Infancy: Phonological Development

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This article provides an overview of phonological development with a focus on production patterns occurring between birth and three years, during which the majority of development occurs. General requirements of phonological acquisition are discussed briefly, followed by a description of prelinguistic vocal development, the transition to speech, and phonological characteristics of first words. Phonetic inventories and error patterns of children acquiring English are discussed.

Phonological Development: What Is Learned?

Within linguistics, the branch of phonology involves the study of sound systems, often in reference to the system of a particular language. A description of the phonological system includes the phonemes and allophones of the language, the phonotactic patterns affecting permitted sequences of phonemes within words, and the suprasegmental features of stress, tone, and timing, among other features. There is a long-standing debate as to which aspects of phonology are 'learned' and which are innate; a full discussion of this issue is beyond the scope of this article. It is clear, however, that acquisition of the phonological system of a language involves knowledge (implicit or explicit) of the phonological properties of that language, phonological representations of the words of the language, and mastery of the articulatory and phonatory gestures associated with adult-like pronunciation of these words. Thus, phonological acquisition involves both cognitive–linguistic learning and the development of the speech-motor skills needed for production.

A key aspect of the cognitive aspect of phonological learning revolves around 'mental' representations that are stored and accessed in the encoding and decoding of words. In spite of a good deal of research regarding the nature and complexity of these representations, key questions remain unanswered, including:

1. Does the child have an auditory representation for word recognition (a form that is presumably close to the adult form) and an articulatory representation for production (a form that may be quite different from the adult form)?
2. If there is a single representation for both perception and production, how are auditory and articulatory features linked within that representation?
3. What is the 'unit' of storage in mental representations? Phonemes? Features? Syllables? Words? Some combination of these?
4. Do the units of storage change as vocabulary grows?
5. Is the mental representation relatively abstract, containing only essential segmental/suprasegmental information, or is phonetic detail included?
6. Are suprasegmental features such as stress and timing included as part of the representation, or are these features coded as 'rules' that apply during word production?
7. How do children's incorrect productions influence their mental representations?
8. Do mental representations change as new words are added to the receptive and productive lexicon?

It should be noted that some of these questions are not unique to the study of developmental phonology. In spite of years of theoretical and experimental research by psychologists, linguists, and speech scientists, there is a lack of consensus on the nature (and number) of mental representations in adult speakers. It is agreed, however, that some type of mental representation is necessary for the perception and production of words. To understand the word *cat*, for example, an individual must have a stored version of the sound sequence associated with the word; the individual must be able to differentiate the word *cat* from similar sounding words, such as *hat, cap, cut,* and *kite*, among others. In a similar manner, production of the word *cat* involves knowledge of the target sound sequence and the articulatory movements needed to distinguish it from other words with similar sound patterns.

Speech Perception

Several months before they produce their first words, infants can recognize words from the ambient language, indicating that they have some sort of storage for those words. Research on infant speech perception has shown that many aspects of phonological learning occur before the comprehension of words (Jusczyk, 1996). In the first 6 months of life, infants demonstrate a remarkable ability to discriminate speech sounds from a variety of languages. After 6 months, discrimination abilities decline and language-specific sensitivity increases. Thus, infants exposed to English can detect the difference between dental and retroflex /t/ phonemes of Hindi at 6 months but not at 12 months. Increased sensitivity to the sound patterns of the input language is apparent not only at the segmental level, but also with regard to phonotactic patterns and prosodic features. Research shows that infants pay attention to statistical properties of the language they hear, recognizing permissible sequences and frequency of occurrence of phonological features in the input.

Research on infant perception highlights the large gap between perception and speech production in infancy: even before babies utter their first words, many aspects of the perceptual system are nearly adult-like. A major challenge during the period of early acquisition, then, is to learn to **produce** speech so that it resembles the speech the child hears. For instance, a child acquiring English must learn to block the air stream completely for stop consonants and to block it partially for fricatives; to raise the velum for nonnasal consonants and vowels and lower it for nasals; to position the tongue so that it touches the alveolar ridge to make /s/; to begin vocal fold vibration 50 ms (or more) after release of closure to produce initial /p/; and to lower the sides of the tongue to produce /l/. Some of this speech-motor learning occurs prior to the onset of meaningful speech, as shown in the overview of prelinguistic development provided here.

Prelinguistic Development

In the first 12 months, the infant produces a wide variety of vocalizations; some of these are 'speech-like' in that they share features of adult productions, while others, like coughs or burps, bear little resemblance to speech. By definition, 'prelinguistic' vocalizations are non-meaningful, even though they may resemble real words. Thus, productions of [mama] or [dædæ] at 7 months, though sometimes interpreted as attempts to produce *mommy* and *daddy*, are classified as prelinguistic vocalizations unless it can be shown that they have the stable sound-meaning relationships of conventional adult-based words. Word production lags behind comprehension by several months: around 9 months, infants begin to demonstrate limited comprehension of words and simple phrases in particular contexts; by 12 months, the average receptive vocabulary is around 50 words according to parental report (Fensen *et al.*, 1993). First words typically appear between 11 and 14 months, with an average onset of 12 months.

