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The Early Development of Phonological Form

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"The nervous system of man and animals is moulded structurally according to the modes of its functional exercise."
- Henry Maudsley (1867, p. 41).

"Many if not most acquisitions of new structures in the course of evolution can be ascribed to selection forces exerted by newly acquired behaviors...Behavior, thus, plays an important role as the pacemaker of evolutionary change."
- Ernst Mayr (1982, p. 612).

INTRODUCTION

The scope and flexibility of language, as a system of animal communication, depends on its dual structure. There are two levels of structure: phonology (or sound pattern) and syntax. Both depend on combinatorial rules by which a finite set of elements is repeatedly sampled, and the sampled elements combined, to produce novel utterances. At the level of phonology a small set of meaningless elements (consonants and vowels) is used to construct the very large set of meaningful (or syntactically functional) elements (words, morphemes) that constitute a speaker's lexicon. At the level of syntax a large, though finite, lexicon is used to construct an infinite set of utterances. Syntax is a hallmark of human language; so too is phonology. Indeed, syntax presupposes phonology, because the capacity to form words is logically, ontogenetically and, we must presume, evolutionarily prior to the capacity to form sentences. The present paper is entirely concerned with the development of phonological form.

In referring to consonants and vowels as primitive elements of phonological form, I am appealing to the reader's phonetic intuitions and knowledge of the conventions of alphabetic transcription. The fact that a spoken utterance can be transcribed as a sequence of discrete phonetic symbols by a writing listener, and regenerated as a more or less continuous articulatory-acoustic pattern by a reading speaker, is an important psychological datum, without which systematic study of either phonology or syntax would be impossible. Yet, as we have known for some forty years, discrete invariant segments, corresponding to consonants and vowels, cannot be isolated by purely physical measurement of either the articulatory or the acoustic record. The reason for this is that the concepts, consonant and vowel, are abstractions from what we actually observe in speech, namely, the acoustic consequences of repeated patterns of oral constriction and opening that form the basic metrical unit of speech, the syllable.

The syllable arises from complex, interleaved spatio-temporal patterns of gesture, executed by partially independent articulators (larynx, tongue, jaw, velum, lips). That the phoneme (consonant, vowel) has functional rather than merely descriptive status, as a gestural pattern within the syllable, is attested not only by the alphabet itself, and by the familiar poetic devices of alliteration, rhyme and assonance, but also by the systematicity of speech errors. Sub-syllabic metathetic errors ("spoonerisms") almost always entail exchange of elements with corresponding syllabic functions (onset, nucleus, coda). For example, <u>bad dog</u> might be erroneously executed as <u>dad bog</u>, <u>bod dag</u> or <u>bag dod</u>, but rarely as <u>gad dob</u>, never as <u>bdd aog</u>.

Thus, the sound pattern of every spoken language is hierarchically organized: syllable, segment, gesture. My goal in what follows is to sketch a possible course of development for this behavioral hierarchy (and, by implication, for its neural substrate) over the first two years of life.

THE FUNCTIONAL ORIGINS OF STRUCTURE

An entry into this issue is afforded, perhaps surprisingly, by recent studies of sign language "aphasia". Over the past twenty years or so we have learned that sign languages are not, as was once generally believed, adventitious mixes of pantomime and gesture, partly universal, partly parasitic on their surrounding spoken language. Rather, they are full-fledged, independent languages with dual structures of sign formation ("phonology") and syntax, analogous to the dual structures of spoken languages, though adapted to the oro-manual-visual rather than the vocal-auditory modality. I will not elaborate on the structure of sign languages (for which, see Klima and Bellugi, 1979). For the present discussion, it suffices to know that American Sign Language (ASL), the most intensively studied to date, is a heavily inflected language (analogous to, say, Russian or Greek), of which the inflections are elaborate modulations of the manual movements intrinsic to sign stems. In addition to its inflections, ASL syntax formally exploits the space in front of the signer to display complex spatio-temporal patterns that specify the arguments of verbs, and to maintain the anaphoric coherence of discourse. Very broadly, then, we may say that while the phonology and syntax of a spoken language are primarily instantiated in sequential acoustic patterns over time, those of a signed language are primarily instantiated in simultaneous optic patterns over space.

