

THE REALITY OF LINGUISTIC RULES

Edited by

Susan D. Lima

Roberta L. Corrigan

Gregory K. Iverson

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Susan D. Lima, Roberta L. Corrigan and Gregory K. Iverson (eds)

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The Perceptual Infrastructure of Early Phonological Development*

Alice Faber
Haskins Laboratories

Catherine T. Best
Wesleyan University

1. Introduction

Observation of children's vocal behavior in approximately their first two years of life reveals systematic patterns in the way they learn to speak the language spoken around them, whatever that language may be. Our purpose in this paper is to discuss some of the principles underlying this early language learning. In particular, we are interested in how and why changes take place in children's phonological inventories. We will first outline phonological development, as observed in children's babbling and early speech. Then, we will discuss a contrasting view of phonological development, based on studies of infant speech perception. Following that, we discuss some recent findings regarding the development of motor skills, also in approximately the first two years of life, and some differences between older children and adults in articulatory coordination. Finally, we will suggest that both children's limited early productive phonological inventories and the patterns of expansion of these inventories as language learning progresses do not result from increasing perceptual skill or from cognitive maturation; that is, they should not for the most part be attributed to developmental changes in linguistic rule systems. They result rather from increasing motor skill, and are, therefore, attributable to the fact that children are not just learning a language, they are also learning to talk.

1.1 *Babbling to early words to full phonological inventory*

The basic observation — made first in Jakobson (1941 [1968]) and reiterated by many others (see, e.g., Macken (1980) for a review) — is that children acquire the ability to produce the sounds of their native language in a lawful sequence. For present purposes, we will concentrate on the stages in (1).

- (1) Canonical/reduplicative babbling
- Variegated babbling
- Proto-words and first words¹
- Fifty-word stage
- Full phonological inventory
- Adult-like phonological competence

There is (cf. Jakobson) an essential continuity in this sequence in which children learn the phonological systems and rules of their native language (Oller 1980; Locke 1983; Vihman et al. 1985; and, with reference to American Sign Language, Petitto and Marentette 1991).

In canonical and variegated babbling,² infants produce word-like sequences using a variety of sounds, not merely those of the ambient language. While phonotactic constraints can be observed (in particular, babbling tends to consist of one or more CV syllables), infants nonetheless make use of a relatively rich segmental inventory. However, when infants produce their first true words, around 12 months of age, their lexicons make use of a more impoverished segment³ inventory. Furthermore, when their early words are compared with ambient adult models, substitutions and simplifications are evident. The phonological inventory — and the phonotactic complexity of the child's utterances — increase in parallel with lexical growth. But it is only when the infant has acquired a lexicon of approximately 50 words that minimal contrast — and thus true phonology — is likely to be observed. Children vary in how quickly they acquire the full phonological inventory of their native language. Some may do so by the age of 2½, while others (of comparable intelligence) may not do so until after they have entered school. Sounds notorious for being difficult to produce are the approximants /rly/ and fricatives, with /θ/ and /ð/ often acquired after five years of age; the contrasts among labial and anterior coronal fricatives are also late, with voicing or voicelessness preserved in substitutions (Ingram et al. 1980; Gallagher and Shriner 1975).⁴

1.2 Accounts of phonological development

What we are interested in explaining in this paper is the constellation of facts in (2):

- (2) a. Children produce rich segment inventories in babbling;
- b. Children's early words are characterized by an impoverished segment inventory;
- c. When children's early words are compared with their adult models, systematic patterns of substitution are observed;
- d. Children's segment inventories appear to increase in terms of natural classes of segments rather than in terms of individual segments.

Even though several sorts of explanation for these facts appear in the literature, they reduce to three basic approaches, listed in (3) (similarly, Ferguson and Garnica 1975; Strange and Broen 1980).