Ages and Stages in the Prelinguistic Period

Most vocal productions in the first month of life are classified as reflexive vocalizations (e.g., cries, coughs, and hiccups) and are thought to be automatic responses reflecting the physical state of the infant. In contrast, nonreflexive vocalizations (e.g., cooing, babbling, and playful yelling and screaming) are productions containing some of the phonetic features found in adult languages (Oller, 2000). Nonreflexive vocalizations pass through a sequence of developmental stages, beginning with vowel-like utterances at 2 months and progressing through a period of vocal play to productions of sequences of consonant–vowel strings toward the end of the first year. All infants, in all linguistic communities, pass through the same stages of early vocal development. Although called 'stages,' the periods are not discrete, and vocalizations from previous stages continue to be used in subsequent ones. The onset of a new stage is marked by the appearance of vocal behaviors not observed (or observed only rarely) in the preceding period; the new behaviors do not necessarily constitute the most frequent vocalization type during that stage.

Stage 1 (0 to 2 Months): Phonation

The first stage is characterized by productions that bear little resemblance to speech. The vocal behaviors of this stage consist primarily of reflexive (sometimes called 'vegetative') vocalizations, such as crying, fussing, coughing, sneezing, and burping. These vocal types are referred to as 'reflexive' because they involve automatic, involuntary motor patterns. Some nonreflexive vowel-like productions occur at this stage.

Stage 2 (2 to 4 Months): Cooing

This stage is characterized by a new type of vocal production that occurs as infants begin smiling and interacting with adults in their environment. 'Coos' are characterized by nasal resonance and are generally perceived as containing vowels and consonants produced at the back of the mouth (velars, uvulars) and back vowels. Consonant–vowel syllables occurring in this period lack the timing of opening and closure gestures found in syllable timing of adult speech.

Stage 3 (4 to 6 Months): Vocal Play

Although the vocalizations of the previous period still occur, new productions in this stage range from repetitions of vowel-like elements to squeals, growls, yells, raspberries (bilabial or labiolingual trills), and friction noises. It seems as though infants are intentionally exploring the capabilities of the vocal tract. The predominant type of vocalization may vary from week to week or even from day to day, making it difficult to characterize an infant's productions without an extensive sample. During this period the infant produces some consonant–vowel (CV) syllables; however, the timing of the transition between consonant and vowel is slower than that occurring in adult CV syllables.

Stage 4 (6 to 10 Months): Canonical Babble

This stage is characterized by the appearance of syllables composed of alternating consonants and vowels. These syllables occur as single syllables or as strings of repeated syllables, such as [baba]. Because the timing and phonetic characteristics of these syllables are similar to those of adult speech, the productions may resemble words of the language, e.g., [mamama], [dædæ]. Multisyllabic utterances in this stage are categorized as reduplicated babbles (i.e., strings of identical syllables like [bʌbʌ]) or variegated babbles (syllable strings with varying consonants and vowels, like [bagɪ]). While both types of utterances occur in this stage, reduplicated babble predominates initially, while variegated babble increases after the infant reaches 9 to 10 months of age.

Stage 5 (10 Months and Older): Jargon Babble

This stage of babble, also called 'intonated' babble, often cooccurs with both canonical babbling and with the appearance of words. Jargon babble is characterized by strings of sounds and syllables uttered with a variety of stress and intonational patterns. To many adults, it seems as though children are speaking in whole sentences but are using their 'own' language, rather than the standard language spoken by older children and adults around them.

The Sounds of Babble

The repertoire of speech sounds changes dramatically during the first year of life. In the first 6 months, vowel articulations tend to predominate, and most consonantal sounds are produced in the back of the mouth. With the onset of the canonical babbling stage, there is a shift toward labial and coronal consonants, with frequent occurrences of [m], [b], and [d] in particular. Between 6 and 12 months, the consonantal repertoire expands considerably, but claims that babies produce all the sounds of all languages of the world (Jakobson, 1968) in this period have not been substantiated. In fact, a limited set of phones accounts for the great majority of consonantal sounds produced. According to Locke (1983), the consonants [p b m w t d n j k g h] comprise about 90% of the consonants produced by infants raised in American English–speaking environments. Crosslinguistic research has shown that these same manner classes predominate in the babble of infants raised in all linguistic environments.

In the late stages of the prelinguistic period, infant vocalizations show general effects of the ambient language. Babies gradually stop using sounds that do not occur in the ambient language, such as [h] in French, and their syllables start to acquire the timing and pitch contour of the language around them. Thus, while infants from all language communities tend to produce vocalizations with stops, nasals, and glides, there are systematic differences in the frequency of occurrence of particular sound classes and syllable structures that reflect the proportional use in the linguistic input (Vihman, 1996).