Given this contrast between the modalities of spoken and signed languages, the locus of brain specialization for a signed language, such as ASL, takes on a special interest. Does ASL, given its elaborate visuo-spatial structure, lateralize to the right hemisphere? Or do whatever perceptuomotor, or abstract linguistic, properties ASL shares with a spoken language ensure that it lateralize to the left hemisphere? The answer has come from the first systematic studies of ASL aphasia, conducted by Poizner, Klima and Bellugi (1986). They studied six brain damaged native signers of ASL, three with right hemisphere damage, three with left. Patients with right hemisphere lesions displayed normal perception and production of ASL, but were severely impaired on standard tests of visuo-spatial function. Patients with left hemisphere lesions displayed precisely the reverse pattern. Moreover, the patterns of ASL deficit in the three aphasic patients varied with the locus of left hemisphere lesion in a fashion strikingly similar to the variations described for such standard spoken language syndromes as Broca's and Wernicke's aphasia.

Further evidence for the effects on brain organization of learning ASL as a first language comes from the work of Neville (1985; in press). She studied evoked response potentials (ERP's) in normal hearing subjects and in literate, but profoundly deaf subjects whose first language was ASL. In one study she compared ERP's recorded over left and right occipital and anterior temporal sites, to words and signs briefly flashed in left and right visual fields. Words for normal hearing subjects, and both words and signs for native signers were more accurately recognized when flashed in the right visual field than when flashed in the left, indicating greater left than right hemisphere engagement by both words and signs. On the other hand, in normal hearing subjects, words yielded a characteristic pattern of ERP's that was absent in literate deaf subjects, suggesting different neural processes in word perception as a function of the language substrate on which reading was based. Yet signs yielded in deaf, but not in hearing, subjects exactly the same ERP pattern as did words in hearing subjects, suggesting an equivalence between processes of word reading in hearing subjects and of sign perception in deaf subjects. The results are evidently too complex, and the ERP measures too gross, for easy interpretation. But they do indicate an intricate pattern of similarities and differences between the neural processes that support the perception of signs and words. Interestingly, the response patterns characteristic of the deaf subjects, all native signers of ASL, were absent in bilingual English-ASL interpreters who had learned ASL as a second language.

These studies of ASL argue that it is the activity of the developing neural substrate for language, in response to the environment, that determines its final organization. Taken with recent work on the early sensitivity of infants to speech, they cast a new light on neonatal cerebral specializations. Several studies have shown that, in normal infants, the left hemisphere is already at birth more sensitive to speech than the right, and more sensitive to speech than to periodic or aperiodic nonspeech sounds (for review, see Molfese and Betz, 1988). However, recent work suggests that this neonate bias may reflect prenatal experience no less than the presumptive structural predispositions of the left hemisphere. Fifer (this volume) and others (DeCasper and Fifer, 1980; DeCasper and Spence, 1986) have shown that neonates prefer their mother's voice to that of a stranger; Mehler and his colleagues (Mehler, Jusczyk, Lambertz, Halsted, Bertoncini and Amiel-Tison, 1988) have shown that neonates prefer the sounds of their maternal language to those of another language, spoken by the same bilingual woman. Since these preferences are present within days, or even hours, of birth, it would seem that they reflect the infant's intrauterine experience of its mother's voice.

The role of experience in shaping the neural substrate for language is further evidenced by recent studies of babbling. Oller, Eilers, Bull and Carney (1985) compared the vocalizations of a deaf infant from 8 to 13 months of age with those of 11 hearing infants. The patterns of sound-making by the deaf infant never advanced beyond those typical of 4-6 month old hearing infants. The results demonstrated that the normal onset and course of babbling development depend on exposure to the sound patterns of a language. Yet, if a deaf infant is exposed to ASL during the first months of life, "babbling" with the fingers emerges around the age normal for speech babbling, that is, roughly 6-7 months (Newport and Meier, 1985; Laura Petitto, personal communication). Evidently, then, early exposure to the acoustic or optic patterns of a natural language is necessary and sufficient to precipitate the onset of "babbling" in the appropriate modality.