- (3) a. **Perception.** Children at the early stages of language do not yet accurately discriminate all of the segmental contrasts of the ambient language, and thus construct qualitatively different lexical representations from those of adults;
- b. **Motor skill.** Children at the early stages of language discriminate many (or all) of the segmental contrasts of the native language, and have inferred an appropriate rule system, but lack the motor skills necessary for real time correct articulation of meaningful utterances (MacNeilage 1980; Thelen 1991);
- c. **Rules.** Children at the early stages of language perceive many (or all) of the segmental contrasts of the native language, and have adult-like lexical representations, but they have not yet inferred appropriate phonological rule systems (similarly, Stampe (1973), among others).

Our strategy in this paper will be as follows: We will first present evidence from studies of infant speech perception, showing that infants can, before they produce their first words, discriminate most, if not all, of the phonological contrasts of their native language. Following that, we will demonstrate that motor skill development is sufficient to explain most observed patterns of phonological inventory development. Finally, we will place our discussion in the context of current phonological models that do

not and cannot rely on characteristics of linguistic rule systems to account for observed developmental patterns. We will thus argue that, in the aggregate, perceptual maturation and imperfect learning of phonological rules play a relatively minimal role in the ontogeny of mature phonological inventories. Although all of our discussion will be in terms of spoken language, we are not by any means claiming a privileged neurological or ontogenetic status for *spoken* language. Indeed, it appears that bilinguals fluent in American Sign Language and spoken English utilize similar neural substrata in both sign and speech, in contradistinction to non-linguistic gesturing (Corina, Vaid, and Bellugi 1992). Likewise, deaf children acquiring signed language do so in stages parallel to those in which hearing children acquire spoken language (Petitto and Marentette 1991). We expect, therefore, that arguments parallel to ours but based on signed language would be relatively easy to construct.

2. Perception leads production

We will first discuss perceptual evidence that point (3a) is incorrect; rather, prelinguistic infants are capable of detecting sound contrasts in the ambient language. One general characteristic of first language acquisition evident in the literature is that, contrary to second language acquisition, perception tends to lead production (Edwards 1975).⁵ Anecdotal evidence for this abounds (Ferguson and Garnica 1975; Menn 1983). In particular, a child who appears systematically to substitute /w/ for /r/, saying, for example, [wed] for *red*, may nevertheless recognize that an adult's target *wed* is not what he or she meant to say, and may, as a result, get annoyed that the adult fails to understand this. Such a child may, despite the apparent lack of contrast, have acoustic differences between *red* and *wed* such that the initial consonants are measurably and systematically distinct, but, nonetheless, are perceived by adults as representing the same phonemic category (Kornfeld and Goehl 1974). In addition, Locke and Kurtz (1975) find that these children often cannot distinguish their own intended *ring* and *wing*, when the tokens are randomized, and interpret this result to mean that these children are wrong in their belief that they distinguish /r/ and /w/. But, in light of Kornfeld and Goehl's findings, an alternative would be that preschool children whom adults perceive as not distinguishing /r/ from /w/ have already acquired the adult perceptual distinction but, despite their belief

that they are producing the two sounds in adult fashion, they have not yet acquired the articulatory skill necessary to production of a bunched or pharyngeal /r/ meeting adult norms.