The Transition to Meaningful Speech

First words typically appear during the period of canonical babble, and for the next 7 to 10 months, babble and speech coexist. By the age of 18 months, the proportion of babbled utterances has declined markedly, and words and short phrases begin to predominate. Babble and early words share the same phonetic properties in terms of sound types and syllable shapes (Stoel-Gammon, 1992). The consonants that occur most frequently in canonical babbling – stops, nasals, and glides – are the same sound classes that predominate in early word productions, and the manner classes that are infrequent in babble – namely liquids, fricatives, and affricates – are precisely those that appear later in the acquisition of speech. Moreover, the CV syllable structure that is characteristic of the canonical babbling period is also the most frequent syllabic type in early word productions. Developmentally, the sounds of babble serve as the building blocks for the subsequent production of words.

There is strong evidence linking prelinguistic production patterns with general speech and language skills throughout early childhood, indicating continued influence from the babbling period. Longitudinal studies have shown correlations between (1) the age of onset of canonical babble and the age of onset of meaningful speech; (2) the amount of vocalization at 3 months and vocabulary size at 27 months; (3) the number of CV syllables produced at 12 months and the age at which first words are produced; (4) use of consonants at 12 months and phonological skills at 3 years; and (5) the diversity of syllable and sound types at 6 to 14 months and performance on speech and language tests at 5 years. In each case, more in the prelinguistic period (i.e., more vocalizations at 3 months; more CV syllables at 12 months; more consonants in babble) is linked to better performance on speech and language measures. These correlations provide further support for the view that babbling serves as a foundation for subsequent acquisition of speech and language. Infants who produce a greater number of prelinguistic vocalizations, particularly a greater number of canonical utterances with a variety of consonants and vowels, have amassed a greater arsenal of 'building blocks' that can be recruited for the production of words.

Development of Articulatory–Auditory Links

Infants are exposed to two types of input during the pre-linguistic period: the speech of those around them and their own productions. Both are crucial for the acquisition of speech. Adult input (often modified in the form of child-directed speech) provides the basis for learning the sound–meaning associations that underlie word meaning. Hearing their own vocal output is also important for children's production of words, as it is the basis for establishing links between oral-motor movements and the resulting acoustic signal. Thus, the 6-month-old who frequently produces the syllable [ba] becomes aware of the tactual and kinesthetic sensations associated with production of this syllable and of the auditory signal that results from the production. Once this step is accomplished, infants must recognize that that the babbled syllable [ba] resembles the adult words *ball*. When these two types of learning have occurred, the prelinguistic form [ba] can serve as the basis for production of the word *ball*.

Speech production has a skill component and, as with any skilled activity, practice increases the control and precision with which a movement is performed. Thus, the more often a baby makes the movements that shape the vocal tract to produce particular sounds and sound sequences, the more automatic those movements become and, ultimately, the easier it is to execute them in producing meaningful speech. 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 (Vihman, 1992).

As noted previously, word production requires awareness of the link between a particular sequence of speech sounds and a particular meaning and the knowledge of the articulatory movements needed to articulate the sequence of sounds that resembles the target. If the sequence of speech sounds is present in the child's babble, as in the case of the nonmeaningful [ba] used subsequently for the word *ball*, the change from babble to speech is minimal in terms of articulation. In contrast, acquisition of a word like *shoe* involves learning not only the link between sound and meaning but also a set of unfamiliar articulatory movements. The disparity in the amount of learning involved in acquiring the words *ball* and *shoe* leads to the prediction that, all other things being equal, 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 prelinguistic repertoire.

Sounds and Syllables of the 'First-Word' Period

The first-word period, from the onset of meaningful speech to acquisition of a 50-word vocabulary, is characterized by a phonetic inventory of simple syllabic structures and a small segmental repertoire. (The term 'phonetic inventory' is used here to describe the elements occurring in a child's productions and does not take into account accuracy of production.) In English, syllable types predominating in the first-word period include CV (consonant–vowel), CVC, and CVCV; in terms of consonantal repertoire, productions are composed primarily of stops, nasals, and glides, with a few fricatives, mainly in word-final position.

Research on first-word production in languages other than English reveals the same general properties in terms of sound classes and syllable structure: in all languages, CV syllables tend to predominate, and stops, nasals, and glides occur frequently. Language-specific influences are apparent, however, in the frequency of occurrence of particular sound classes, syllable types, and stress patterns. For example, children acquiring English produce many CVC words and disyllables with trochaic stress; French-learning children, by comparison, produce more disyllabic forms, more words with iambic stress, and more nasals, all features of French.

In spite of the presence of common production patterns, substantial individual variation does occur, presumably arising from a combination of innate and environmental factors. Individual differences have been noted in a range of domains, including consonantal repertoire in babble, 'favorite' sounds in early words, rate of acquisition, degree of phonetic accuracy, variability of production within and across words, and number and type of errors in word productions.

