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THE BEGINNINGS OF SPEECH

MICHAEL STUDDERT-KENNEDY

Man's life is diverse. The range of habitats, natural and man-made, to which he has adapted is incomparably wider than that of any other species. This is so because man evolved capacities for rapid cultural evolution to augment the lengthier biological processes of adaptive radiation. These capacities have permitted him to create new and unpredictable patterns of behavior in the face of both old and new contingencies. The nature of these capacities is unknown. But we can be sure that language is among them, and that an understanding of its biology would take us a long way toward understanding the history of man and the earth during the past 10,000 years.

Unfortunately, "the development of human speech represents a quantum jump in evolution comparable to the assembly of the eucaryotic cell" (Wilson 1975:556). Whatever the lost links in phyletic evolution since the first hominids diverged from the apes, presently living species offer few analogies and even fewer homologies with language. In fact, the most fruitful approaches to its biology seem to be those that have been followed for many years by developmental psycholinguists (for reviews, see Brown 1973; Dale 1976; Ferguson & Slobin 1973) and by students of neurophysiology (e.g., Lenneberg 1967; Lenneberg & Lenneberg 1975; Whitaker & Whitaker 1976): first, study of its ontogeny, with particular attention to similarities within and across language communities; second, study of its pathology in childhood and adult aphasia.

The present chapter makes no attempt to review the vast resulting literature. Instead it undertakes to examine critically several tempting analogies with language in the great apes and in the song learning of oscine birds. Analogies often have the heuristic value of leading us to look at familiar facts from a fresh viewpoint. Moreover, they may be instructive even if they prove to be false.

THE NATURE OF LANGUAGE

If we compare language with other animal communication systems, it is by its breadth of function that we are struck. The flashing white rump of the fallow deer denotes alarm; the "peep" of the squirrel monkey indicates that it is alone and wishes it wasn't; the song of the chaffinch informs the interested listener of its species, sex, local origin, personal identity, and readiness to breed or fight.

Even the elaborate dance of the honeybee merely conveys information about the direction, distance, and quality of a nectar trove. But language can convey information about all these matters and many more besides. In fact, it is the peculiar property of language to set no limits on the possible topics of discourse.

More exactly, no language consists of a finite number of sentences. This fact may be demonstrated by formal proof (Chomsky 1956) or by the persuasive calculation that a single rendering of all grammatical English sentences of up to, say, 20 words in length would last several hundred years (Miller et al. 1960:146). In fact, no normal speaker of a language - no matter how limited his vocabulary or tedious his conversation - speaks by rote or constructs an utterance by drawing its components from a store of ready-made phrases.

How does language achieve this openness or productivity? There are several crucial features to its design (Hockett 1960). First, language is learned; it develops under the control of an open rather than a closed genetic program (Mayr 1974). Transmission of the code from one generation to the next is therefore discontinuous; each individual re-creates the system for himself. There is ample room here for creative error - probably a central factor in the evolution of language and in the constant process of change that all languages undergo (Kiparsky 1968). One incidental consequence is that the universal properties of language (whatever they may be) are largely masked by the surface variety of the several thousand languages now spoken in the world, not to mention their thousands of dialects and idiolects.

A second condition of productivity is that linguistic signals are arbitrary. With a few onomatopoeic exceptions, only by coincidence does a sign share any property with its referent. Of course, many other animal signals are arbitrary: the courtship rituals of the great-crested grebe, the abdomen of the egg-laden stickleback, the blush of a shamed human. But under the surface of such instances, some unknown physiological necessity is at work. These are not the arbitrary signs of convention by which *bird*, *oiseau*, *Vogel*, and *uccello* are equivalent. Notice that if signs were iconic rather than arbitrary, the number of possible referents would be limited by the signaling organism's physical capacity to represent or depict.

A third, closely related condition of productivity is that signals are discrete rather than analog (Marler 1963). To be precise, signals are perceived as discrete, even if they are not physically separable. Here again, if signals were not categorized by the receiver and if changes of meaning required changes of degree along some continuous scale, the number of possible signals would be limited by the number of possibly and perceptibly variable dimensions of the signal.

A final condition of productivity, and the one to which we will give most attention, is that language has two hierarchically related levels of structure: Its signal elements are combined according to two more or less independent systems of rules. At the lower level of each language, that of phonology or sound system, a small set (usually between 20 and 60) of meaningless phonemes (consonants and vowels) is specified, together with rules for their combination into morphemes (meaningful units that, for present purposes, we may treat as roughly equivalent to words). These are the rules that permit a vast, if not

infinite, lexicon to be constructed by permutation and combination of a few dozen alphabetic units.

At a second level of structure, that of syntax, the rules for combining words into meaningful sentences are specified. These are the rules that permit us to predicate relations among objects or events. Central to the syntax of every language are recursive rules by which a sentence may be treated as a component in another sentence. This capacity to embed a sentence within a sentence means that the set of all possible sentences in a language is infinite (Chomsky 1956). Moreover, it is through this device that we can extend our communicative reach by constructing complex sentential names for referents not represented in our lexicon, a trick already in the armory of many 3-year-olds: "I want the one Mary's got" (Limber 1973). Incidentally, it is this central, inventive (though commonplace) use of language that Premack (1976:15) thinks it "absurd" to expect of the chimpanzee.

IMPLICATIONS OF DUAL STRUCTURE

We begin to apprehend the importance of a dual structure if we imagine a language with only one level, say that of sound (cf. Liberman & Studdert-Kennedy 1978). Such a language would consist of meaningless elements (perhaps consonants and vowels) combined into lexical items, a set of words each with a different referent. Its users would presumably be confined to ostensive definition. For even if they were able to conceive of absent objects ("the bear we met yesterday") or abstract ideas ("the solar year") and were able to construct, from their phonetic resources, new lexical items to refer to them, they would be quite unable, lacking discursive speech, to establish the new meanings with their fellows. It is only by means of syntax that we are able to deploy old (known) words into new (previously unknown) statements – such as those that define new words. In short, rules for syntactic structure are a sine qua non of linguistic productivity.

The lack of a sound structure, on the other hand, would be less crippling. For even if we were to replace every word in the lexicon with an arbitrary number (as might be done if the lexicon were stored in a computer), the syntactic structure of any particular utterance would be preserved despite the total loss of phonetic equivalences. (It is for this reason that linguists sometimes describe a language as an abstract system of communication, independent of its medium of expression.) Each lexical item would then be a totally distinct sign, lacking any systematic physical relation to any other. Of course, the number of such irreducible, holistically distinct signals that humans are capable of recalling, producing, and identifying at even a moderate rate – let alone the 50 bits per second typical of much speech – is certainly small, and it is not surprising that most vertebrate communication systems dispose of no more than 10 to 40 signals (Wilson 1975:183). However, a small lexicon does not preclude a productive syntax. That is why Premack (1976) and Rumbaugh (1977) saw no need for a formational structure in the visual symbols they devised for their pongid pupils.

Nonetheless, having granted that phonological (or word formational) structure is not, in principle, necessary for productive language, we must next

acknowledge that every known language does, in fact, display it. The extra level of sound structure - which perhaps was prior to syntax in phyletic evolution, as it is in ontogeny - must therefore fulfill some function.