Given the developmental continuity between babble and speech, now reported in several studies (e.g., Oller, Weiman, Doyle and Ross, 1975; Vihman, Macken, Miller, Simmons and Miller, 1985), and given that motor coordination of both the speech apparatus and the hands is normally vested in the left hemisphere, we may infer that the onset of babbling, whether spoken or signed, reflects the incipient growth of neuromotor support systems in that hemisphere. Evidently, the precise form of this early growth depends on the modality of the surrounding language.

In short, a diverse range of studies supports the principle that behavior (broadly understood as patterns of both perception and action) is the pacemaker of development, no less than of evolution (Mayr, 1982). We may therefore justly apply to the development of language in general, and of phonology in particular, the sound Darwinian principle that function determines form, rather than form function.

FROM MOUTH SOUNDS TO PHONEMES

Preliminary

Animal communicative displays often seem to arise by ritualization of motor routines that evolved for other purposes (Hinde, 1970). The change of function is presumably accompanied by a change in neuromotor control. For example, the topography of spreading wings in the African crane's courtship display may be identical with their topography immediately before flight, but we would not expect identity of underlying neural mechanisms. Indeed, in humans, dissociation of the capacity to use a tool from the capacity to imitate its use is sufficiently well known to have been given a diagnostic name, ideomotor apraxia. And recently, Poizner et al. (1986) have demonstrated, in ASL aphasics, dissociation of the capacities for linguistic and non-linguistic manual gesture. Thus, movements of identical topography, but different function, may come under different regimes, and even loci, of neural control.

I raise this issue here because in what follows I will sketch a speculative account of the process by which disparate and uncoordinated patterns of oral activity (and their correlated mouth sounds) are gradually harnessed to linguistic function, and so brought under specialized neural control. Most of what I have to say will concern production rather than perception because that is what we know most about. But this should not be taken to imply that perception is unimportant. On the contrary, it is obviously through perception that the infant gains access to the surrounding language.

At birth, as noted above, normal infants are already sensitive to at least the prosodic patterns of their maternal language (Mehler, et al., 1988). Within a few days or weeks they can discriminate virtually any speech contrast on which they are tested, and by six months (perhaps earlier, but we have no data) they can form sound categories based on the onset or coda of a consonant-vowel syllable -- a capacity they share with other animals (Kuhl, 1987), including Japanese quail (Kluender, Diehl and Killeen, 1987). Presumably, these capacities are somehow brought to bear on the language that infants hear around them. We have seen that some form of perceptual input is necessary for normal onset of babbling, around the seventh month. We also know that 6-month-old American infants are sensitive to acoustic correlates of clausal units in English utterances (Hirsh-Pasek, K., Kemler Nelson, D. G., Jusczyk, P. W., Cassidy, K. W., Druss, B., and Kennedy, L., 1987). We know too that, during the second six months, infants lose their sensitivity to certain subsyllabic contrasts that are not put to contrastive use in their native language (Best, McRoberts and Sithole, 1988; Werker and Tees, 1984). Finally, we know that around one year, before they have been heard to utter their first attempt at an adult word, infants may recognize the meanings of as many as 150 words (Benedict, 1979).

We can be quite confident then that the processes of differentiation and integration we observe in production are grounded in earlier, hidden processes of perception and memory. In short, without denying a possible role to articulatory exploration and its resulting feedback in refining infant perceptual skills, we may assume that perceptual growth generally precedes and guides production.