Beyond First Words

The end of the first-word stage, around 18 months, is signaled by a rapid increase in vocabulary size, an expansion of the repertoire of segments and syllable shapes, and the onset of two-word utterances. By 24 months, the typically developing child learning English has acquired a productive vocabulary of 250 to 350 words and can produce multiple-word sentences. Although the child's phonological system is far from complete, the basic elements are present: the child can produce words with labial, alveolar, and velar stop consonants, both voiced and voiceless; labial and alveolar nasals; glides; and some voiceless fricatives. In terms of syllable structures, the repertoire includes open and closed syllables that can combine to form disyllabic words. In addition, the average 2-year-old can produce some words with consonant clusters in initial and final positions. Compared with consonants, the vowel repertoire at 24 months is relatively complete, although some lax vowels and the r-colored vowels may be missing. By age 36 months, the phonetic inventory of the typically developing child has expanded to include consonants from all place, manner, and voice classes of English, as well as a variety of syllable and word shapes. Although the productive repertoires of typically developing children may be quite similar at 36 months, the developmental paths leading to the repertoire will vary considerably. For this reason, it is difficult to talk about 'order of acquisition' of phonemes because, in spite of general patterns, there is no fixed order.

With expansion of syllable types and segmental repertoire, accuracy of production improves markedly between 24 and 36 months. A majority of children acquiring English can accurately produce all stops, nasals, and glides, as well as /f/ and /h/ in some word positions (see below); by 42 months, the repertoire of accurate segments, at least in some word positions, has increased to include /s, v, ʃ, tʃ, dʒ, r, l/.

Effects of Word Position, Word Length, and Word Stress

Phonological development involves more than learning accurate storage and production of individual speech sounds; accurate production is heavily influenced by the phonetic context in which the target sound occurs. In English, for example, fricatives, velars, and liquids are likely to appear first in word- (or syllable-) final position. As might be expected, production accuracy is affected by syllable structure, with a singleton consonant less prone to error than the same consonant in the context of a cluster. Thus, /s/ may be produced accurately in the word *sun* but not in the word *spoon* or *star.*

Two more factors that influence segmental production are word length and word stress. In general, words of three or more syllables have more errors in syllabic structure and segmental accuracy than shorter words. Stress patterns of the target language also play a role. Almost all disyllabic words in the lexicon of a 2-year-old acquiring English conform to a trochaic pattern of a strong (or stressed) syllable followed by a weak (unstressed) syllable, as in *BAby, TAble, MOmmy, COOkie; DOggie* (where capital letters indicate the stressed syllable). There are occurrences of words with iambic stress (a weak syllable followed by a strong syllable), as in *baLLOON, caNOE, guiTAR*, but words with iambic stress are less frequent and tend to appear later in the child's productive vocabulary. Attempts to produce trochaic and iambic words yield quite different outcomes: trochaic words are produced with two syllables from the early stages; iambic words, in contrast, are often reduced to a single syllable. Resulting forms may include the entire strong syllable, e.g., [nu] for *caNOE*, or the onset of the weak syllable followed by the rime of the second syllable, e.g., [bun] for *baLLOON*. Words of more than two syllables are also affected by stress pattern. In English, the predominant form is reduction of the three-syllable form to a two-syllable trochaic production. For example, in the word *animal*, the medial syllable is omitted, while in the word *baNAna,* the initial syllable is dropped.

Child Productions: Adult Targets

A child's phonological system can be described in two ways: through an independent analysis, i.e., with a focus on the child's productions without reference to the adult model; or via a relational analysis, i.e., comparing the child's production to the adult model. Each type of analysis provides important information. An independent analysis includes a summary of the child's phonetic inventory, i.e., a list of segments, sound classes, syllable and word structures, and suprasegmental patterns in the child's speech. A 'relational' analysis, in contrast, focuses on similarities and differences between the child's pronunciation of a word and the target form.

As most adults are aware, mispronunciations are one of the hallmarks of child speech. In some cases, the mispronunciation is so profound that it is impossible to determine what the child was trying to say; in this case, the child's form is classified as unintelligible. At the age of 2 years, about half of a child's utterances are intelligible (i.e., can be understood by an adult who is not familiar with the child). By the age of 3 years, the level of intelligibility increases to 75%, and by age 4, it is 100%. This does not mean that the child's productions are fully adult-like by age 4; rather, it means that the errors do not interfere with intelligibility. Although the level of intelligibility is closely linked to the child's productive phonology, it can also be influenced by other factors, such as syntactic complexity and pragmatic context.

Differences between a child's production of a word and the adult target can stem from problems in a number of areas: with perception of the adult input; with storage and/or retrieval of the word form; or with the articulatory movements associated with production. In some cases, several of these 'problems' may be involved in single production. Studies of speech perception in infants and young children, however, indicate that children have relatively accurate perception of target forms; moreover, they are often aware that their production is incorrect. For example, Smith (1973) noted the following exchange with his son:

Father: Say 'jump.'
Child: Dup.
Father: No, 'jump.'
Child: Dup.
Father: No, 'jummmp.'
Child: Only Daddy can say 'dup.'