That function, as we have already suggested, is to facilitate the formation of a lexicon. Whether or not the lexical, or naming, function is at the root of language, as is sometimes argued (e.g., Lancaster 1968), most linguistic communities do have - in addition to their everyday lexicon of several thousand words - large, more or less specialized vocabularies, crucial to their cultural elaboration of the environment. This is as true of "primitive" peoples, such as the Hanunoo of the Philippines with their vast inventories of flora and fauna (Levi-Strauss 1968), as of a modern industrial society with its proliferation of technical terms and subculture jargon. Thus, the seemingly trivial discovery that an essentially unlimited lexicon could be constructed from a small alphabet of sounds may have been the catalyst that set linguistic development in motion by providing an interface between man's intellect and his peripheral anatomic structure (Liberman 1970; Mattingly 1975). Certainly, it is at the level of the signaling system (that is, of speech), rather than of the abstract syntactic and semantic structure, that we find the clearest traces of biological adaptation, and it is therefore primarily with speech that the following sections are concerned.

THE SIGNALING SYSTEM

The sounds of any language can be viewed as the product of a sound source and a resonant filter. The sound source is usually either the voice produced by rapid pulsing of the vocal cords (as in the final sounds of *be* and *do*), the hiss of air blown through a narrow constriction (as in the initial and final sounds of *safe* and *thrush*), or both (as in the final sounds of *leave* and *bees*). The resonant filter is the vocal tract, that is, the cavities of the pharynx, mouth, and nose.

The pulsing of the vocal cords at fundamental frequencies of roughly 90 to 250 Hz for males, 150 to 350 Hz for females, and somewhat higher for small children yields a signal rich in harmonic frequencies (multiples of the fundamental). Relatively slow variations in fundamental frequency over the course of an utterance yield the characteristic melody or intonation of speech. Taken with systematic variations in intensity, rate, and rhythm, this melody is the basis of speech prosody and plays an important role in communicating the emotional tone of an utterance as well as, to some extent, its syntactic structure (e.g., question, statement, imperative). To the unfamiliar listener (whether infant or foreigner), the slow variations of prosody are probably more salient than the rapid patter of consonant-vowel syllables. But it is primarily by syllables that the distinctively linguistic (lexical and syntactic) information is carried. That, incidentally, is why writing systems encode phonetic segments, but not prosody.

For the most part, this distinctively linguistic information is conveyed by systematic variations in the tuning of the vocal tract. The curved column of air in the tract, like that in an alpine horn, resonates in characteristic frequency bands (or formants) when set in motion by air from some vibrating source, with the result that some of the source frequency components are amplified whereas

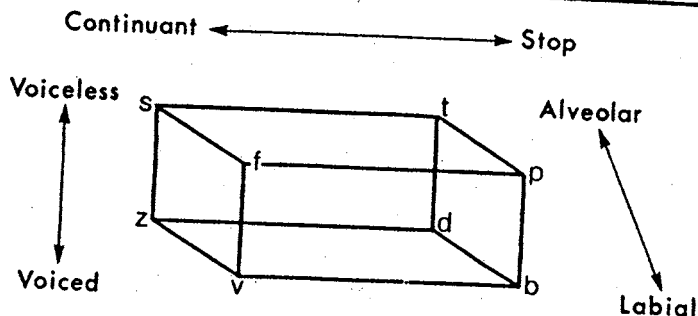


Figure 21.1. A three-dimensional binary feature space, excerpted from the multidimensional feature space that describes the English phonological system.

others are attenuated. If we vary the size and shape of the resonating tract by shifting the relative positions of the articulators, especially the tongue, lips, jaw, and soft palate, the resulting shifts in the formants yield the various sound spectra characteristic of particular phonetic segments. The reader may find it instructive to monitor the position and shape of his tongue as he runs it around the vowel triangle: *eat, it, et, at, aht, ought, oot*.

THE SOUND PATTERN OF LANGUAGE

Here we must introduce the concept of a sound system or phonology. Each language forms its words from a relatively small alphabet of distinctive phonetic segments, termed *phonemes*. These are its consonants and vowels, and in English there are about 35 of them, depending on dialect. The phonemes are not chosen randomly. Each may be described in terms of the small set of binary features (usually a dozen or so) deployed in a particular language. The phonemes may then be classified according to their shared features and the resulting classes contrasted to one another on the basis of their feature oppositions. A basic division, observed in every language, is between consonants, formed by a more or less complete constriction of the vocal tract, and vowels, formed with a relatively open tract. From their contrastive combination is formed the fundamental unit of all spoken language, the consonant-vowel syllable. It is the repeated opening and closing of the tract and the consequent repetitive frequency and amplitude modulation, or syllabic beat, that establishes the characteristic rhythms of human speech.

We may draw further contrasts among the phonemes (Fig. 21.1). For example, in English we may draw contrasts between voiced (*/b, d, v, z/*) and voiceless (*/p, t, f, s/*), between continuant (*/s, f, z, v/*) and stop (*/t, p, d, b/*), between constriction at the alveolar ridge behind the upper front teeth (*/s, z, t, d/*) and constriction at the lips (*/f, v, p, b/*). Taken together, these eight phonemes, formed from three binary contrasts, constitute a little system within the large system of English phonology.

The particular selection of features used in any language is largely determined by phonetic drift over time and by a complex of historical and social

forces. But the universal stock of phonetic features is presumably constrained by human anatomy and physiology: They must be drawn from the (as yet unspecified) intersection of what we can articulate with what we can perceive. The goal of much work (e.g., Chomsky & Halle 1968; Jakobson et al. 1963; Ladefoged 1971) has been to define the smallest set of universal features (perhaps fewer than 20) that will include all features that may be distinctive in any language.

But there is more to the phonology of a language than the structure of its phonemic system. Each language also disposes of more or less elaborate rules for combining phonemes into words: These are the rules of its syllable structure. For example, in English the basic syllable structure can be represented as (C) (C) (C) V (C) (C) (C) (C), where C = consonant, V = vowel, and parentheses indicate that the slot may or may not be filled. Thus, the simplest syllable is an isolated vowel. But in most syllables the required vowel is preceded by up to three consonants and followed by up to five consonants (the latter only in a few rare words such as *triumph'st*; Abercrombie 1967).

Moreover, there are strict limits on the permissible consonant clusters. For example, in English, if two obstruents (stops or fricatives) occur together, the voicing of the second must match the voicing of the first. Accordingly, English words may begin with *sp-*, *st-*, or *sk-*, but not with *sb-*, *sd-*, or *sg-*. Hence, too, the plurals in *-s* or *-z* (*apes*, *lions*), the present indicatives in *-s* or *-z* (*she raps*, *she loves*), and the past in *-t* or *-d* (*rapped*, *loved*). A subsidiary rule states that, if the two obstruents are formed by closure at roughly the same point in the vocal tract, a neutral vowel (the so-called schwa) must be inserted between them, giving the plural, *roses*, the present indicative, *she kisses*, and the past, *she hated*. Most normal children growing up among English speakers have unconsciously learned these rules by the age of about 6 and therefore have no difficulty in forming the correct plural, present, and past forms of words they have never heard before (Berko 1958).