<u>From mouth sounds to canonical babble: integration of movements</u>

At birth the infant has two independent sound-making systems (Stark, 1986). The first, reflexive crying and fussing, has the obviously communicative, though not linguistic, function of signaling distress. The sounds are largely voiced "vocants" (Bauer, in press), sounds formed with an unconstricted vocal tract, displaying variations in duration, amplitude, pitch contour and rhythm. The second system, the vegetative movements and sounds associated with feeding and breathing, has no communicative function. The sounds may be voiced or voiceless vocants or "closants" (sounds formed with a constricted vocal tract) (Bauer, in press). Vegetative closants are typically voiceless clicks, stops, friction noises and trills (Stark, 1986).

Development over the first six months apparently entails the gradual harnessing and adaptation of these disparate phonatory and articulatory elements to what we might term protolinguistic use, in the closant-vocant, or "consonant-vowel" (CV) syllable of canonical babble. Particularly during the second trimester, the infant begins to superimpose movements of the velum, tongue, jaw and lips on the laryngeal actions associated with cry (Koopmans-Van Beinum and van der Stelt, 1986). Perhaps these combinations of cry and upper articulator action initially occur quite by chance. But the infant, already by 4-5 months (Kuhl and Meltzoff, 1982) and perhaps even earlier (Meltzoff, 1986), is inclined to imitate the actions of its conspecifics, and so to shape its sound-making to the rhythmic patterns of the surrounding language. Thus, the proportion of supraglottal to glottal articulations gradually increases (Holmgren, Lindblom, Aurelius, Jalling and Zetterström, 1986), and the fully voiced syllable emerges.

Oller (1986) has described the acoustic properties of a canonical CV syllable to which true babbling conforms. Salient among them are its temporal properties: the ratio of syllable opening (or release) to syllable nucleus drops, often quite suddenly around the seventh month, to the values typical of an adult stop-vowel syllable. The patterns of movement in early babble are not random. Partial closures, as in fricatives, affricates and glides, are less frequent than complete closures, as in stops. Points of closure are biased toward the front of the mouth, so that the "consonants" most often transcribed tend to be those formed with the lips or with tongue tip or blade (engaging muscle systems essential to sucking): /b,d,m,n,w,j/. During the open phase of the syllable the favored tongue positions are those associated with low-to-mid, front-to-central vowels, indicating that little or no upward movement of the tongue compensates for the lowering of the jaw. As would be expected, if these patterns were largely determined by the maturational state of the vocal anatomy and physiology, they have been observed (at least for the closants) in virtually every language studied (Locke, 1983).

The integration of simple movements into a more complex pattern may be facilitated by the emergence of rhythmic oscillations of the jaw (cf. Thelen, 1981; this volume). For much early canonical babble consists of strings of reduplicated syllables (/bababa, nenene, dadadada/, and so on), in which the infant seems to be running off a rhythmic sequence of stereotyped, undifferentiated syllables. In fact, MacNeilage and Davis (in press) propose that early babbling consists largely of rhythmic jaw opening and closing, with little or no active control over points of closure or over tongue position during the open phase.

If this is so, we may say that the principal achievement of the first half year is to integrate the mouth movements of feeding and breathing with the laryngeal actions of cry into the holistic spatio-temporal patterns of canonical syllables. Presumably this first step in the shift of function from nonlinguistic to linguistic use of movement is accompanied by an incipient shift in the underlying neural mechanisms and loci of perceptuomotor processing.

From canonical babble to early words: differentiation of gestures

Toward the end of the first year, full syllable reduplication begins to fade. "Variegated" sequences appear in which the consonant-like onset or vowel-like open phase, or both, may vary from one syllable to the next (Oller, 1980). The onset of variegated babbling seems to follow from two cognitive processes, already noted. First is the infant's growing capacity to recognize and store in memory syllables, or sequences of syllables, as units of meaning (words) (Benedict, 1979). Second is the infant's apparent capacity, around 10-12 months, to recognize the contrastive function of small sound variations within words, as evidenced by its loss of sensitivity to phonetic distinctions that are not put to contrastive use in the adult language (Best, et al., 1988; Werker and Tees, 1984).