2.1 *Methods for study of infant speech perception*

Study of adult speech perception involves playing sounds for subjects and asking them what they hear. This method is obviously not available for study of the speech perception abilities of prelinguistic infants. Rather it is necessary to recruit behaviors available even to very young infants, and to measure these behaviors as a reflection of the infants' time-varying interest in differences between particular classes of speech sounds. Various methods have evolved for assessing infants' interest in classes of speech sounds, and indirectly which sounds infants of different ages consider to be the same. What all of these methods have in common is that they test whether infants can hear the difference between two physically different groups of sounds. In the visual habituation paradigm, which we use for studies in our laboratory (e.g., Best, McRoberts, and Sithole 1988; Best 1994),⁶ the infant views a brightly colored slide of a smiling person. Whenever the infant is looking at the slide, as judged by a hidden observer, sounds from one group are played over a speaker. When the infant looks away from the slide, the sounds cease, and when it looks back at the slide, the sounds return. This contingency creates a conditioned association between looking at the slide and hearing the sounds. The infant's motivation for listening to the sounds is that infants find human speech intrinsically interesting (Leavitt et al. 1973, with references). When the infant's looking falls below an individually determined threshold, that is, when it appears to have lost interest in listening to the group of sounds it has been hearing, the sounds presented are changed to the other group. Thus, if the infant has been hearing, for example, *pa...pa...pa* it might now hear *ba...ba...ba*. At this point, one of two things can happen. The infant may notice that it is hearing something new, in which case it is likely to show renewed interest in listening to the sounds, which will be reflected in increased looking at the slide. Alternatively, the infant may not notice (or care) that it is hearing a new category of sounds, in which case it will continue to show a declining interest in looking and listening. This procedure can be used with infants as young as two months of age, and, with some modification, with children, and even with adults.

The results of this procedure are interpreted as follows: Sounds that the infant discriminates potentially represent two distinct categories for the infant, and sounds that the infant appears not to discriminate may well be perceived by the infant as exemplars of a single category (assuming the infant is paying attention at all). In a typical experiment, infants in cohorts of several distinct ages will be tested. Within each age cohort, some infants will hear sounds from two conceptually distinct categories of sounds in the two phases of the experiment, and others will hear sounds that do not differ in category membership. The study of infants in several different age groups with the same experimental materials allows for the establishment of a developmental progression.

2.2 *From the universal to the particular*

With some systematic exceptions, infants younger than eight months old can discriminate whatever consonant contrasts they hear,⁷ regardless of the phonological relevance of the contrast to the ambient language. That is, just as 6-8 month old infants being raised in an English speaking environment can discriminate between *ba* and *pa*, like English speaking adults can, so too can they discriminate between the Hindi dental and retroflex stops, a contrast that is not utilized in American English. English speaking adults cannot discriminate between the dental [t] and the retroflex [ɖ] (even though we can easily produce the distinction!); neither can ten month old infants.⁸ But the 6-8 month old infants can, apparently with no difficulty (Werker and Tees 1984). Janet Werker, who first observed this phenomenon, has suggested that infants younger than about 8 months of age discriminate consonant contrasts on the basis of the phonetic differences among the members of the contrast. Older infants and adults, in contrast, discriminate consonants on the basis of their *phonological* potential to distinguish lexical items in the ambient language. Between approximately 8 and 10 months of age, a perceptual reorganization takes place.⁹ Thus, before a child produces its first words at approximately one year of age, the phonological structure of the language spoken around it influences the way it perceives speech sounds.

However, as we already noted, there are some contrasts, both native and non-native, that infants younger than 8 months old cannot discriminate. Four month olds cannot, for example, discriminate the native *sa-za* contrast (Eilers and Minifie 1975; Eilers 1977), but 6-8 month olds, tested

in a different paradigm, can discriminate $s\epsilon-z\epsilon$ (Best 1994). In addition, the 6-8 month old infants cannot discriminate the Zulu fricative contrast $\mathfrak{z}-\mathfrak{z}$ (Best 1994). With regard to fricative place of articulation, 1-4 month olds can discriminate $sa-\mathfrak{z}a$ (Eilers and Minifie 1977), but they cannot, according to one report, discriminate $fi-\theta i$ or $fa-\theta a$ (Eilers 1977);¹⁰ Levitt et al. (1988), in contrast, found that 6-12 week olds can discriminate $fa-\theta a$. According to one study, 6-8 month olds cannot discriminate $fi-\theta i$ or $fa-\theta a$ (Eilers 1977), although another study shows that they can form distinct categories for /f/ and /θ/, albeit less easily than they can for /s/ and /ʒ/ (Kuhl 1980).

