages. Some of the variation is likely due to differences in cultural attitudes and child-rearing practices, and some to variation across linguistic and phonological systems. In their discussion of findings from the Communicative Developmental Inventories of various languages, Bleses *et al.* (2008a; 2008b) suggest that the relatively slow early vocabulary development among Danish children is related, in part, to the phonological patterns of Danish. On the same topic, Tardif *et al.* (2009) cite phonology as one explanation for their finding of substantial differences in the rate of vocabulary acquisition in children acquiring Mandarin and Cantonese. At age 2;0, the mean vocabulary size for Mandarin learners (from Beijing) was about 550 words, compared with 300 words for Cantonese learners from Hong Kong. (By comparison, the mean vocabulary size of American two-year-olds is 307 words; for Swedish, the number is approximately 180–200 words (Bleses *et al.*, 2008a).

Accuracy and stability of children's productions

Many of the studies cited above used accuracy of production as the prime behavioral indicator of lexical organization. While production data can provide useful information on the way in which children are structuring input–output relations, accuracy may not be the most appropriate measure of change, particularly in the early stages of development (Vihman, 1996). To take an example cited earlier, Waterson's son produced the words *another, finger, Randall* and *window* using a CVCV output pattern where the consonants were palatal nasals (not part of the phonemic system of English) and the vowels were reduplicated. The boy's productions bear little resemblance to the targets in terms of accuracy; they do, however, provide information on the underlying organizational structure the boy was using, to link his productive phonology to words in his vocabulary.

Finally, the interrelationships among accuracy, variability and underlying representations should be further explored. How do we interpret data showing that a child's pronunciation of a word is stable but inaccurate vs. data showing that the pronunciation is variable, ranging from one inaccurate form to another, or ranging from inaccurate to accurate. Production variability may indicate that a word has a 'fuzzy' UR wherein the details are not fully formed; alternatively, it may be an indicator of a transition from one output form to another, or a sign of motor immaturity. Word productions that involve a stable, but inaccurate, pronunciation, are also subject to alternative interpretations: on the one hand, we could say that the UR for the form is stable, but incorrect; on the other hand, the UR could be stable and adult-like, and the mispronunciation linked to practiced, incorrect motor routines, or to lack of motor abilities.

In conclusion, research to date shows the existence of bi-directional links between phonological and lexical development in children from birth to age 4;0. At this point, questions remain about the nature of the links and how they change over time. Future investigations with a broader array of languages, a wider range of ages and careful attention to methodology will provide new insights regarding the interplay between these aspects of language development.

REFERENCES

Anglin, J. (1989). Vocabulary growth and the knowing–learning distinction. *Reading Canada* **7**, 142–46.

Aslin, R., Saffran, J. & Newport, E. (1998) Computation of conditional probability statistics by 8-month-old infants. *Psychological Science* **9**, 321–25.

Bates, E., Marchman, V., Thal, D., Fenson, L., Dale, P., Reznick, S., Rielly, J. & Hartung, J. (1994). Development and stylistic variation in the composition of early vocabulary. *Journal of Child Language* **21**, 85–123.

Bavin, E., Prior, M., Reilly, S., Bretherton, L., Williams, J., Eadie, P., Barrett, Y. & Ukoumunne, O. (2008). The Early Language in Victoria Study: Predicting vocabulary at age one and two years from gesture and object use. *Journal of Child Language* **35**, 687–701.

Beckman, M. & Edwards, J. (2000). Lexical frequency effects on young children's imitative productions. In J. Pierrehumbert & M. Broe (eds), *Papers in laboratory phonology*, 5, 207–217. Cambridge: Cambridge University Press.

Beckman, M., Munson, B. & Edwards, J. (2007). Vocabulary growth and the developmental expansion of types of phonological knowledge. In J. Cole & J. Hualde (eds), *Laboratory phonology* 9, 241–64. New York: Mouton de Gruyter.

Bernhardt, B. & Stemberger, J. (1998). *Handbook of phonological development: from a nonlinear constraints-based perspective*. San Diego: Academic Press.