These growing perceptual and memorial processes would not suffice to induce variegated babble were the child not able to recognize the equivalence or disparity between adult sound patterns and its own. Exploitation of this ability, essential to the development of imitation, seems to be fostered by babbling itself. Recently, Locke and Pearson (1988) have reported on a child deprived of babbling experience, from five to twenty months of age, by a tracheostomy, for bronchopulmonary dysplasia. The child's vocal output, upon removal of the cannula, was that of a child of less than six months of age. She vocalized, but showed little interest in vocalizing for communicative purposes. Only 2% of her utterances qualified as canonical syllables, according to the criteria of Oller (1986), and her consonant inventory was roughly one fifth of what would be expected in a normal 20-month old child. In fact, her level of vocal development was roughly that of a deaf child of the same age. Unlike the deaf, she had regularly heard adult speech around her since birth, perhaps permitting some degree of normal perceptual development; but the lack of vocal practice, with feedback from her own vocalizations, had blocked normal motor development. However, the effect was not permanent. On last report, at a chronological age of 4;4, her performance on a standard test of receptive and expressive language was at the level of 4;7. This, of course, as Locke and Pearson remark, testifies to the plasticity of the system rather than to the lack of any function for babbling in normal development.

Guided, then, by its growing apprehension of sound variation and function in the surrounding language, and by its growing perceptuomotor skills, the child launches into variegated babble at around the same time as it first attempts adult words. The two modes of output proceed concurrently, often for many months, with the words gradually coming to predominate. During this period the principal domain over which the child attempts to organize its articulations, whether of babble or speech, seems to be the syllable or disyllable. Within this "prosodic unit" (Macken, 1979 p. 11), the child strives to differentiate, and control the timing of, the component laryngeal and supralaryngeal gestures.

Evidence that an utterance (syllable, disyllable, word) is indeed a prosodic unit, and so planned as a whole (Menn, 1983), comes from gestural interactions: the child often fails to execute two different places or manners of articulation within the same utterance, thus maintaining some of the reduplicative tendencies of early babble. The most familiar examples are of consonant harmony (assimilation): gog for dog, guk or kuk for truck, and so on. Recently, Davis and MacNeilage (in press) have reported an extensive study of a child's concurrent babbling and speech over the period from 14 to 20 months of age. Their data are replete with instances not only of consonant, but of vowel and even consonant-vowel assimilation. The latter is revealed by the child's preference for high front vowels following alveolar closures, and for low, front-central vowels following labial closures. At the same time, these authors also report an inverse relation between consonant and vowel reduplication: where the child succeeds in combating assimilation in the open phases of a disyllable, she often fails to do so in the closing phases, and vice versa. This demonstrates an incipient segregation of consonants and vowels into phonetic classes.

The study by Davis and MacNeilage is particularly important because the child deployed an unusually large lexicon, growing from about 25 words at 14 months to over 750 words at 20 months. (A typical lexicon at 20 months would be from 1-300 words (Davis and MacNeilage, in press)). Evidently, a child may have a substantial lexicon long before it has fully mastered segmental structure. The principal phonological achievement of this period, then, is internal modification of the integrated syllable by differentiation of its gestural components.

From gestures to phonemes: integration

The final step in the path from mouth sounds to segments is the integration of gestural patterns of syllabic constriction and opening into the coherent perceptuomotor structures we know as consonants and vowels (Studdert-Kennedy, 1987). As we have seen, the status of the segment is problematic. For, on the one hand, we can neither specify the invariant articulatory-acoustic properties shared by all instances of a particular consonant or vowel, nor isolate any given segment as a discrete articulatory-acoustic entity within a syllable. On the other hand, across-word metathetic errors in speaking typically entail exchanges between consonants and vowels that occupy corresponding slots in their respective syllables. Since the exchanging elements may be physically quite disparate, it is evident that their exchange is premised on shared function (onset, nucleus, coda) in the formation of a syllable. There are therefore two aspects to the emergence of phonemes as elements of word formation in a child's lexicon. First is the grouping of all instances of a particular gesture-sound pattern into a single class (e.g., grouping the initial or final patterns of dad, dog, bed, etc. into the class /d/). Second is the grouping of these gesture-sound patterns into higher-order classes (consonants, vowels) on the basis of their syllabic functions.