In the aggregate, then, these studies show that by the time infants are starting productive use of language they can already discriminate almost all of the phonological contrasts of their native language. While they cannot yet produce adult-like forms, they appear, in many respects, to have adult-like representations, which are reflected, among other things, in their vociferous rejections of adult imitations of their phonologically impoverished productions. Nonetheless, perceptual maturation may be related to children's relatively late acquisition of fricatives, although it is not clear to us whether infants and young children have difficulty distinguishing fricative contrasts because fricatives are rare in early language, or whether fricatives are rare in early language because infants and young children have difficulty detecting fricative contrasts. In any case, the well-documented ability of pre-linguistic infants to discriminate a wide range of potentially distinctive phonetic contrasts is a crucial part of the infrastructure for their eventual development of a phonological system for their native language.¹¹

3. Walking precedes running

We now turn to point (3b), motor skill development. In our research, we take the position that phonological patterning is not merely a set of abstract relationships among abstract elements devoid of any essential physical characteristics. Rather, the elements in a phonological system are characterized by physiological and acoustic properties, and the relationships among them follow, at least in part, from auditory constraints on perceptual distinctiveness and neuromuscular constraints on articulator movement. In terms of perception, we observe that for a phonetic contrast to be phonologically useful it must be robust enough to be discriminated by

humans using language under a variety of conditions (similarly, Thelen 1991; Faber 1992). While the relationship between auditory and phonetic perception is not completely understood, it is clear that they are different (Best, Morriongiello, and Robson 1981; Werker and Logan 1985; Repp 1981; Mann and Liberman 1983; Liberman and Mattingly 1985). Furthermore, if a phonological contrast is observed in one or another language, we *infer* that it is auditorily and phonetically robust. With regard to production, we consider talking to be a motor skill comparable to walking, running, or catching a ball. And as such it must be learned. Thus, investigation of how infants and children acquire other motor skills is clearly relevant to an understanding of how they learn to talk.

3.1 *Patterns of motor skill development*

As our example of non-speech motor skill development, we will examine walking, following the discussion in Thelen and Ulrich (1991). Like talking, upright walking is a biologically basic, non-arbitrary human activity, that, presumably, has been selected for in the course of the evolution of our species. Skilled walking can be broken down into several component skills: (i) an aggregate of muscles must be synchronously contracted; (ii) the two legs must alternate between being airborne and supporting all body weight; (iii) the body must maintain its balance as weight shifts between the two legs. At a finer level of detail, the alternation between the two legs in adult stepping requires a complex phasing between flexion and extension of the hips, knees, and ankles. And maintenance of balance normally requires synchronized input from the visual and vestibular systems. Newborn infants are biomechanically unsuited for walking because of their high centers of gravity and their small, weak limbs. In particular, newborn muscular activity, perhaps as a result of the constrained intrauterine environment, overwhelmingly involves muscle flexion rather than extension. However, if the needs for balance and for ankle extension are removed, by holding infants with their feet touching a backward-moving treadmill, some infants as young as one month old will stay in place by stepping forward in the alternating stepping pattern characteristic of adult walking.¹² This treadmill pattern, like the alternating kicking that young infants also engage in, is like walking; but it is not walking. It is not walking, because it does not involve all of the components of skilled walking, and because it is an involuntary response to the moving treadmill, rather than being goal-directed like skill-

led walking is. Walking requires an aggregate of skilled behaviors, and only when the last of these has developed does the overall skill develop, recruiting what Thelen and Ulrich (1991: 44) refer to as skills constructed from "continuous, available precursors." Yet there is an essential continuity between the alternating stepping of pre-walking and of walking. What discontinuity there is results from the embedding of the alternating stepping pattern in purposeful locomotion. That is, it is a discontinuity of function rather than of movement pattern.