Bernhardt, B. & Stoel-Gammon, C. (1996). Underspecification and markedness in normal and disordered phonological development. In C. E. Johnson & J. H. V. Gilbert (eds), *Children's language, vol. 9*, 33–54. Mahwah NJ: Lawrence Erlbaum Associates.

Bleses, D., Vach, W., Slott, M., Wehberg, S., Thomsen, P., Madsen, T. & Basboll, H. (2008a). Early vocabulary development in Danish and other languages: a CDI-based comparison. *Journal of Child Language* **35**, 619–50.

Bleses, D., Vach, W., Slott, M., Wehberg, S., Thomsen, P., Madsen, T. & Basboll, H. (2008b). The Danish Communicative Developmental Inventories: validity and main developmental trends. *Journal of Child Language* **35**, 651–69.

Bloom, P. (2000). *How children learn the meanings of words*. Cambridge, MA: MIT press.

Bybee, J. (2001). *Phonology and language use*. Cambridge: Cambridge University Press.

Chapman, K., Hardin-Jones, M. & Halter, K. (2003). The relationship between early speech and later speech performance for children with cleft lip and palate. *Clinical Linguistic and Phonetics* **17**, 173–97.

Chomsky, N. & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Coady, J. & Evans, J. (2008). Uses and interpretations of non-word repetition tasks in children with and without specific language impairments (SLI). *International Journal of Language and Communication Disorders* **43**, 1–40.

Coplan, J. & Gleason, J. (1988). Unclear speech: recognition and significance of unintelligible speech in preschool children. *Pediatrics* **82**, 447–52.

Corrigan, R. (1978). Language development as related to stage 6 object permanence development. *Journal of Child Language* **5**, 173–89.

Dale, P. S. & Fenson, L. (1996). Lexical development norms for young children. *Behavior Research Methods, Instruments & Computer* **28**, 125–27.

Dinnsen, D. & Gierut, J. (2008). Optimality Theory: a clinical perspective. In M. Ball, M. Perkons, M. N. Muller & S. Howard (eds), *The handbook of clinical linguistics*, 439–51. Malden, MA: Blackwell Publishing Ltd.

Edwards, J. & Beckman, M. (2008). Some cross-linguistic evidence for modulation of implicational universals by language-specific frequency effects in phonological development. *Language Learning and Development* **4**, 122–56.

Edwards, J., Beckman, M. & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in nonword repetition. *Journal of Speech, Language and Hearing Research* **47**, 421–36.

Ellis, N. (2002). Frequency effects in language processing: a review with implications of implicit and explicit theories of language acquisition. *Studies in Second Language Acquisition* **24**, 143–88.

Fenson, L., Dale, P., Reznick, J. S., Thal, D., Bates, E., Hartung, J., Pethick, S. & Reilly, J. (1993). *MacArthur Communicative Development Inventories* (*CDI*). San Diego, CA: Singular Publishing Group.

Fenson, L., Marchman, V., Thal, D., Dale, P., Reznick, S. & Bates, E. (2007). *MacArthur-Bates Communicative Development Inventories: user's guide and technical manual*, 2nd edn. Baltimore: Paul H. Brookes.

Ferguson, C. & Farwell, C. (1975). Words and sounds in early language acquisition: initial consonants in the first fifty words. *Language* **51**, 419–39.

Fry, D. (1966). The development of the phonological system in the normal and deaf child. In F. Smith & G. A. Miller (eds), *The genesis of language*, 187–206. Cambridge, MA: MIT Press.

Ganger, J. & Brent, M. (2004). Reexamining the vocabulary spurt. *Developmental Psychology* **40**, 621–32.

Garlock, V., Walley, A. & Metsala, J. (2001). Age-of-acquisition, word frequency and neighborhood density effects on spoken word recognition by children and adults. *Journal of Memory and Language* **45**, 267–83.

Gathercole, S. (2006). Nonword repetition and word learning: the nature of the relationship. *Applied Psycholinguistics* **27**, 513–43.

Goldfield, B. (1993). Noun bias in maternal speech to one-year-olds. *Journal of Child Language* **20**, 85–99.