Two possible selection pressures may precipitate formation of these classes. One pressure is toward economy of storage as the lexicon increases in size. We have seen that a child may accumulate an appreciable lexicon of some 750 words without showing signs of independent segmental control (Davis and MacNeilage, in press). But this lexicon is roughly one hundredth of the size that it will eventually become, and it seems reasonable to suppose that, as the lexicon increases, words should organize themselves on the basis of their shared gestural and sound properties. Recurrent patterns of laryngeal and supralaryngeal gesture would thus form themselves into unitary classes of potential utility for recognition and activation of lexical items (cf. Lindblom, 1988; Lindblom, MacNeilage and Studdert-Kennedy, 1983).

A second possible selection pressure is toward rapid lexical access in the formation of multi-word utterances. Several authors (e.g., Branigan, 1979; Donahue, 1986) have argued that the form of early multi-word combinations may be constrained by the child's limited ability to organize and execute the required articulatory sequences. One such constraint might be a child's inability to produce two successive words with different initial places of articulation. Donahue (1986), for example, describes two strategies adopted by her son in his first two-word utterances. One strategy was to attempt only those words that conformed to his preexisting rule of labial harmony: big book, big bird, big ball were all attempted, but big dog and big cooky were "adamantly refused" (p.215). The second strategy was to circumvent the consonant harmony rule by adopting vocalic words lacking consonants (e.g., where [ejʌ], want [wa]) as pivots that could be comfortably combined with many of the words already in his vocabulary. Such findings imply that the integration of gestures into independent phonemic control structures, or articulatory routines (Menn, 1983), may serve to insulate them from articulatory competition with incompatible gestures, and so facilitate their rapid, successive activation in multi-word utterances.

Finally, I should note that we have no reason to believe that this, or any earlier step in development, affects the child's entire speech repertoire at the same time. We have already seen that a child may be producing variegated, and even reduplicated, babble during the same period that it is producing a substantial number of words. We should also note that, although we may reasonably expect to see the same developmental progressions in different children, we should not expect to see all children develop at the same rate. Individual differences in style and rate of phonological development have become a commonplace of the field (e.g., Ferguson, 1979; Studdert-Kennedy, 1986; Vihman, Ferguson and Elbert, 1986). Children may vary widely not only in when their lexicon begins to take on segmental structure, but in when they first give evidence of that structure in speech errors.

Doubtless, many parents have anecdotal evidence of their young children's errors, but the only systematic data known to me come from Jeri Jaeger (personal communication). She reports her daughter's first across-word metathesis as occurring in her 27th month: <u>ummy takes</u> for <u>tummy aches</u>. This was followed in her 30th month by <u>fritty pace</u> for <u>pretty face</u>, <u>sea tet</u> for <u>tea set</u>, and <u>Bernie and Ert</u> for <u>Ernie and Bert</u>. Jaeger did not report data on the size of her daughter's lexicon at this time, nor on the complexity of her multi-word utterances. But the collection of errors suggests that both were well advanced. Further systematic diary data of this kind should throw light on the conditions under which phonemic structure emerges.

CONCLUSION

I have sketched the outline of a behavioral "embryology" of phonological development. The outline extends the principles of differentiation and integration observed in fetal growth to the postnatal development of behavior, and of its presumed neural substrate. Such an approach offers a way of accommodating both the enormous individual variability in developmental paths and the striking uniformity of outcome. This apparent paradox fits comfortably into a view of development as an epigenetic process, in which diverse environmental pressures combine with constraints from already established patterns of behavior, to guide the child toward a stable adult state.

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References

Bauer, H. (in press). The ethologic model of phonetic development: I. Phonetic contrast estimators. Clinical Linguistics and Phonetics.

Benedict, H. (1979). Early lexical development: comprehension and production. Journal of Child Language, 6, 183-200.