3.2 *Speech production as motor skill*

When we turn to the development of talking, that is, of skilled articulation, both continuity and discontinuity are similarly observed. The articulatory routines that children use for their early words are a subset of those that they use in babbling, so there is a continuity of motor routine. What differentiates words (and proto-words) from babbles is that the former have linguistic value and the latter do not.¹³ Thus, we submit, the discontinuity between babbling and early words results from the emergence of meaning and lexicon. The sequence *dædæ*, as a word meaning *Daddy*, is embedded in a different complex control structure than as a meaningless reduplicative babble (similarly, Labov and Labov 1978). This additional covert complexity of referential expressions *vis à vis* non-referential expressions increases the difficulty of producing what might seem to be the 'same' articulatory maneuver, and is compensated for by overt articulatory simplification.

That infants' and young children's utterances can be transcribed in terms of adult phonological categories should not mislead us into thinking that they produce these sounds in the same way adults do. Adults' transcriptions of children's speech are necessarily filtered through the adults' perceptual systems, which, in turn, are filtered by the phonological systems of the languages they speak (similarly, Macken 1980); as a result of this modulation by adult categorical perceivers, gradual changes in children's productions may appear in transcriptions to be abrupt. As to how children are actually producing their early words, there is little relevant evidence available, due to the difficulties of interpreting acoustic analysis of utterances produced with high fundamental frequency and possibly unknown targets and of eliciting infants' cooperation in measuring articulator position or configuration during speech. Nevertheless, one recent study (Stathopoulos and Sapienza 1993) documents differences between adults

and four-year old children in respiratory and laryngeal control for speech. Perceptually, all of the children's utterances seemed normal to the experimenters; there were none of the substitutions and simplifications that characterize early phonology or the phonology of older children with language disorders. Yet the children's respiratory and laryngeal patterns for speech differed measurably and systematically from the adults'. The children, due presumably to their smaller lung volume, use a larger proportion of their vital capacity for speech breathing, and produce fewer syllables per inspiration. And the children and the adults appear to use different laryngeal settings for ordinary speech. Thus, even when children have adult phonological inventories they are not yet producing the sounds the same way adults do. While Stathopoulos and Sapienza did not study children younger than four, there is no reason to expect younger children to be more adult-like than the 4-year olds studied in their respiratory and laryngeal control. Smith (1992) likewise suggests that the greater duration of 2- and 4-year olds' utterances relative to adult controls and the greater durational variability in the children's utterances are independent reflections of the children's immature speech motor control systems.

4. Conclusion: A unified account of learning to talk

Thus far, we have argued that prelinguistic infants can discriminate most but not all of the linguistically significant contrasts in the ambient language (3a). We have also argued that the patterns observed in beginning talkers are consistent with other patterns of motor skill development (3b). Thus, of the potential explanations for the patterns of phonological development outlined in (2), we have eliminated perceptual learning as a general explanation, although perceptual attunement may ultimately lead to a plausible account for the late acquisition of the ability to perceive and produce contrasts among fricatives. We have also reasoned that motor skill development is a plausible explanation for the patterns of phonological development observed, and will now suggest some ways in which our account of phonological development can be related to current phonological models.

We have already noted the different control structures that it is reasonable to assume for the sequence *dædæ*, depending on whether it refers to *Daddy* or is merely a meaningless babble. This difference finds easy expression in the Articulatory Phonology of Browman and Goldstein (1986;

1989). In this view, the phonological primitives are gestures. Similar opening and closing gestures can be implemented by different articulators, and there is a difference between a complete closing and closing only to a critical position; a complete closing gives a stop, and a closing to critical position gives a fricative. One way in which this model differs from current generative models — although not necessarily so (cf. Mohanan 1986) — is that the temporal relationship among the various gestures composing an utterance must be explicitly stated as part of the phonological representation, and these timing statements interact with non-contrastive characteristics like speech rate to bring about many of the casual speech phenomena that are, in other models, attributed to rules. Thus, in Browman and Goldstein's view, one of the things that children must learn in the course of language acquisition is the patterns of articulator phasing that are appropriate for their language. And, children's early preference for stops can be interpreted to mean that they have not yet mastered incomplete or critical closure.