Comparisons of children's productions and adult targets show that the differences between the two are not random but can be described in terms of phonologically based 'phonological processes' that simplify the target by reducing syllabic complexity or substituting one sound class for another. These processes can be divided into four types: syllable structure processes, substitution processes, assimilation processes, and voicing processes. Examples of each of the types, based on the acquisition of English, are provided below.

Syllable Structure Processes

'Syllable structure processes' affect the overall 'shape' of a syllable or word by omitting one or more elements (segments or syllables) from the target form. The influence of the primitive CV syllable shape, common in babble, can be seen in these examples:

1. Omission of a weak syllable, usually in initial or medial position, from the target form; e.g., *telephone* produced as [tɛfon] or *about* produced [baʊt]
2. Omission of the final consonant of a word, e.g., *dog* produced [da] or *ball* produced [ba]
3. Omission of one or more consonants in a cluster, e.g., *snow* produced as [no] or *ant* produced as [æt]

Substitution Processes

'Substitution processes' involve substitution of one sound class for another. Consonants that appear in the child's form tend to be those occurring in babble and in the early word stage. Examples include:

1. Substitution of stops for target fricatives and affricates, e.g., *see* is produced [ti], *zoo* is [du], and *chin* is [tɪn]. The stop is produced at the same (or nearly the same) place of articulation as the target phoneme.
2. Substitution of alveolar stops for target velar stops, e.g., *key* is produced as [ti] and *go* is produced [do].
3. Substitution of alveolar consonants for target alveolo-palatal consonants, e.g., *shoe* is produced [su] and *juice* is [dzus].
4. Substitution of glides for prevocalic liquids, e.g., *red* is produced [wɛd] and *light* is [jaɪt] or [waɪt].
5. Substitution of vowels for post-vocalic liquids and syllabic liquids, e.g., *door* is produced [dɔə] and *bottle* is produced [badu].

Assimilation Processes

'Assimilation processes' (also referred to 'harmony' processes) affect the segments, primarily the consonants, of a target word by making one consonant more like another. These forms resemble reduplicated syllables of canonical babble and early word forms such as *mommy, daddy,* and *baby*. Examples include:

1. Assimilation of a nonvelar consonant to a velar consonant in the same words, e.g., *dog* is produced [gag]
2. Assimilation of a nonlabial consonant to a labial consonant in the same word, e.g., *boat* is produced [bop]
3. Assimilation of a nonnasal consonant to a nasal consonant in the same words, e.g., *bean* is produced [min]

Context-Sensitive Voicing Processes

'Context-sensitive voicing processes' affect the voicing feature of prevocalic and word-final obstruents. Examples include:

1. Voiceless obstruents (primarily stops) in prevocalic position are produced as their voiced cognate, e.g., *two* is produced [du] and *papa* is produced [baba].
2. Voiced obstruents in word-final position are produced as their voiceless cognate, e.g., *cheese* is produced [tʃis]; *bag* is produced [bæk].

In some cases, a single word may be affected by more than one process. For example, when *table* is produced as [bebu], initial /t/ is assimilated to the following labial and syllabic /l/ is rendered as a vowel; when *surprise* is produced as [pwaɪs], the target form is affected by deletion of the initial weak syllable, by gliding of /r/, and by devoicing of word-final /z/.

The patterns described above have been described within a number of theoretical frameworks, including analyses based on features, phonemes, or 'correspondence' rules; more recently, nonlinear models, connectionist approaches, and optimality theoretic descriptions have appeared. Regardless of the phonological framework, the patterns are the same: word productions tend to be simplified to reflect the basic elements that were used in the prelinguistic stages. In terms of views on phonological acquisition, the primary differences across current phonological theories lies in proposals regarding underlying representations, in the emphasis on prosodic versus segmental aspects of development, and in formal descriptions of differences between child productions and the target form.

Summary and Conclusion

This article has provided a brief description of phonological development from birth to 3 years, with emphasis on production and examples primarily from English. It should be remembered that, for the child, the goal of phonological development is not to learn the phonology of the target language but to learn to recognize words from the input and to produce adult-like forms as output.

Basic production patterns first appear in the prelinguistic period, during which the fundamental articulatory patterns emerge: CV syllable structures and use of stop, nasal, and glide consonants. As children begin to recognize and attempt to produce words, they must move beyond the basic repertoire and learn to produce the phonetic, phonological, and prosodic features of the target language.

See also: Generative Phonology; Harmony; Infancy: Sensitivity to Linguistic Form; Metrical Phonology; Natural Phonology; Phonology: Optimality Theory; Underspecification.

Bibliography

Bernhardt B & Stemberger J S (1998). *Handbook of phonological development.* San Diego: Academic Press.

Bleile K (2004). *Manual of phonological and articulation disorders.* Clifton Park, NY: Delmar Learning.

Braine M D S (1974). 'On what might constitute a learnable phonology.' *Language 50,* 270–299.