The point of this example is to make it clear that much more is required to learn the sound structure of a language than the capacity to listen and to imitate. In fact, as we shall see ("The infant as pattern seeker"), even within its first year of life, the infant has begun to discover and apply rules.

THE FUNCTION OF PHONETIC FEATURES

We have defined features up to this point in articulatory terms. In part, this is because precise acoustic description, drawing on spectrographic analysis, has proved intractable. But it is principally because articulation is, in fact, prior to the acoustic signal. Indeed, it has been plausibly argued that the feature structure of spoken language was primarily a solution to the problem of getting high-speed articulatory performance out of low-speed articulatory machinery (Lieberman et al. 1967). The feature structure permits a shift from one phoneme to the next by a change of no more than one or a few articulatory features. The value of articulatory ease is attested to by the universal phenomenon of assimilation. Every language has many rules by which certain sounds or classes of sounds take on features of neighboring sounds, permitting a lazier and so more rapid articulation. For example, the final *n* of the prefix *syn-* (*synthesis*,

synechdoche) becomes *m* in *symbiosis* and *sympathy*, taking on the labial articulation of the following consonant. Similarly, normally voiced *l*, sounded with laryngeal pulsing in *light*, takes on the voiceless feature of *s* in a word such as *slight*.

Of course, a gain for the speaker may be a loss for the listener. It is precisely such shifts in articulation and the consequent subtle shingling of the acoustic properties of neighboring phonemes that have thwarted attempts at automatic speech recognition and given rise to the central problems for a theory of speech perception. Parallel (or co-) articulation of consonant and vowel in the integral ballistic gesture of the syllable (Stetson 1952) gives rise to an acoustic signal in which the cues to a particular phoneme vary widely as a function of context and in which the boundaries between successive phonemes are obliterated. The tempting model that language might have been expected to offer for the division of motor behavior into natural units is thus a mirage. The units are not to be found either in the articulation or in the acoustic signal. The problem of segmentation appears to be solved by perceptual fiat. Not surprisingly, this has encouraged theorists of speech perception to invoke exotic perceptual mechanisms such as analysis-by-synthesis (Stevens & Halle 1967; cf. Liberman et al. 1967) and "dedicated" property or feature-detecting devices (see "Templates and feature detectors").

Perhaps specialized perceptual mechanisms have indeed evolved to match the specialized motor mechanisms. There is strong evidence in vocal tract morphology, in tongue and lip innervation, in mechanisms for breath control during speech, and so on, that extensive adaptations for speech did occur (Du Brul 1977; Lenneberg 1967; Lieberman 1972). Perhaps these and matching perceptual adaptations (including specialized sensorimotor processes for imitation) underlie the evolution of language. However, once the capacity for language had evolved, man was able to deploy it in another mode. What is interesting is that, when he does so, as in American Sign Language, the formal structure of the system remains largely unchanged.

AN ALTERNATIVE SIGNALING SYSTEM: MANUAL SIGN LANGUAGE

Visual and tactile finger-spelling, like alphabetic and syllabic writing, are parasitic on speech: They simply transpose its units into another modality. However, some visual languages are independent of spoken language: for example, the sign languages of the American Plains Indians (West 1960), of the Australian aborigines (Umiker-Sebeok & Sebeok 1977), and of countless deaf communities in the various countries of the world (Stokoe 1974). The signs of these languages do not necessarily correspond to the words of any particular spoken language, nor do the rules for their combination follow the syntax of any spoken language.

Consider, as an example, because it has been the most extensively studied, American Sign Language (ASL). ASL is a derivative of the French sign language (SL) introduced by Gallaudet to the United States in 1817. Users of Ameslan today understand French SL better than British SL - evidence for the independence of sign and spoken languages. The first dictionary of ASL (Stokoe et al. 1965) contains over 2,000 signs. Many of them seem iconic, but

usually not until one knows what they mean – just as one may not recognize the metaphor in, say, “The road *runs* west” until it is pointed out. Other signs are indexical; pronouns, for example, are often formed by pointing. However, pantomime is rare. The overwhelming majority of signs is arbitrary or, if once iconic, has now lost much of the iconicity (Frishberg 1975).

Signs may require the use of one or two hands and may vary along at least three orthogonal dimensions: shape, position within the signing area (a rough circle around the head and chest, centered below the chin), and movement. Stokoe et al. (1965) have analyzed the values along these dimensions into some 55 *cheremes*, a number well within the phonemic count of spoken languages. Later work (e.g., Battison 1974; Klima & Bellugi 1979; Lane et al. 1976) has demonstrated that formational rules govern the possible combinations of cheremes into signs, just as the phonological rules of a language govern the combination of phonemes into words. Finally, ASL has a grammar with various inflections and a syntax, that is, a set of rules governing the spatial and temporal ordering of signs into sentences (Klima & Bellugi 1979; Siple 1978). In short, ASL displays all the distinctive properties of a human language, including a dual pattern of shape and syntax.

The significance of this recent work on ASL is twofold. First, it underlines the link between hand and mouth and the likely importance of a rapid, informationally dense signaling system for efficient linguistic communication, a point to which we return below. Second, it demonstrates the abstractness of the capacities underlying language development. So far as we know, no other animal has developed a capacity for essentially equivalent communication in two different sensorimotor systems.

THE GREAT APES

Recent successes in training apes to communicate by means of artificial symbol systems (Premack 1976; Rumbaugh 1977) or a natural sign language (Ameslan) (Gardner & Gardner 1969, 1975; Patterson 1978; Terrace et al. 1976a, 1976b) have shown that the cognitive, representational, and perhaps even linguistic capacities of chimpanzees and gorillas, though vastly inferior, are nonetheless much closer to those of man than was once thought. Given the close genetic relation between man and chimpanzee (King & Wilson 1975) and their very different ecologies, one may wonder whether these apparently similar behavioral capacities in man and ape may not be homologous capacities derived by genetic transmission from a common ancestor.

Unfortunately, the degree of similarity and its evolutionary implications are difficult to assess because none of the supposedly linguistic behaviors of the apes seems to occur naturally. All have required intervention by animals of another species in the form of systematic operant conditioning. This is particularly striking in the work of Premack (1976) and Rumbaugh (1977), in which chains of behavior are established by direct shaping and primary reinforcement of hundreds of responses with food, drink, bodily contact, and so on. For the signing chimpanzees, such as Washoe (Gardner & Gardner, 1975) and Nim (Terrace et al. 1976a, 1976b), the social reward of trainer approval is more usual. Nonetheless, even here the fundamental training

procedure has been operant shaping and molding of specific behaviors. In other words, language learning in the great apes does not proceed without the establishment of stimulus-response contingencies.

By contrast, the human infant apparently has a disposition to learn language even in the absence of specific response shaping and reinforcement. Although it too may require the generalized social reinforcement of a partner's attention, the infant does not require shaping and reinforcement of particular responses. On the contrary, as Brown (1973) has remarked, parents tend to reinforce the truth value but not the form of their children's utterances. In other words, language appears to develop in spite of the absence of stimulus-response contingencies.