Best, C. T., McRoberts, G. W., and Sithole, N. W. (1988). Examination of perceptual reorganization for nonnative speech contrasts: Zulu click discrimination by English-speaking adults and infants. Journal of Experimental Psychology: Human Perception and Performance, 14, 345-360.

Branigan, G. (1979). Some reasons why successive single word utterances are not. Journal of Child Language, 6, 411-421.

Davis, B. L. and MacNeilage, P. F. (in press). Acquisition of correct vowel production: A quantitative case study. Journal of Speech and Hearing Research.

DeCasper, A. J. and Fifer, W. P. (1980). Of human bonding: Newborns prefer their mothers' voices. Science, 208,1174-1176.

DeCasper, A. J. and Spence, M. J. (1986). Prenatal maternal speech influences newborns' perception of speech sounds. Infant Behavior and Development, 9, 133-150.

Donahue, M. (1986). Phonological constraints on the emergence of two-word utterances. Journal of Child Language, 13, 209-218.

Ferguson, C. A. (1979). Phonology as an individual access system: Some data from language acquisition. In C. J. Fillmore, D. Kempler and W.S-Y. Wang (eds.), Individual Differences in Language Ability and Language Behavior. New York: Academic Press, pp. 189-201.

Hinde, R. A. (1970). Animal Behavior. New York: McGraw Hill.

Hirsh-Pasek, K., Kemler Nelson, D. G., Jusczyk, P. W., Cassidy, K. W., Druss, B., and Kennedy, L. (1987). Clauses are perceptual units for young infants. Cognition, 26, 269-286.

Holmgren, K., Lindblom, B., Aurelius, G., Jalling, B. and Zetterstrom, R. (1986). On the phonetics of infant vocalization. In B. Lindblom, and R. Zetterström (eds.) op. cit., pp. 51-63.

Klima, E. S. and Bellugi, U. (1979). The Signs of Language. Cambridge, MA: Harvard University Press.

Kluender, K. R., Diehl, R. L., and Killeen, P. R. (1987). Japanese quail can learn phonetic categories. Science, 237, 1195-1197.

Koopmans-van Beinum, F. J., and Van der Stelt, J. M. (1986). Early Stages in the Development of Speech Movements. In B. Lindblom, and R. Zetterström (eds.) op. cit., pp. 37-50.

Kuhl, P. K. and Meltzoff, A. N. (1982). The bimodal perception of speech in infancy. Science, 218, 1138-1141.

Kuhl, P. K. (1987). Perception of speech and sound in early infancy. In P. Salapatek (ed.), Handbook of Infant Perception, Vol. 2. New York: Academic Press.

Lindblom, B. (1988): Some remarks on the origin of the "phonetic code". In C. von Euler (ed.) Brain and Reading. Basingstoke, England: MacMillan.

Lindblom, B. and Zetterstrom, R. (eds.). (1986). Precursors of Early Speech. Basingstoke, England: MacMillan.

Lindblom, B., MacNeilage, P., and M. Studdert-Kennedy. (1983). Self-organizing processes and the explanation of language universals. In B. Butterworth, B. Comrie, and O. Dahl (eds.), Explanations for Language Universals. The Hague: Mouton, pp. 181-203.

Locke, J. (1983). Phonological Acquisition and Change. New York: Academic Press.

Locke, J. and Pearson, D. M. (1988). Linguistic significance of babbling: Evidence from a tracheostomized infant. Report from the Neurolinguistics Laboratory at Massachusetts General Hospital (Whole issue).

Macken, M. A. (1979). Developmental reorganization of phonology: A hierarchy of basic units of organization. Lingua, 49, 11-49.

MacNeilage, P. F. and Davis, B. L. (in press). Acquisition of speech production: Frames, then content. In M. Jeannerod (ed.), Attention and Performance, XIII: Motor Representation and Control.

Maudsley, H. (1867). The Physiology and Pathology of the Mind. New York: Appleton. (Reprinted in Significant Contributions to the History of Psychology, Series C: Medical Psychology, Vol. IV. Washington, DC: University Publications of America, 1977).