Fenson L, Dale P, Reznick S, Thal D, Bates E, Hartung J, Pethick P & Reilly J (1993). *The MacArthur communicative developmental inventories.* San Diego: Singular Press.

Ferguson C A, Menn L & Stoel-Gammon C (eds.) (1992). *Phonological development: models, research, implications.* Timonium, MD: York Press.

Grunwell P (1986). *Phonological assessment of child speech.* Boston, MA: College-Hill Press.

Ingram D (1976). *Phonological disability in children.* London: Elsevier.

Jakobson R (1968). *Child language, aphasia, and phonological universals.* The Hague: Mouton. [First published in 1941.]

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

Locke J L (1983). *Phonological acquisition and change.* New York: Academic Press.

Menn L & Stoel-Gammon C (2005). 'Phonological development: learning sounds and sound patterns.' In Berko Gleason J (ed.) *The development of language,* 6th edn. Boston, MA: Pearson Education. 62–77.

Oller D K (2000). *The emergence of the speech capacity.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

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

Stoel-Gammon C (1992). 'Prelinguistic vocal development: measurement and predictions.' In Ferguson, Menn & Stoel-Gammon (eds.). 439–456.

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

Stoel-Gammon C & Dunn C (1985). *Normal and disordered phonology in children.* Baltimore, MD: University Park Press.

Vihman M (1992). 'Early syllables and the construction of phonology.' In Ferguson, Menn & Stoel-Gammon (eds.). 393–422.

Vihman M (1996). *Phonological development: the origins of language in the child.* Cambridge, MA: Blackwell Publishers.

Yeni-Komshian G, Kavanagh J & Ferguson C A (1980). *Child phonology, vol 1: Production; vol 2: Perception.* New York: Academic Press.

Infancy: Sensitivity to Linguistic Form

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Until recently, much of our understanding of how first language develops has come from children's utterances, and particularly their errors. However, recent work on language development in infants has revealed their remarkable sensitivity to linguistic form, especially as it is embodied in the statistical patterns of their input. This article will outline three domains of sensitivity: phonology, the lexicon, and syntax.

The Development of Phonetic Categories

Although infants in the first months of life appear to be able to discriminate most speech sounds used in the world's languages, adults are not. The groundbreaking research of Werker and colleagues has shown that infants lose their ability to discriminate non-native consonant contrasts, and therefore become more like adults, some time between 8 and 10 months of age (Werker and Tees, 1984). These results are generally taken to indicate that infants have begun to form categories of those speech contrasts that are relevant in their language. What causes infants to form phonetic categories has been a puzzle. We might naïvely assume that infants lose their ability to discriminate sounds that are not in the input. However, such an assumption misses the point that many acoustic differences that are phonemic in one language appear in another language as allophones of a single phoneme. For example, English-speakers have the option of releasing or not releasing and aspirating word final stops. Thus, English-learning infants may be exposed to both released and unreleased stops, but this phonetic difference does not affect meaning in English. The same acoustic difference does affect meaning in Hindi. What causes the English-learning infant and the Hindi-learning infant, both of whom hear variation in aspiration in their input, to treat aspiration differently?

One hypothesis is based on the observation that infants show a decline in non-native consonant discrimination at roughly the period of development that they begin to recognize and produce first words (Best, 1995; Jusczyk, 1985; Lalonde and Werker, 1995; MacKain, 1982; Werker and Pegg, 1992). Perhaps associating word forms with meanings as part of building a lexicon causes learners to focus on which aspects of form are relevant to meaning and which are not. Another hypothesis about the mechanism that underlies infants' focus on the phonetic features that are relevant in the target language concerns their attention to the statistical properties of their input (Jusczyk *et al.*, 1990; Kuhl, 1993; Maye *et al.*, 2002). On this view, an English-learning infant might hear a continuum of different degrees of aspiration on word-final stops, with most of the values clustering around a particular point in the acoustic distribution. That is, English-learning infants are likely to hear a monomodal distribution of aspiration. Hindi-learning infants are also likely to hear a range of aspiration values; however, the values should cluster around two points in the distribution – one for segments in which the speaker intends aspiration and the other for intentionally unaspirated segments. Thus, the Hindi-learner is exposed to a bimodal distribution of this acoustic variable. Recent research by Maye and colleagues using the preferential listening technique suggests that even 6-month-olds respond differently to mono-versus bimodal distributions of speech sounds (Maye *et al.*, 2002).

The Development of the Lexicon

A great deal of research over the past decade has focused on the cues that infants might use to identify potential word forms, and particular, to segment words from the speech stream. Suggested segmentation cues include words produced in isolation (Brent and Siskind, 2001), phrase-final position (e.g., Fernald *et al.*, 2001; Saffran *et al.*, 1996b), language-specific canonical stress patterns (e.g., Echols *et al.*, 1997; Johnson and Jusczyk, 2001; Morgan and Saffran, 1995), phonotactic information (Christophe *et al.*, 1994; Johnson and Jusczyk, 2001), and the probability with which one syllable is followed by another (Jusczyk *et al.*, 1999; Morgan and Saffran, 1995; Saffran *et al.*, 1996a).