For a meaningless babble *dædæ*, the tongue just happens to contact the alveolar ridge, but for the word *Daddy* a complete alveolar closure is required and produced. The physical action of the tongue tip or blade contacting the alveolar ridge might be the same in the two cases, just as the infant's prelocomotory leg kick is physically like a step; in the two cases, the pairs of actions are distinguished by the differing control regimes that they are embedded in. For a child to be able to walk, it is necessary that it be able to swing the legs in alternating fashion. Likewise, for a child to be able to produce an alveolar stop, it is necessary for it to be able to bring the front part of the tongue into contact with the alveolar ridge. However, in neither case is the second ability sufficient to guarantee the first.

In Browman and Goldstein's Articulatory Phonology, and in most versions of Generative Phonology, the basic units of phonological representation are considerably smaller than the minimal one-syllable utterance; these units are not pronounceable in isolation but only in concatenation with enough other phonological units to form a minimal utterance. In contrast, many accounts of children's phonological development suggest that children's earliest phonological representations are of larger units, Ferguson's (1986: 41) "whole word shape." On this view, phonological segments of the sort generally manipulated in phonological analysis only emerge as the child's lexicon increases in size and allows for the possibility of true minimal pairs. Aside from the relatively late emergence of contrast, the primary evi-

dence for this view is the larger scope of children's articulatory gestures, together with the different phasing relationships among these gestures (Nittrouer, Studdert-Kennedy and McGowan 1989; Goodell 1991). Consequently, adults and children at the early stages of language have qualitatively different representations. We disagree. We first note the (to us) obvious point that pronunciation of even a reduplicated CVCV 'word' involves the complex sequencing of discrete and disparate articulator actions (similarly, MacNeilage and Davis 1990). So even a global, holistic lexical representation must, in order for the child to utter it, be translated into a sequential motor program of some sort. Secondly, positing holistic representations makes it difficult to account for the well documented cases in which a child's attempts to produce a given, new word involve repeated and different permutations of some or all of the features or gestures that would be present in a full, adult representation of the word. Ferguson (1986), for example, presents 10 different attempts by a child approximately 15 months old to produce the word *pen* within a span of thirty minutes: [mã^a], [v̄], [de^h], [hln], [m̄bō], [p^hln], [t^hŋt^hŋt^hŋ], [ba^h], [d^haun], [buã]. While nasalization, labiality, and aspiration are variously combined in these attempts, none represents an adequate [p^hen]. Sequences such as this are generally taken to indicate that the child has constructed a tentative representation for *pen* containing these features, but in no particular order. It seems to us, however, that if this were the case, the child would not have made nearly so many attempts to produce these features in the sequence appropriate to more adult-like renditions of *pen*. The fact that the child made so many attempts, incorporating many of the phonological features found in its adult model, suggests that child's representation contains discrete specification of, among others, a labial closing and a velar opening, as well as the sequence in which these gestures occur, and that the child recognizes when she has implemented them in the wrong order.

Finally, the view that children at the early stages of language have qualitatively different phonological systems than the adults around them assumes a model of adult phonology that is inconsistent with modern autosegmental and metrical approaches, as described in e.g., Goldsmith (1990) (and for child phonology, Iverson and Wheeler 1987), and with Articulatory Phonology (Browman and Goldstein 1986, 1989).

[...] the individual gestural components of articulation — the features of modern phonology — each have quite separate lives of their own, and an adequate theory of phonology will be one that recognizes this, and pro-

vides a way to understand the linkages between the individual gestures of the tongue, lips, and so forth, and larger units of organization, such as the syllable. (Goldsmith 1990: 9)

So, in claiming an essential similarity between adults' and early language learners' phonological representations we are suggesting that neither children's nor adults' representations of words contain discrete phonological segments representable as columns in a distinctive feature matrix, of the sort posited by classical generative phonology (e.g., Chomsky and Halle 1968). Rather, in both cases, the phonological primitives are articulator movements, or gestures, and children in the early stages of language (as in somewhat later stages) differ from adults in exactly how the gestures required for a particular word are implemented. For adult speakers, there is sufficient overlap in the gestures bringing about a particular articulatory configuration that the common idealization that speech consists of discrete segments, linearly arranged like beads on a string, does not do too much damage to the articulatory facts. For child speakers, however, the segmental idealization does more damage. But the difference between children and adults resides in the amount of gestural overlap (Nittrouer, Studdert-Kennedy, and McGowan 1989; Goodell 1991), not, we would claim, in the nature of the phonological representation that is most appropriate for each.