Particularly striking in this context is the recent work of Feldman et al. (1977) on the spontaneous development of signing in deaf children. They studied six deaf children, over an age span of 1 year and 5 months through 4 years and 6 months whose parents were following the oralist practice recommended by some authorities in the United States. These authorities believe that signing to congenitally deaf children lowers their motivation to lip-read and articulate English; they therefore urge parents and siblings of such children to avoid all gestures, formal or informal. According to Feldman et al. the families of their six subjects were largely successful in following this practice.

The procedure of the study was to videotape each child playing and passing time with its mother and the experimenter during several standardized home visits. In the course of playing with the toys and games introduced by the experimenter, every child devised its own *home-signs*, that is, a characteristic set of motor-*iconic* gestures to refer to objects, actions, and predicates. Moreover, each child gradually began to combine these signs into two-, three-, and even six-sign sequences, creating its own semantically based syntax, including systematic deletion rules of the kind observed in a normal hearing child's telegraphic speech. This last point is particularly interesting, because telegraphic signing was not produced by the adults conversing with the children any more than is telegraphic speech under normal circumstances. The authors end their lengthy analysis with the conclusion that "there are significant internal dispositions in humans that guide the language acquisition process" (Feldman et al. 1977:132).

There is, of course, no evidence for such dispositions in the ape. This argues that the cognitive capacities now being discovered in the apes are general rather than specifically linguistic. The adaptive functions of these capacities are not always obvious. For example, how does the wild chimpanzee use its capacity to symbolize? Or is this capacity perhaps a *neo-phenotype* (Kuo 1976; Chap. 2), an item of general behavioral plasticity not normally deployed but available for use in the face of the right selective pressures?

Another general capacity, impressively displayed in recent language projects, does have obvious utility, namely, the capacity to learn a new motor response by observation and imitation. This capacity requires that the animal, first, be able to parse perceived behavior into action components and, second, have sensorimotor connections by which the parsed patterns may be mapped into motor commands (cf. Terrace et al. 1976a:21). Field observations attest to

the role of imitation in the young chimpanzee's learning to fish for termites, for example, or to build its nest (van Lawick-Goodall 1971).

Yet a third chimpanzee capacity, essential to linguistic communication, has recently been demonstrated by Premack & Woodruff (1978) - the attributing of intention to the behavior of another organism. Here again, the capacity, whatever its linguistic worth, obviously contributes to the development of social intelligence. In fact, laboratory studies of ape language acquisition probably have more to teach us about the evolutionary origins of mind than of language. Certainly, as Limber (1977) suggests, conversational chimpanzees may offer an experimental approach to the study of relations between language and thought (for example, does naming facilitate problem solving?), but the focus would then be on thought rather than on language. For insight into the origins of language, the frank analogues of bird song may have more to offer than the possible homologues of ape signs.

THE SONGBIRDS

Templates and feature detectors

Unlike observational learning of other motor behavior, vocal learning can have no value beyond its use in communication. The analogous appearance of vocal learning in both man and bird is therefore of special interest (Marler 1970, 1975; Nottebohm 1970, 1975). Indeed, Marler has proposed as "a significant evolutionary step toward... the strategy of speech development of *Homo sapiens*" the emergence of "new sensory mechanisms for processing speech sounds" as well as "neural circuitry... to modify patterns of motor outflow so that sounds generated can be matched to preestablished auditory templates" (Marler 1975:32-33). As we shall see, the evidence for "new sensory mechanisms" or "auditory templates" in humans is weak, but there is good evidence for specialized sensorimotor processes.

Birds and other animals. Species-specific templates were proposed by Marler (1963) and Konishi (1965) to account for the fact that many songbirds learn only the songs of their own species. Even if they are deprived of conspecific song during the sensitive phase and are exposed to the songs of closely related species (e.g., Marler & Peters 1977), they do not learn them.

The form of these templates "lying in the auditory pathway" (Marler 1975:26) has never been specified. However, presumably they could consist of networks of specialized neurons tuned to particular properties of the species's song. Cortical neurons sensitive to changing frequencies were reported for cats ("miaow cells") by Whitfield and Evans (1965). Cells tuned to species calls have been reported for the bullfrog (Capranica 1965; Frishkopf & Goldstein 1963), the squirrel monkey (Wollberg & Newman 1972), several species of echolocating bat (Neuweiler 1977), and the starling (Leppelsack & Vogt 1976).

Humans. A possible analogy between species-specific call or song detectors and phonetically relevant acoustic feature detectors was not lost on students of speech perception (e.g., Abbs & Sussman 1971; Liberman et al. 1967; Studdert-

Kennedy 1974). The feature detector promised to solve at a single blow a variety of problems in speech perception, including that of syllable segmentation. Moreover, the notion of feature with its roots in ethology, linguistics, and pattern recognition was attractive to biologically inclined students of language looking for signs of an innate acquisition device (e.g., Stevens 1975). Unfortunately, the several lines of evidence and speculation seem to have converged on an error.

The story begins with the phenomenon of categorical perception (Liberman et al. 1967; Studdert-Kennedy et al. 1970). Early work with speech synthesizers showed that it was a simple matter to construct acoustic tokens of opponent phonetic types by manipulating a single acoustic variable. For example, by varying the interval between plosive release and the onset of laryngeal pulsing, that is, voice onset time (VOT), one could construct a continuum of, say, a dozen tokens ranging in equal acoustic steps from /ba/ to /pa/ or from /da/ to /ta/.

If listeners were asked to identify these tokens, they showed a strong tendency to call any particular stimulus by the same name (e.g., /ba/) every time they heard it. There were few, if any, ambiguous tokens. Furthermore, if they were asked to discriminate between neighboring pairs of tokens, they tended to do badly if they judged the two tokens to be members of the same phoneme class but well if they judged the tokens to be members of opponent phoneme classes - even though the acoustic interval between pairs was identical in the two cases. This phenomenon, dubbed *categorical perception*, seemed to be a useful process for speech perception. After all, one cannot afford to judge a word to be more or less *bat* or more or less *pat*. One must categorize it instantly as one or the other: Classification is a crucial process in phonetic perception.

The next event in the story was the demonstration by Eimas et al. (1971), using a nonnutritive sucking habituation procedure, that 1- and 4-month-old infants could discriminate between two tokens differing by 20 milliseconds along a voice onset time continuum, providing they were tokens that adults normally classified as different phonemes. But the infants could not discriminate between tokens that adults normally classified as the same phoneme. Similar results for a variety of synthetic speech continua were reported in due course for infants growing up in other language communities (see Eimas 1975 for a review).

The suspicion that these results reflected categorical perception mediated by specially tuned, innate feature detectors was not easy to resist - particularly because the phylogenetic emergence of such detectors might then be the evolutionary step that carried hominids from a graded to a categorical communication system (cf. Marler 1975). The hunt for independent evidence of such detectors operating in human adults began, and by 1973 Eimas and Corbit were able to report success.

They modified a procedure with a long history in visual studies: adaptation. The paradigm is simple enough. For example, prolonged fixation of a red patch of light adapts or fatigues a red detector cell and relatively sensitizes its opponent green detector cell, so that upon looking at a white screen, the viewer sees a relatively unsaturated green patch the same shape as the red adaptor.