Once word candidates have been segmented from the speech stream, they must be compared to existing words in the lexicon. There is some evidence that infants' ability to access stored word representations is highly dependent on there being an acoustic match between the stored word and the currently heard one. For example, infants are better able to recognize words spoken by the same talker at familiarization and test (Houston and Jusczyk, 2003). One topic of current debate in infant lexical development is whether infants gradually become more and more competent at accessing stored word forms (Swingley and Aslin, 2002), or whether there is a discontinuity in lexical representation that occurs when infants begin to associate word forms with referents (Stager and Werker, 1997; Werker *et al.*, 2002).

The Development of Syntax

The first studies examining infants' sensitivity to the syntactic forms of utterances involved making modifications to the language the infant was already learning. Shady *et al.* (1995) demonstrated that 10.5-month-olds could discriminate normal English sentences from sentences in which determiners and nouns were reversed (e.g., "kitten the"). Other studies demonstrated that infants at a similar age could discriminate normal English sentences from those in which a subset of grammatical morphemes (e.g., a, was) were replaced by nonsense syllables (Shafer *et al.*, 1998). Santelmann and Jusczyk (1998) showed that 18-month-olds, but not 15-month-olds, discriminated sentences in which auxiliaries and verb inflections were grammatically correct (e.g., "is running") from sentences with mismatches ("can running").

Other studies have asked what infants are able to learn about the syntax of an artificial language with very brief exposure in the laboratory. Gómez and Gerken (1999) presented 12-month-olds with a subset of strings produced by one of two finite state grammars. Half of the infants were trained for about two minutes on strings from Grammar 1 and half on strings from Grammar 2. During test, both groups of infants heard strings in which new vocabulary was substituted for the syllables in the training grammar (e.g., JED, FIM, TUP, DAK, SOG replaced VOT, PEL, JIC, RUD, TAM, respectively). Infants showed a preference for strings that were consistent with their training grammar, suggesting that they had abstracted some aspect of grammatical structure above and beyond pairs of specific elements. Other researchers (Marcus *et al.*, 1999) found a similar result with 7-month-olds who were exposed to a simpler grammar. In both sets of studies, it is likely that infants were relying on a pattern of repeating and alternating syllables to determine whether what they heard during test was the same as or different from the training stimuli, making the task somewhat different than most aspects of syntax learning.

Still other studies combine learning in the lab with natural language. In one study, 17-month-old English-learning infants were exposed to a Russian gender paradigm with six masculine and six feminine noun stems each appearing with two case endings (Gerken *et al.*, 2005). Two of the feminine and two of the masculine words were withheld during familiarization and presented at test (grammatical items), along with the same stems with the opposite gender case endings (ungrammatical items). Infants discriminate grammatical from ungrammatical items, but only when a subset of the familiarization stimuli contained a second indicator of gender (/k/ on feminine stems and /tɛl/ on masculine stems.

Summary

The studies outlined in this article suggest that infants approach the task of language learning with very sophisticated statistical pattern detection and storage abilities. They raise the possibility that much of the work of language acquisition in the toddler to early school years is to link the language forms noted in infancy with meaning. It remains to be seen whether and how such domain neutral abilities interact with any biological endowment specifically for language.

See also: Design Features of Language; Infancy: Phonological Development; Language Development: Overview; Language Processing: Statistical Methods; Speech Perception.

Bibliography

Best C T (1995). 'Learning to perceive the sound pattern of English.' In Rovee-Collier C & Lipsitt L (eds.) *Advances in infancy research.* Norwood, NJ: Ablex Publishing Co. 217–304.

Brent M R & Siskind J M (2001). 'The role of exposure to isolated words in early vocabulary development.' *Cognition 81,* B33–B44.

Christophe A, Dupoux E, Bertoncini J & Mehler J (1994). 'Do infants perceive word boundaries? An empirical approach to the bootstrapping problem for lexical acquisition.' *Journal of the Acoustical Society of America 95,* 1570–1580.

Echols C, Crowhurst M & Childers J B (1997). 'The perception of rhythmic units in speech by infants and adults.' *Journal of Memory and Language 36,* 202–225.

Fernald A, McRoberts G W & Swingley D (2001). 'Infants' developing competence in understanding & recognizing words in fluent speech.' In Weissenborn J & Höhle B (eds.) *Approaches to bootstrapping in early language acquisition.* Benjamins: Amsterdam.

Gerken L, Wilson R & Lewis W (2005). '17-month-olds can use distributional cues to form syntactic categories.' *Journal of Child Language, 32*, 249–268.

Gómez R L & Gerken L A (1999). 'Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge.' *Cognition 70,* 109–135.

Houston D M & Jusczyk P W (2003). 'Infants' long-term memory for the sound patterns of words and voices.' *Journal of Experimental Psychology: Human Perception & Performance 29,* 1143–1154.