Goldstein, M., King, A. & West, M. (2003). Social interaction shapes babbling: testing parallels between birdsong and speech. *Proceedings of the National Academy of Sciences* **100**, 8030–35.

Goodman, J., Dale, P. & Li, P. (2008). Does frequency count? Parental input and the acquisition of vocabulary. *Journal of Child Language* **35**, 515–31.

Gopnik, A. & Meltzoff, A. (1992). Categorization and naming: basic-level sorting in eighteen-month-olds and the second year and its relationship to language. *Child Development* **63**, 1091–1103.

Gros-Louis, J., West, M., Goldstein, M. & King, A. (2006). Mothers provide differential feedback to infants' prelinguistic sounds. *International Journal of Behavioral Development* **30**, 509–516.

Grunwell, P. (1981). *The nature of phonological disability in children*. New York: Academic Press.

Hart, B. & Risley, T. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore: Paul H. Brookes.

Hoff, E. (2003). The specificity of environmental influence: socioeconomic status affects early vocabulary development via maternal speech. *Child Development* **74**, 1368–78.

https://doi.org/10.1017/S0305000910000425 Published online by Cambridge University Press

Hoff, E., Core, C. & Bridges, K. (2008). Non-word repetition assesses phonological memory and is related to vocabulary development in 20- to 24-month olds. *Journal of Child Language* **35**, 903–916.

Jakobson, R. (1968). *Child language, phonological universals and aphasia*. The Hague: Mouton.

Jusczyk, P. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Jusczyk, P., Luce, P. & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language* **33**, 630–45.

Kucera, H. & Francis, W. (1967). *Computational analysis of present day American English*. Providence, RI: Brown University Press.

Leonard, L. & McGregor, K. (1991). Unusual phonological patterns and their underlying representations: a case study. *Journal of Child Language* **18**, 261–72.

Leonard, L., Schwartz, R., Morris, B. & Chapman, K. (1981). Factors influencing early lexical acquisition: lexical orientation and phonological composition. *Child Development* **52**, 882–87.

Lifter, K. & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior and Development* **12**, 395–423.

Locke, J. (1993). *The emergent lexicon: the child's development of a linguistic vocabulary*. New York: Academic Press.

Luce, P. & Pisoni, D. (1998). Recognizing spoken words: the neighborhood activation model. *Ear and Hearing* **19**, 1–36.

Macken, M. A. (1996). Prosodic constraints on features. In B. Bernhardt, J. Gilbert & D. Ingram (eds), *Proceedings of the UBC international conference on phonological acquisition*, 159–72. Somerville, MA: Cascadilla Press.

Maekawa, J. & Storkel, H. (2006). Individual differences in the influence of phonological characteristics on expressive vocabulary development by young children. *Journal of Child Language* **33**, 439–59.

Menn, L. & Matthei, E. (1992). The 'two lexicon' account of child phonology: looking back, looking ahead. In C. A. Ferguson, L. Menn & C. Stoel-Gammon (eds), *Phonological development: models, research, implications*, 211–47. Timonium, MD: York Press.

Metsala, J. & Walley, A. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (eds), *Word recognition in beginning literacy*, 89–120. Mahwah, NJ: Lawrence Erlbaum.

Moeller, M., Hoover, B., Putman, C., Arbataitis, K., Bohnenkamp, G., Peterson, B., Lewis, D., Estee, S., Pittman, A. & Stelmachowicz, P. (2007). Vocalizations of infants with hearing loss compared with infants with normal hearing: Part II – transition to words. *Ear and Hearing* **28**, 628–42.

Munson, B., Edwards, J. & Beckman, M. (2005). Relationships between nonword repetition accuracy and other measures of linguistic development in children with phonological disorders. *Journal of Speech, Language, and Hearing Research* **48**, 61–78.

Munson, B., Edwards, J. & Beckman, M. (in press). Phonological representations in language acquisition: climbing the ladder of abstraction. In A. C. Cohn, C. Fougeron & M. K. Huffman (eds), *Handbook of laboratory phonology*. Oxford: Oxford University Press.