Related effects in form and tilt also occur. Such effects have frequently been taken as evidence for the operation of opponent feature detectors.

Eimas and Corbit (1973) asked listeners to categorize members of a synthetic voice onset time continuum and demonstrated that the perceptual boundary between voiced and voiceless categories along that continuum was shifted by repeated exposure to (that is, adaptation with) either of the endpoint stimuli: There was a decrease in the frequency with which stimuli close to the original boundary were assigned to the adapted category and a consequent shift of the boundary toward the adapted stimulus. They took the effect to be evidence for the operation of an opponent feature-detecting system. Several dozen studies over the next 5 years replicated the effect on several other synthetic speech continua (see Ades 1976 for reviews; Cooper 1975; Eimas & Miller 1978).

Thus, the chain of inference and speculation from percept to detector was complete. Unfortunately, each link in the chain has proved weak. First, several studies have shown that categorical perception is not peculiar to speech, or even to audition. For example, Pastore et al. (1977) demonstrated categorical perception of critical flicker, with a sharp boundary at the flicker-fusion threshold. Second, other studies (e.g., Carney et al. 1977) have demonstrated that the degree of categorical perception varies with the experimental method used to measure it: Listeners can be trained to hear a supposedly categorical continuum noncategorically or to shift category boundaries from one point on a VOT continuum to another. Finally, cross-language studies have found that speakers of different languages may place phonetic boundaries at different points along the same acoustic continuum, demonstrating that acoustic-phonetic categories are linguistically rather than physiologically determined (for a review of cross-language studies, see Strange & Jenkins 1978).

The demise of categorical perception as a specialized phonetic process also cuts the other links in the chain. Thus, instances of what appears to be infant categorical perception will doubtless find a straightforward explanation in terms of auditory psychophysics, similar to that developed for the adult case. In fact, Pisoni (1977) has already developed such an explanation for VOT.

By the same token, we no longer need opponent process feature detectors to account for a general psychophysical phenomenon - particularly because there are other reasons for doubting the opponent detector model. Most obvious is the model's lack of behavioral or neurological motivation. For although the facts of additive color mixture and retinal neurophysiology make an opponent detector account of aftereffects entirely plausible, the facts of perceived stop consonant onset and cochlear neurophysiology certainly do not. However, an adequate discussion of speech adaptation is well beyond the scope of this chapter, and it must suffice to remark that plausible accounts of the effects in terms of stimulus range (Rosen 1979), auditory contrast (Simon & Studdert-Kennedy 1978), or other general psychophysical processes (Remez 1979) have already begun to appear.

We must conclude that we now have no evidence for the operation in speech perception of specialized sensory mechanisms analogous to the auditory templates postulated for certain songbirds.

Lateralization and the sensorimotor device

Birds. One of the most remarkable discoveries in recent years is the lateralization of neural function in bird song (Nottebohm 1971, 1972, 1977)—at present, the only securely attested-to instance of lateralized behavior apart from man (although see Dewson 1977 and Petersen et al. 1978). The typical songbird syrinx, as instanced by that of the canary (Nottebohm 1977), has two independently innervated and functionally separate halves. Sections of the right and left halves (or of their innervating hypoglossal branches) have very different effects: right-side sections lead to the loss of no more than 0 to 15% of preoperative song syllables, whereas left-side sections lead to a 90 to 100% loss. Similar effects of peripheral lesion have been observed in the chaffinch and the white-crowned sparrow (Nottebohm 1971, 1972). For the canary, Nottebohm (1977) has also traced motor pathways from the syrinx to the associated brain structures: Unilateral brain lesions indicate that the left hemisphere contributes radically more to song control than does the right.

All these effects are motor, and no perceptual lateralization has been demonstrated. However, it is of interest that the principal motor control center lies next to the telencephalic auditory projection, where processes involved in establishing the species-specific song template are believed to occur. Indeed, it was Nottebohm's (1970) original notion that lateralization might be associated with complex learned behaviors. This view has been thrown into question by the discovery of peripheral lateral equipotentiality in the orange-winged Amazon parrot (Nottebohm 1976), a bird well known for its vocal plasticity, and of left lateralization in the domestic fowl (Youngren et al. 1974), a bird of equally well-known vocal stereotypy. Nonetheless, current research on the canary is attempting to chart links between the two centers, that is, to establish the sensorimotor connection presumably essential to song learning (Nottebohm 1977).

Humans. It has been known for many years that the left cerebral hemisphere contributes more to language function than the right in most normal humans. The bulk of our knowledge comes from studies of aphasia, induced by stroke, tumor, or gunshot wound (e.g., Hécaen & Albert 1978; Jenkins et al. 1975) and, more recently, from studies of split-brain patients, whose cerebral hemispheres have been surgically separated by section of the connecting pathways for relief of epilepsy (e.g., Zaidel 1978a, 1978b). The latter condition permits an investigator to assess the linguistic capacities of each hemisphere independently.

Of particular interest, in light of the bird song findings, is that left hemisphere specialization seems to be primarily for control of the articulatory apparatus and for perceptual analysis of spoken words into their phonetic segments. The human larynx and its associated articulatory structures (tongue, velum, jaw) are bilaterally innervated but unilaterally controlled. Thus, *verbal apraxia*, or aphasic disturbance of articulation, is associated with damage to motor areas of the left hemisphere. As a corollary, the right hemisphere, despite a fair capacity for understanding speech, is essentially (that is, apart from a limited capacity for expletive and nonpropositional utterance) mute. Interest-

ingly, skilled manual movements (Kimura & Archibald 1974) and nonverbal oral movements (Mateer & Kimura 1977) also tend to be impaired in cases of nonfluent aphasia. Moreover, disturbances of sign language in the deaf are associated with left-hemisphere damage (Kimura et al. 1976). From a review of such evidence, Kimura (1976:154) suggests that "the left hemisphere is particularly well adapted, not for symbolic function *per se*, but for the execution of some categories of motor activity which happened to lend themselves readily to communication."

However, more than specialization is involved. Studdert-Kennedy and Shankweiler (1970) concluded, from a study of normal subjects' performance on a test in which competing nonsense syllables were presented simultaneously to left and right ears, that the left hemisphere was specialized for phonological analysis of spoken language. Recent work with split-brain patients has confirmed this conclusion (Zaidel 1978a). The dissociated right hemisphere of such a patient has a sizeable auditory lexicon and a rudimentary syntax sufficient for understanding phrases of up to three or four words in length. However, it is incapable of identifying nonsense syllables or of recognizing that, say, *rose* rhymes with *toes* (Levy 1974). In other words, the right hemisphere is not only mute but is organized by meaning rather than by linguistic structure: Unlike the left hemisphere, it perceives language holistically, seizing meaning from the "auditory contours" of words rather than by phonological analysis. If, as we suggested earlier, the characteristic feature structure of speech sounds derives from articulatory constraints, we should perhaps not be surprised to discover that their perception is linked neurologically to their production.