Johnson E K & Jusczyk P W (2001). 'Word segmentation by 8-month-olds: when speech cues count more than statistics.' *Journal of Memory & Language 44,* 548–567.

Jusczyk P W (1985). 'On characterizing the development of speech perception.' In Mehler J & Fox R (eds.) *Neonate cognition: beyond the blooming, buzzing, confusion.* Hillsdale, NJ: Erlbaum. 199–229.

Jusczyk P W, Bertoncini J, Bijeljac-Babic R, Kennedy L J & Mehler J (1990). 'The role of attention in speech perception by young infants.' *Cognitive Development 5,* 265–286.

Jusczyk P W, Houston D M & Newsome M (1999). 'The beginnings of word segmentation in English-learning infants.' *Cognitive Psychology 39,* 159–207.

Kuhl P K (1993). 'Early linguistic experience and phonetic perception: Implications for theories of developmental speech perception.' *Journal of Phonetics 21,* 125–139.

Lalonde C E & Werker J F (1995). 'Cognitive influences oncross-language speech perception in infancy.' *Infant Behavior and Development 18,* 459–475.

MacKain C (1982). 'Assessing the role of experience in infant speech discrimination.' *Journal of Child Language 9,* 527–542.

Marcus G F, Vijayan S, Rao S B & Vishton P M (1999). 'Rule learning by seven-month-old infants.' *Science 283,* 77–80.

Maye J, Werker J F & Gerken L A (2002). 'Infant sensitivity to distributional information can affect phonetic discrimination.' *Cognition 82,* B101–B111.

Morgan J L & Saffran J R (1995). 'Emerging integration of sequential and suprasegmental information in preverbal speech segmentation.' *Child Development 66,* 911–936.

Saffran J R, Aslin R N & Newport E (1996a). 'Statistical learning by 8-month-old infants.' *Science 274,* 1926–1928.

Saffran J R, Newport E & Aslin R N (1996b). 'Word segmentation: the role of distributional cues.' *Journal of Memory & Language 35,* 606–621.

Santelmann L M & Jusczyk P W (1998). 'Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space.' *Cognition 69,* 105–134.

Shady M E, Gerken L A & Jusczyk P W (1995). 'Some evidence of sensitivity to prosody and word order in ten-month-olds.' In MacLaughlin D & McEwan S (eds.) *Proceedings of the 19th Boston University Conference on Language Development,* vol. 2. Sommerville, MA: Cascadilla Press.

Shafer V, Shucard J, Shucard D & Gerken L A (1998). 'An electrophysiological study of infants' sensitivity to the sound patterns of English speech.' *Journal of Speech and Hearing Research 41,* 874–886.

Stager C L & Werker J F (1997). 'Infants listen for more phonetic detail in speech perception than in word-learning tasks.' *Nature 388,* 381–382.

Swingley D & Aslin R N (2002). 'Lexical neighborhoods and the word-form representations of 14-month-olds.' *Psychological Science 13,* 480–484.

Werker J F, Fennell C, Corcoran K & Stager C L (2002). 'Infants' ability to learn phonetically similar words: effects of age and vocabulary size.' *Infancy 3,* 1–30.

Werker J F & Pegg J E (1992). 'Infant speech perception and phonological acquisition.' In Ferguson C A, Menn L & Stoel-Gammon C (eds.) *Phonological development: models, research, implications.* Timonnium, MD: York Press. 285–311.

Werker J F & Tees R C (1984). 'Cross-language speech perception: evidence for perceptual reorganization during the first year of life.' *Infant Behavior and Development 7,* 49–63.

Inference: Abduction, Induction, Deduction

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Abductive reasoning was championed by the early pragmatist Charles Peirce as an empirically focused procedure for the construction of classes and categories from observed data. He defined it as follows:

> The surprising fact, C, is observed; But if A were true, C would be a matter of course, Hence, there is reason to suspect that A is true (Peirce, 1940: 151).

Abduction does not really require that the fact observed be surprising. Peirce's definition of abductive reasoning is presented as a syllogism. We use (a1), (a2) to mark assumptions; '∧' is logical conjunction; and '(c)' is the inferred conclusion of valid reasoning procedure.

(1) (a1) Fact C is observed;
∧ (a2) If A were true, C would be a matter of course;
―――――――――――――――――
(c) There is a reason to suspect that A is true.

Abductive inferences lead to testable hypotheses about states of affairs. Data are correlated on the basis of their similarity or by analogy with some known system, usually with an eye to their apparent function or relevance within the emerging general description. An example of abductive reasoning in historical linguistics is (2).

(2) (a1) In the ancient Indic language Sanskrit, words for numbers 2–7 are *dva, tri, catur, pañca, ṣaṣ, sapta*. These are similar to number words in European languages known to be related to one another: e.g., Slovak *dva*, Latin *duo* '2'; Slovak *tri*, Italian *tre* '3'; Latin *quattuor* '4'; Welsh *pump*, German *fünf* '5'; Spanish *seis*, English *six* '6'; Latin *septem* '7'.