Nusbaum, H. C., Pisoni, D. B. & Davis, C. K. (1984). Sizing up the Hoosier Mental Lexicon: measuring the familiarity of 20,000 words. In *Research on Spoken Language Processing Report*, No. 10, 357–76. Bloomington, IN: Speech Research Laboratory, Indiana University.

Oller, D. K., Wieman, L., Doyle, W. & Ross, C. (1976). Infant babbling and speech. *Journal of Child Language* **3**, 1–11.

Ota, M. (2006). Input frequency and words truncation in child Japanese: structural and lexical effects. *Language and Speech* **49**, 261–95.

Paul, R. & Jennings, P. (1992). Phonological behavior in toddlers with specific expressive language delay. *Journal of Speech and Hearing Research* **35**, 99–107.

Prather, E., Hedrick, D. & Kern, C. (1975). Articulation development in children. *Journal of Speech and Hearing Disorders* **40**, 179–91.

Prince, A. & Smolensky, P. (2004). *Optimality Theory: constraint interaction in generative grammar*. Malden, MA. Blackwell Publishing Ltd.

Rescorla, L. & Ratner, N. B. (1996). Phonetic profiles of toddlers with specific expressive language impairment (SLI-E). *Journal of Speech and Hearing Research* **39**, 153–65.

Schwartz, R. & Leonard, L. (1982). Do children pick and choose? An examination of phonological selection and avoidance in early lexical acquisition. *Journal of Child Language* **9**, 319–36.

Schwarz, I-C., Burnham, D. and Bowey, J. (2006). Phoneme sensitivity and vocabulary size in 2-1/2- to 3-year-old children, 142–47. In P. Warren and C. Watson (eds), *Proceedings of the 11th Australian Conference on Speech Science and Technology*. Aukland: Australian Speech Science and Technology Association.

Smith, B. (2006). Precautions regarding nonword repetition tasks. *Applied Psycholinguistics* **27**, 584–87.

Smith, B., McGregor, K. & Demille, D. (2006). Phonological development in lexically precocious 2-year-olds. *Applied Psycholinguistics* **27**, 355–75.

Smith, N. V. (1973). *The acquisition of phonology: a case study*. Cambridge: Cambridge University Press.

Snow, C. (1977). The development of conversation between mothers and babies. *Journal of Child Language* **4**, 1–22.

Sosa, A. V. (2008). Lexical effects in typical phonological acquisition. Unpublished doctoral dissertation, University of Washington, Seattle.

Sosa, A. V. & Bybee, J. (2008). A cognitive approach to clinical phonology. In M. Ball, M. Perkins, N. Muller & S. Howard (eds), *The handbook of clinical linguistics*, 480–90. Malden, MA: Blackwell Publishing Ltd.

Sosa, A. V. & Stoel-Gammon, C. (2006). Patterns of intra-word phonological variability during the second year of life. *Journal of Child Language* **33**, 31–50.

Stampe, D. (1969). *A dissertation on natural phonology*. New York: Garland.

Stoel-Gammon, C. (1985). Phonetic inventories, 15–24 months: a longitudinal study. *Journal of Speech and Hearing Research* **28**, 505–512.

Stoel-Gammon, C. (1987). The phonological skills of two-year-old children. *Language, Speech, and Hearing Services in Schools* **18**, 323–29.

Stoel-Gammon, C. (1991). Normal and disordered phonology in two-year-olds. *Topics in Language Disorders* **11**, 21–32.

Stoel-Gammon, C. (1992). Prelinguistic vocal development: measurement and predictions. In C. A. Ferguson, L. Menn & C. Stoel-Gammon (eds), *Phonological development: models, research, implications*, 439–56. Timonium, MD: York Press.

Stoel-Gammon, C. (1998a). The role of babbling and phonology in early linguistic development. In A. M. Wetherby, S. F. Warren & J. Reichle (eds), *Communication and language intervention series vol. 7: transitions in prelinguistic communication*, 87–110. Baltimore: Paul H. Brookes.

Stoel-Gammon, C. (1998b). Sounds and words in early language acquisition: the relationship between lexical and phonological development. In R. Paul (ed.), *Exploring the speech–language connection*, 25–52. Baltimore: Paul H. Brookes.