Direct evidence for a sensorimotor link in the left hemisphere comes from the work of Sussman and MacNeilage (1975). They devised a bizarre tracking task in which a sinusoidal waveform, fed into one ear, could be tracked (i.e., copied) by lateral movements of the tongue, jaw, or hand. The results of the tracking movements, electronically multiplied into the audio-frequency range, were then fed to the opposite ear. In three experiments, Sussman and his colleagues showed that tracking movements made by a speech articulator (tongue, jaw) were more accurate if auditory feedback from the movements came to the right ear (i.e., left hemisphere) rather than to the left ear. There was no ear difference if the tracking movements were made by hand. The authors concluded that the results reflected "a lateralized, speech-related, auditory-sensorimotor integration mechanism" (1975:139).

The ultimate function of such a mechanism is, of course, unknown. However, if anything is to be made of the analogy with bird song, we may speculate that unilateral control is necessary for motor coordination of a bilaterally innervated apparatus (cf. Liberman 1974; Marler 1970). This might be achieved either by assigning execution primarily to one side of the peripheral apparatus and therefore to lateralized control centers in the brain (as seems to be done in the canary) or by assigning to one side of the brain central coordination of a symmetrically innervated peripheral apparatus (as seems to be done in humans). Lateralization of the associated perceptual center would then follow to facilitate sensorimotor learning. In humans, evolution of the sensorimotor mechanism led to the development of a lateralized syntactic

device, itself perhaps motoric in origin and specialized for precise temporal coordination of hierarchically ordered structures. The result is that the left hemisphere "does seem to possess an innate and highly specialized linguistic mechanism whose paradigmatic functions are phonetic and syntactic encoding and analysis" (Zaidel 1978a:196).

Finally, in humans, lateralized control of the vocal apparatus seems to have been laid down on the neural substrate of manual lateralization, already evolved for tool use and/or gestural communication (Levy 1976). Semmes (1968) has provided an account of the association by arguing (from a lengthy series of gunshot lesions) that the left hemisphere is focally organized for fine motor control, the right hemisphere diffusely organized for broader control. More generally, Zaidel (1978b:263) has suggested that "each hemisphere specializes for a different style of information processing," and Levy (1976) proposes that hemispheric specialization may achieve functional dissociation of neurologically incompatible behaviors. But the important point here is not the possible complementary functions of the cerebral hemispheres (Zangwill 1960). Rather it is the notion, developed by Kimura (1976) and touched on in our discussion of manual sign language, that the origin of cerebral lateralization for language is in the control of skilled movement rather than in any higher symbolic processes.

What is puzzling, of course, is that, unlike song lateralization in birds, which has been observed in virtually every individual studied (Nottebohm 1977), human lateral specializations are neither uniform across the population nor perfectly associated. The incidence of right-handedness in the U.S. population is estimated at roughly 89% (Levy 1976) and the incidence of left dominance for language at roughly 95% among the right-handed, 60% among the left-handed (Milner et al. 1964). If such figures prove reliable across the human population, the network of lateralized functions would seem to offer an instance of an *evolutionarily stable strategy* (Maynard Smith & Price 1973:15), a balanced polymorphism that it will be a challenge to explain.

SENSITIVE PHASES

Birds. Many songbirds can learn their species song only if they are exposed to that song during a sensitive phase. The phase may range from as little as 40 days for the white-crowned sparrow, to 10 months for the chaffinch, to as long as 2 years for the Oregon junco. In some birds, such as the white-crowned sparrow or the marsh wren, there may be two distinct phases separated by weeks or even months: an input phase for perceptual learning and an output phase for subsong and learning to sing. In other birds, such as the chaffinch, the two phases may overlap, with elements of subsong appearing before the input phase has ended. Presumably such variations have adaptive value and can be related to the ecologies and life histories of the different species. In fact, Chapter 14 points out that it is precisely the systematic variations in temporal patterns of song learning that validate the concept of a sensitive phase and prove it to be more than a handy descriptive term for a process begun by maturation and ended by song acquisition. Much recent work is therefore aimed at pinning down the ultimate selective pressures (Chap. 20).

However, the proximate mechanisms controlling the onset and offset of sensitive phases are not well understood. Hormone levels are often suggested (e.g., Bateson 1973). Nottebohm (1967) castrated a male chaffinch during its first winter, thus precluding either the learning or the singing of song during its first spring. In its second spring the bird was implanted with a testosterone pellet and proved able to learn two tutor songs, but no more. Nottebohm suggests that "the ability to develop song for the first time is not age-dependent" (1967:278). However, *age* is a cover term for aspects of physical maturity as well as for the mere passage of time. Because castration may have delayed, if not halted, normal maturational processes, the experiment does not rule out physical maturation as the determinant of the onset of song learning. Moreover, because a total of two songs falls within the normal chaffinch repertoire range of 2 to 6 songs (Nottebohm 1967), we might reasonably hypothesize that song learning had ceased when the available neural space was filled (cf. Bateson 1973; Kroodsma in press). The point here is that, as noted in Chapter 14, specialized proximate mechanisms beyond physical maturation and neural preemption may not always be necessary for delimitation of a sensitive period in songbirds.

Humans. Lenneberg (1967:125-187) was the first to postulate a *critical period* for language learning. He was careful to make clear that he was offering no more than an analogy with the critical periods (or sensitive phases) of filial imprinting and song learning in birds. He placed the period roughly between the end of the second year and the beginning of the twelfth. Broadly, his argument is based on (1) the regularity of the time of onset of speech across cultures; (2) the different effects on language of various pathologies, particularly cerebral insult and deafness, as a function of age; in general, the younger the child at the time of the brain injury or the older the time of onset of deafness, the better the prognosis for language development; (3) the commonly observed increased difficulty of learning a foreign language after puberty - at least without appreciable interference from already known languages. Within the critical period, Lenneberg argued, languages are fully learned by mere exposure; after the critical period, they are learned less well and with increasing difficulty - an analogy with song learning in the zebra finch (Immelmann 1969).

Lenneberg attributes onset of the critical period to general maturation of the central nervous system. Cerebral structure (cell density, dendritic arborization) and chemical composition, as well as characteristic brain wave rhythms measured by electroencephalography, have reached roughly 75% of their adult asymptotic values by the age of 2 years. Thus, Lenneberg does not propose, nor is there any evidence for, a specialized onset mechanism analogous to the changes in hormone levels postulated for some birds.

The lateness of the proposed onset is largely a matter of definition. Because Lenneberg regarded syntax as the distinctive property of language, he identified language onset with the first putting together of words. This typically occurs between 18 and 28 months. Moreover, Lenneberg specifically denied the importance of experience during the first 2 years, largely on the grounds that children deafened as late as the end of their second year find it no easier to learn language than do those who have been deaf since birth. However, his evidence

is drawn entirely from informal personal observation, and it seems unlikely that the orderly progression during the first year of life from prespeech oral play through cooing, intonation, and babbling is devoid of functional value. If we take the presence of language-specific structure in infant babble at roughly 8 months (Mehler personal communication) or even the prespeech lip and tongue movements in train with a mother's behavior (Trevvarthen et al. 1976) as evidence that language sensitivity has begun, we may place the onset of the sensitive phase in the second half of the first year or even as early as the second month of life. The factors controlling this onset may still then be, as Lenneberg proposed, a combination of physical maturation and appropriate environmental stimulation.