Despite the overwhelming evidence in favor of a motor-skill-based account of phonological acquisition, rule-based accounts of differences between children's and adults' phonological systems must still be considered (3c). The attractiveness of such accounts, as noted by Stampe (1973), follows from the lawful nature of the relationship between mature and immature phonological systems. And, indeed, the systematic nature of this relationship underlay the development of Stampe's natural phonology, according to which language acquisition consists in large measure in suppressing innate natural processes. On this account, the primary difference between mature and immature phonologies is that children with small phonological inventories have not yet learned to suppress those phonological processes that do not apply in their native language.

Menn (1983) takes a somewhat different approach. Essentially, her proposal is that children at the early stages of language are subject to severe output constraints on possible phonological forms. These output constraints are presumably similar to Surface Phonetic Constraints (MSCs) of the sort proposed by Shibatani (1973) to account for phonotactic regularities. Such MSCs are at least partially language specific (some languages, for example,

allow word initial consonant clusters, and some do not), and, hence, must be considered part of the grammar of a language. Although it may appear that Menn is thus claiming that children's lexical representations are different from adults', she is not. These output constraints restrict what children can say in various ways, including, in addition to modification and deletion of segments, avoidance of lexical items that a child cannot yet pronounce. While the output constraints for a particular child at a particular point in time are clearly not universal, Menn nonetheless sees them as outside the child's developing grammar; rather, they in some sense represent a metalinguistic codification of the child's articulatory capacities.

Either Stampe's or Menn's approach may appropriately capture the range of regularities in early phonology and in children's attempts to produce understandable words; however, it is not clear that they vitiate the need to appeal to motor skill development to account for some acquisitional patterns. Furthermore, many of the surface differences that lead Stampe and others (e.g., Stemberger 1988; Matthei 1989) to posit different rule systems for children and adults may simply reflect children's gestures being implemented with different phasing relations than adults' gestures are. We suppose, in addition, that this formal difference reflects underlying motor skill differences between children and adults, rather than constituting *per se* a crucial difference between children's and adults' linguistic skills. Our account of increasing segment inventories in early language, then, relies on the difficulty inherent in embedding previously mastered articulatory maneuvers in the new, hierarchical control structure of non-linear phonology or of a gestural score. In terms of generative phonology, an alternative could be proposed utilizing underspecification (Archangeli 1988; and, with regard to child language, Iverson and Wheeler 1987; Stemberger and Stoel-Gammon 1991). That is, children's lexical representations contain less phonological information than do adults' and therefore, more putatively redundant information is specified by rule. Thus, all vowels could, for example, be specified as dorsal, and the feature [low] provided by rule, not merely in cases in which adults have a low vowel, but across the board. Likewise, consonants could be unspecified for place and manner, and the feature labial would be specified by rule in all cases and continuant would be specified in no cases.¹⁴ Such an alternative is, we believe, incorrect, in that it supposes that children's representations differ systematically from adults' and in that it assumes that children who cannot produce the contrast between *Daddy* and *doggy* cannot perceive it. That the latter assumption is clearly wrong suggests that the former is as well.