Stoel-Gammon, C. (2008). Lexical acquisition: effects of phonology. Paper presented at the XIth International Association for Study of Child Language, University of Edinburgh, August.

Stoel-Gammon, C. & Cooper, J. (1984). Patterns of early lexical and phonological development. *Journal of Child Language* **11**, 247–71.

Stoel-Gammon, C. & Dale, P. (1988). Aspects of phonological development of linguistically precocious children. Paper presented at Child Phonology Conference, University of Illinois, Champaign-Urbana.

Stoel-Gammon, C. & Peter, B. (2008). Syllables, segments, and sequences: phonological patterns in the words of young children acquiring American English. In B. Davis &

K. Zajdo (eds), *Syllable development: the frame/content theory and beyond*, 293–323. Mahwah, NJ: Lawrence Erlbaum.
Stoel-Gammon, C. & Sosa, A. V. (2007). Phonological development. In E. Hoff & M. Schatz (eds), *Handbook of child language*, 238–56. Oxford: Blackwell Publishing Ltd.
Storkel, H. (2009). Developmental differences in the effects of phonological, lexical and semantic variables on word learning by infants. *Journal of Child Language* **36**, 291–321.
Swingley, D. & Aslin, R. N. (2002). Lexical neighborhoods and the word-form representations of 14-month-olds. *Psychological Science* **13**, 480–84.
Tamis-LeMonda, C., Bornstein, M. & Baumwell, L. (2001). Maternal responsiveness and children's achievement of language milestones. *Child Development* **72**, 748–67.
Tardif, T., Fletcher, P., Liang, W. & Kaciroti, N. (2009). Early vocabulary in Mandarin (Putonghua) and Cantonese. *Journal of Child Language* **36**, 1115–44.
Tyler, A. & Edwards, J. (1993). Lexical acquisition and the acquisition of initial voiceless stops. *Journal of Child Language* **20**, 253–73.
Velleman, S., Mangipudi, L. & Locke, J. (1989) Prelinguistic phonetic contingency: data from Down syndrome. *First Language* **9**, 159–74.
Velleman, S. & Vihman, M. (2002). Whole-word phonology and templates: trap, bootstrap, or some of each? *Language and Speech* **32**, 149–70.
Velten, H. V. (1943). The growth of phonemic and lexical patterns in infant language. *Language* **19**, 281–92.
Veneziano, E. (1988). Vocal-verbal interaction and the construction of early lexical knowledge. In M. D. Smith & J. L. Locke (eds), *The emergent lexicon*, 109–147. New York: Academic Press.
Vihman, M. (1992). Early syllables and the construction of phonology. In C. A. Ferguson, L. Menn & C. Stoel-Gammon (eds), *Phonological development: models, research, implications*, 393–422. Timonium, MD: York Press.
Vihman, M. (1996). *Phonological development: the origins of language in the child*. Cambridge, MA: Blackwell Publishing Ltd.
Vihman, M. & Croft, W. (2007) Phonological development: toward a 'radical' templatic phonology. *Linguistics* **45**, 683–725.
Vihman, M., Macken, M., Miller, R., Simmons, H. & Miller, J. (1985). From babbling to speech: a re-assessment of the continuity issue. *Language* **61**, 397–445.
Vihman, M. & Velleman, S. (1989). Phonological reorganization: a case study. *Language, Speech, and Hearing Services in Schools*, **33**, 9–23.
Walley, A. C. (1993). The role of vocabulary development in children's spoken word recognition and segmentation ability. *Developmental Review* **13**, 286–350.
Waterson, N. (1971). Child phonology: a prosodic view. *Journal of Linguistics* **7**, 179–211.
Woodward, A., Markman, E. & Fitzsimmons, C. (1994). Rapid word learning in 13- and 18-month-olds. *Developmental Psychology* **30**, 553–66.
Zamuner, T. (2009). The structure and nature of phonological neighbourhoods in children's early lexicons. *Journal of Child Language* **36**, 3–21.
Zamuner, T., Gerken, L. & Hammond, M. (2004). Phonotactic probabilities in young children's speech production. *Journal of Child Language* **31**, 515–36.