The difficulty of learning a language after puberty is commonly known. Formal evidence for the likelihood of both grammatical and articulatory defects in a second language learned as an adult comes from Oyama (1973, cited by Krashen 1975). Evidence for even greater defects in a first language learned after puberty has recently come from Genie, a California "wild child" (Curtiss 1977). When discovered at the age of 13.5 years, after nearly 12 years of brutal undernourishment and isolation in a silent back room, Genie had virtually no language. Five years later, she had learned some language by mere exposure without specific training. Interestingly, her capacity for phonetic perception was normal, perhaps because her isolation had not begun until 20 months, when the phonetic groundwork has already been laid and she had begun to speak a few words. But her speech was severely distorted and her syntax deficient - for example, she could not use any *wh*-question words, verbal auxiliaries, or embedded structures. In other words, she learned language far less well than a normal child, as Lenneberg would have predicted.

The factors controlling offset at puberty are not known. Lenneberg proposed a loss of cerebral plasticity due to completed lateralization of function - without, however, offering any suggestion as to why language should be lateralized. His argument was based on clinical evidence of recovery from aphasia as a function of age. The picture has been confused by recent work suggesting that lateralization may be present from birth (Glanville et al. 1977; Molfese et al. 1975) and essentially complete by 5 years - roughly coinciding with the time when first language acquisition is approaching completion (Krashen 1975). But the question of an offset mechanism is important if the concept of a sensitive phase for language learning is to retain validity.

This question is important because we cannot justify the concept of sensitive phase by referring to interspecies differences of the kinds observed in songbirds, or by reference to its onset mechanism, because this appears to correlate with general physical maturation. If, further, its offset mechanism were merely preemption of neural space, as the articulatory, syntactic, and even lexical interference between earlier and later learned languages perhaps suggests, we might be dealing with a general loss of cerebral plasticity and with a process common to other classes of behavior rather than one peculiar to language. In short, the validity of the concept may rest on the demonstration that the offset mechanism is directed specifically at language learning. At present, we have no evidence that this is so.

Finally, we must ask what the function of a sensitive phase for language might be. First, following Immelman (1976:152), we must distinguish between the period during which a behavior can be learned and the period during which it normally is learned. It is on the offset of the former that we might expect selective pressures to bear. If offset were early, roughly contemporaneous with release of offspring into a peer world, the language learned would be that of the parents, and we might reasonably suspect that dialect serves to attract sexual partners from ecologically similar backgrounds. Dialects might then, indeed, be "signs of incipient speciation" (Marler 1963:796; cf. Armstrong 1963:chap. 5). Such a function is unlikely in humans, despite the presumably high correlation between inbreeding and dialect in, say, the highlands of New Guinea or Austria, because many more salient features (such as habitat and body ornament) serve to isolate human breeding populations.

In fact, offset in humans is relatively late, well beyond the point when the child has abandoned the nuclear family for its peers. Accordingly, whether a child learns the dialect of its parents rather than of its peers (as is said of some English upper-class children thrown, by the accidents of war, among lower-class peers), or of its peers rather than of its parents (as do the children of non-English-speaking immigrants to Australia or the United States), may sometimes depend on social rather than directly biological factors. An echo in the behavior of Bewick's wren, which learns the song not of its father but of neighbors in its newly chosen breeding site (Kroodsmma 1974), suggests that social bonding may be among the biological functions of dialects in both bird song and language (see Chap.4).

Whether this function is important enough to account for a sensitive phase in language learning is doubtful. In fact, given the weakness of this function and the lack of any clear evidence for proximate controlling mechanisms directed specifically at language, one may be tempted to conclude that a critical period for human language acquisition is more apparent than real, a mere matter of cerebral maturation in its onset and of neural preemption (or atrophy) in its offset.

THE INFANT AS PATTERN SEEKER

In song birds, both the species-specific template and sensitive phases are adapted to the same end, namely, acquisition of the species song within a few months of birth. The song to be learned is relatively brief and simple. A template ensures that from the varied songs around it, the young bird will learn to recognize (if female) as well as to practice and execute (if male) the song of its own species, whereas a sensitive phase usually confines learning to the weeks before dispersal from the home site and/or to the weeks soon after the bird has settled among its breeding peers. Nonetheless, not all birds that learn to sing have either a template or a sensitive phase. Indeed, certain mimics, such as the North American mockingbird, learn, presumably without a template and even late in life, the songs of species quite unrelated to themselves. Perhaps it is among such generalized, all-purpose song learners that we should look for an analogy with the human infant.

In any event, far from being constrained to learn the sound pattern of its

language within a few months of birth, the human newborn has before it some 2 years of infancy. Moreover, what it must learn is not merely to imitate the sounds of the speakers around it – important though this undoubtedly is – but also to perceive and deploy their characteristic sound system. Rather than narrowly defined templates, we might therefore expect the infant – and its caretakers – to have evolved broad behavioral programs that will encourage vocal interchange and facilitate discovery of the spoken pattern. The general process seems, in fact, to be one of gradual differentiation: sound from silence, voice from sound, mother's voice from stranger's, intonation from monotone, syllabic beat from intonated melody, consonant from vowel, perhaps feature from phoneme.

One-day-old infants will suck a pacifier to turn on music and soon begin to prefer voices to music (Friedlander 1970). Indeed, within a few days of birth, they have learned to turn toward a voice, twisting the mouth as if in expectation of a nipple and crying when none is there (Alegria & Noirot 1977). By 20 to 30 days the infant has learned to recognize its mother's voice, as she reads from behind a screen, and will suck more rapidly for her voice than for a stranger's (Mills & Melhuish 1974) – provided she speaks with her customary intonation rather than reads backward from a text (Mehler et al. 1978).

From around the second month, the infant becomes accessible to "conversations" with its mother, watching her eyes (humans are the only animals with permanently visible whites to their eyes, contrasting to the iris), smiling, moving its lips and tongue in apparent imitation of the mother (*prespeech*), and gurgling (Trevarthen et al. 1975). With the child's discovery that events in the external world – particularly the vocalizations, touches, and gestures of its mother – may be contingent on its own behavior, the way is opened for games (e.g., peekaboo), rhythmic interactions, cooing, and laughter (Papousek & Papousek 1975; Watson 1979). The very precise temporal patterning of mother-infant interaction, with its alternating vocalizations, pauses, exaggerated facial displays, and so on, lays the groundwork for later social interchange (Stern et al. 1975). Freedle and Lewis (1977) find that vocalization occupies a special place in early mother-infant interaction: It is more likely to accompany playing, looking, holding, or touching than changing, feeding, or rocking. Moreover, vocalization by one partner is the most likely behavior to follow vocalization by the other, leading to the conclusion that "vocalization is the central behavior which maintains interaction" (Freedle & Lewis 1977:160). However, this interactive pattern is not specific to the vocal modality: For deaf children growing up as signers, signing occupies the privileged position (Feldman et al. 1977). From this we may conclude that mother-infant interaction is broadly adapted to the development, not simply of speech, but of any communicatively viable signaling system. This, in turn, suggests that the infant's discovery of speech may be guided more by the pattern of input from its environment than by the triggering of tuned detectors.