We close with one final point. Our suggestion in this paper has been that the pervasive and systematic phonetic differences between children's early linguistic forms and those of adults, as well as the developmental path by which children finally arrive at the normative forms of the ambient language primarily reflect developmental differences in motor skill, in particular in articulatory agility. To the extent that these differences can be formalized in current models of phonology, one is tempted to attribute them to cognitive rather than motor skill immaturity. We have argued that this would be mistaken. Despite this, we are unwilling to take the further step of claiming that no developmental phonological phenomena can be attributed to infants' immature perceptual systems or to their construction of inappropriate or overgeneralized rules. Indeed, the latter phenomena are well-documented in morphology and syntax, although perhaps not as pervasive as is generally thought (see Marcus et al. 1992 for details). We would like to suggest, however, that only when those aspects of phonological development that result from motor skill development are factored out will it be possible properly to understand the true roles of perceptual maturation and grammar construction in phonological development.

Notes

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- 1. Proto-words function like words, but differ from them in having no obvious adult prototypes. See Menn (1983) for details.
- 2. Canonical babbling is characterized by a relative lack of within-utterance variation in consonants and vowels (Oller 1980). Canonical babbles are likely to be reduplicated utterances like *bæbæbæbæbæ*, while variegated babbles have more varied phonological structure.
- 3. Here and throughout, our use of the term *segment* as an expository shorthand in no way involves an explicit claim that the child's early words are constructed bottom-up from discrete phonological units rather than being wholistic units which are only metalinguistically analyzable into component segments.

4. The ability to perceive fricative contrasts is also acquired relatively late. For example, 12-14 month old infants can discriminate *fi-θi* but not *fa-θa* (Eilers 1977). Two year olds cannot discriminate *fis-θis* (Eilers and Oller 1976) and 3-5 year olds (Abbs and Minifie 1969) have difficulty with *fʃl-θʃl* and *ʃvl-θʃl*.
5. For production abilities leading perception abilities in second language learning, see Goto (1971) and Sheldon and Strange (1982).
6. Other common procedures involve the non-nutritive sucking paradigm (Eimas et al. 1971) and the Visually Reinforced Head-Turn paradigm (Kuhl et al. 1992). In addition, some researchers monitor attention-related changes in heart rate. See Eilers (1980) for further details on these paradigms. The conditioned visual fixation paradigm described in the text is the most flexible, in that it can be used with infants in a wide variety of age groups, simplifying longitudinal comparison.
7. Less attention has been paid to the perception of non-native vowel contrasts. Kuhl et al. (1992) concerns the development of prototypes for native (but not, of course, for non-native) vowel phonemes. We are currently doing pilot work for a study of infants' discrimination of non-native vowel contrasts, and a similar study has recently been completed by Polka and Werker (1994).
8. Likewise, 3-year old children can discriminate neither [t] from [t̥] nor [t̥] from [t] (Locke 1978).
9. Werker's conclusions are with reference to consonantal phonology. The results of Kuhl et al. (1992) suggest that native language effects on vowel perception may be observable in infants as young as six months of age.
10. These same 5-16 week old infants could discriminate [as]-[a:z], in which a naturalistic vowel length distinction supplements the fricative voicing contrast; the [a:s]-[a:z] data from comparable infants show a non-significant tendency toward discrimination (Eilers 1977). Levitt et al. (1988) suggest that the failure of Eilers' young subjects to discriminate *fa-θa* might be the result of degraded stimuli; only c. 70% of the adults tested could correctly identify the stimuli.
11. While our position is superficially similar to that of Eimas (e.g., Eimas et al. 1971), we do not mean to claim that phonetic categories are innate, but rather that the cognitive ability to discern categories in the environment is.
12. In Thelen and Ulrich's (1991) study, only some infants exhibited alternating leg movements at one month of age; by seven months, however, all infants in the study did, at least at some treadmill speeds.
13. This distinction is comparable to Sapir's (1925) distinction between producing a voiceless bilabial approximant [hw] and blowing out a candle. While the action may in some sense be the same in the two cases, only in the former is approximating the two lips required by a particular communicative intent.
14. The sequence in the text is one of many possible within underspecification theories; one child might at first implement all stops as labial, and another as coronal. Nothing in the theory implies, to our knowledge, a particular order of acquisition.

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