Mayr, E. (1982). The Growth of Biological Thought. Cambridge, MA: The Belknap Press.

Mehler, J., Jusczyk, P., Lambertz, G., Halstead, N., Bertoncini, J., and Amiel-Tison, C. (1988). A precursor of language in young children. Cognition, 29, 143-178.

Meltzoff, A. N. (1986). Imitation, intermodal representation, and the origins of mind. In B. Lindblom, and R. Zetterström (eds.) op. cit., pp. 245-265.

Menn, L. (1983). Development of articulatory, phonetic and phonological capabilities. In B. Butterworth (ed.). Language Production, Vol. II. London: Academic Press.

Molfese, D. L. and Betz, J. C. (1988). Electrophysiological indices of the early development of lateralization for language and cognition, and their implications for predicting later development. In D. H. Molfese, and S. J. Segalowitz (eds.), Brain Lateralization in Children. New York: The Guilford Press, pp. 171-190.

Neville, H. (1985). Effects of early sensory and language experience on the development of the human brain. In J. Mehler, and R. Fox (eds.), Neonate Cognition. Hillsdale, N.J., pp. 349-363.

Neville, H. J. (in press). Whence the specialization of the language hemisphere? In I. G. Mattingly and M. Studdert-Kennedy (eds.), Modularity and the Motor Theory of Speech Perception. Hillsdale, N. J.: Lawrence Erlbaum Associates.

Newport, E. L. and Meier, R. P. (1985). The acquisition of American Sign Language. In D. I. Slobin (ed.), The Cross-Linguistic Study of Language Acquisition, Volume I: The Data. Hillsdale, N.J.: Lawrence Erlbaum Associates, pp. 881-938.

Oller, D. K., Wieman, L. A., Doyle, W., and Ross, C. (1975). Infant babbling and speech. Journal of Child Language, 3, 1-11.

Oller, D. K. (1980). The emergence of the sounds of speech in infancy. In G. Yeni-Komshian, J. F. Kavanagh, and C. A. Ferguson (eds.). Child Phonology, Volume 1: Production. New York: Academic Press, 93-112.

Oller, D. K., Eilers, R. E., Bull, D. H. and A. E. Carney. (1985). Prespeech vocalizations of a deaf infant: A comparison with normal metaphonological development. Journal of Speech and Hearing Research, 28, 47-63.

Oller, D. K. (1986). Metaphonology and infant vocalizations. In B. Lindblom, and R. Zetterström (eds.) op. cit., pp. 21-35.

Poizner, H., Klima, E. S. and U. Bellugi. (1986). What the Hands Reveal About the Brain. Cambridge, MA: MIT Press.

Stark, R. E. (1986). Prespeech segmental feature development. In P. Fletcher, and M. Garman (eds.), Language Acquisition (second edition). New York: Cambridge University Press, pp. 149-173.

Studdert-Kennedy, M. (1986). Sources of variability in early speech development. In J. S. Perkell and D. H. Klatt (eds.), Invariance and Variability of Speech Processes. Hillsdale, N.J.: Lawrence Erlbaum Associates, pp. 58-76.

Studdert-Kennedy, M. (1987). The phoneme as a perceptuomotor structure. In A. Allport, D. MacKay, W. Prinz and E. Scheerer (eds.), Language Perception and Production. London: Academic Press, pp. 67-84.

Thelen, E. (1981). Rhythmical behavior in infancy: An ethological perspective. Developmental Psychology, 17, 237-257.

Vihman, M. M., Macken, M. A., Miller, R., Simmons, H., and Miller, J. (1985). From babbling to speech: A reassessment of the continuity issue. Language, 61, 397-445.

Vihman, M. M., Ferguson, C. A., and Elbert, M. (1986). Phonological development from babbling to speech: Common tendencies and individual differences. Applied Psycholinguistics, 7, 3-40.

Werker, J. F., and 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.