Of interest here is the nature of the mother's vocalizations, that is, of what has come to be called *baby talk* (BT), the style of speech used by adults, and even young children, when addressing infants (as well as animals and lovers). Baby talk has been studied in many cultures and is characterized by what Ferguson (1978) has termed a *simplified register*. The principal acoustic

characteristics of this register are, according to Sachs (1978), an overall higher pitch, a wider frequency and intensity range, and a more markedly regular rhythmic structure (cf. nursery rhymes). In short, BT exaggerates the acoustic contrasts on which speech is based. Although it is unlikely that any single property of the speech addressed to the infant is essential to normal development (cf. Newport et al. 1978), it is equally unlikely that a culturally widespread phenomenon such as BT is devoid of function. If function can be inferred from structure, the function of BT is to draw the infant's attention to important acoustic contrasts in speech (cf. Garnica 1978) and to launch it on its search for pattern. Thus, we may see BT as the exogenous auditory counterpart of the endogenously controlled eye movements and head turning with which the human newborn searches for visual contour (Haith 1979).

What the infant has learned perceptually about its native language begins to emerge in babble around the sixth to ninth month. Jakobson (1968) dismisses babble as irrelevant to language acquisition on the grounds that it is primarily a motor activity devoid of linguistic import. He is correct inasmuch as normal perception of speech and language, as well as a highly educated level of reading and writing, can be developed, by prolonged and careful instruction, even when articulation has been pathologically precluded since birth (e.g., Fourcin 1975). But this does not mean that, under normal circumstances, babble contributes nothing to perceptual or especially expressive development. Indeed, it is unlikely that a behavior so regular in its time of onset and developmental course should altogether lack function.

Babble offers an obvious analogy with subsong, the low-intensity, generalized singing that precedes true song in many songbirds. Here, too, function is in doubt, largely because subsong recurs each year, as though it might simply reflect lower motivation early in the season (Thorpe 1956:373). Moreover, the female learns to recognize the male's song even though she herself (like the pathological humans cited above) never engages in subsong. Nonetheless, subsong does last longer in the bird's first year and bears several interesting analogies with babble - enough to suggest that both activities may be necessary to normal motor, if not to normal perceptual, development.

In the chaffinch, for example, subsong seems to be a poorly differentiated version of the species song with a much greater frequency range. Learning involves dropping unwanted elements and organizing the remaining notes into the correct rhythm (Thorpe 1956:374), presumably to accord with the inborn template, as modified during the early months of the sensitive phase. In the human, babble also seems to begin as a poorly differentiated stream, with many more components than will eventually be used. Gradually, over the course of 2 or 3 months, the stream begins to take on properties of the native language, presumably revealing what the infant learned perceptually during its first months of life. Just what these properties are is not yet known, partly because reliable phonetic transcription is difficult. Intonation is the most obvious, and characteristic pitch contours can be traced in spectrograms (e.g., Nakazima 1962), but language-specific consonant-vowel syllables may also be present (Huxley & Ingram 1971:162ff.; Kewley et al. 1974). In any event, Mehler (personal communication) has found that French-speaking adults can reliably identify infant babble, even in the second month of babbling, as French or not-French.

All this is consistent with the view that babble and subsong enable the organism to discover the limits of its vocal apparatus and to establish necessary sensorimotor links. Here, however, parallels between bird and infant cease. For whereas the end of subsong is true song, the use of which does not have to be learned, the end of babble is a modest articulatory repertoire, already language-specific but enough for no more than a start on the discovery of a linguistic system.

The process of discovery is, so far as we know, without parallel in the communication system of any other animal. The infant does not simply imitate, matching a particular utterance to a particular type of situation. Rather, it searches out contrasts among components of its own repertoire and uses them to signal contrasts in its desires, experience, or behavior. Often the contrasts, in both signal and message, are entirely novel and without counterpart in the adult system.

The process is well illustrated in a recent study by Menn (1978). She followed the development of intonation (pitch contour) in the babble and early speech of an American English boy between the ages of about 13 and 15 months. She classified his behavioral routines into categories such as greeting, curiosity, narrative, desiderative, and donative. Then she classified the pitch levels of babble in these situations as either moderate or high and the pitch contours as either rising or falling. Finally, she correlated pitch levels and contours with behavioral routines.

Among the outcomes, predicted from adult speech and observed in the data, were that narrative routines were accompanied by falling contours, whereas curiosity or desiderative routines were almost always accompanied by rising contours. However, the most interesting finding was that rising desiderative contours, addressed to adults, were split according to absolute pitch levels into high (peak above 550 Hz) and moderate (peak below 450 Hz), according to whether the child was seeking an object (e.g., food, toy) or social interaction (e.g., play). In other words, at a stage of his linguistic development when isolated words were still rare and word combinations did not occur at all, this boy had constructed a subclassification of his own rising pitch contours into moderate for sociable occasions and high for object-seeking occasions. Because adult speakers of American English do not use absolute pitch to contrast the uses they wish to make of other people, we must conclude that the child has created its own "erroneous" rules of intonation (Menn 1978).

Such invention is not without a precursor. The process of discovering meaning, and of seeking its correlates in the gestures or vocalizations of others, probably begins with the earliest mother-infant interchanges (cf. Bruner 1975; MacNamara 1972). In due course the infant chances upon such correlates in its own vocal repertoire and, with recognition of the first contrasts in intonation, there begins the slow discovery of sound pattern that will end, several years later, in a full and intricate phonological system. For this and for the parallel processes of syntactic development we find no analogues among birds or apes.

CONCLUSIONS AND QUESTIONS

A language is an open system, adapted by its dual structure of sound pattern and syntax for unlimited communication. If, as was argued, the dual structure

evolved to interface man's intellect with his peripheral anatomy, it is unlikely that analogous duality of patterning will be found in animals of appreciably lower cognitive complexity.

A dual structure is also found in manual sign languages. That sign languages are manual emphasizes the importance of rapid articulatory gesture to effective linguistic communication. So far as we know, no other animal has developed a capacity for essentially equivalent communication by means of two different sensorimotor systems.

Because none of the supposedly linguistic behavior of the great apes occurs in a natural environment, recent successes in training them to communicate symbolically have little bearing on the origins of language. However, laboratory studies of the apes may lend insight into the evolution of intelligence and relations between language and thought.

The capacity for vocal learning has no value beyond its use in communication, its appearance (and pivotal social role) in both man and songbird is of great interest. However, of several possible analogies between bird song - and language-learning - auditory templates, sensitive phases, and lateralized sensorimotor mechanisms - only the last invites fruitful speculation. Lateralized motor control of bird song, as well as the association of speech, right-handedness, and manual sign language with left hemisphere mechanisms in humans, suggests that the origin of cerebral lateralization for language may be in the control of skilled movements. Further work might profitably explore functional relations among manual skills and the perception and production of both speech and sign language, in an attempt to establish the extent of neural overlap.

The long period of human infancy, taken with the diversity of human languages (both spoken and signed), suggests that adaptations for language learning are likely to be behavioral rather than tightly neurophysiological. Study of these behavioral adaptations, particularly mother-infant interaction during the first year of life, may bring fuller understanding of language and of how it is learned.

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