"Language and Brain: Developmental Aspects:" Eric Lenneberg at the Neurosciences Research Program in 1972

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1. Introduction

Neuroscience seems like such an established field that it may surprise readers to learn that it (as distinct from neurophysiology and neuroanatomy as separate disciplines) was established only in 1962, with the founding of the Neurosciences Research Program (NRP) at the Massachusetts Institute of Technology (MIT) by Francis O. Schmitt and a variety of scientists interested in the neural basis of behavior and mind. (The Society for Neuroscience was founded in 1969 with Ralph W. Gerard as Honorary President.) The NRP hosted four summer schools and multiple Work Sessions over the next 20 years to help establish the new field. Schmitt not only brought together a variety of brain-centered disciplines but also championed the application of molecular biology and genetics to the study of the brain. For a history of the NRP, see the essay by George Adelman (2010) who was for many years librarian—and more—for the NRP.

Eric Lenneberg published *Biological Foundations of Language* in 1967. Five years later, he published "Language and Brain: Developmental Aspects" (Lenneberg 1972). This was a Bulletin based on an NRP Work Session organized by Lenneberg and held November 19–21, 1972. The report contained an edited record of the presentations as updated by the participants, and closed with an epilogue written by Lenneberg. This is an almost-forgotten work. When I last checked Google Scholar (August 2017) there were more than 10,000 hits for the book, yet only 3 for Lenneberg's epilogue and none for the work as a whole. The aim of this article is to bring the Bulletin to the attention of all those who value Lenneberg's work, with the bulletin itself made accessible on-line by presenting it as supplementary material in the Appendix to this piece. The article first presents, and to some extent comments on, the individual presentations at the Work Session, grouped under themes as in the bulletin, and closes with a perspective on Lenneberg's epilogue.

2. Neuroanatomical Approaches to the Study of Language

Georges Schaltenbrand (1972: 512–524)[1] reviewed the "Neuroanatomical Aspects of Speech and the Electrical Stimulation of the Brain." He offered clinical obser-

[1] Unless otherwise indicated, all page numbers given in the running text of this paper beyond this point reference the original pages and respective contributions in the NRP Bulletin under discussion (Lenneberg 1972).

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vations related to speech and other vocalizations, but his emphasis (following on the work of Wilder Penfield) was on what he had learned from electrical stimulation of patients undergoing surgery. Such data still provide a useful complement to current research in neurolinguistics which, despite the subsequent wealth of electroencephalography (EEG), positron emission tomography (PET) and functional magnet resonance imaging (fMRI) data, still lacks a unifying framework long after Lenneberg wrote that

> [...] the exact anatomical substrate for language remains elusive, especially for the cognitive side of language. [...] [T]here do not seem to be sharply delimited or structurally well defined areas that are alone responsible for the appearance of specific clinical language deficits.
>
> (1972: 524)

A few pages later, Lenneberg continues as follows:

> Perhaps the function of [...] large, transcortical, intrahemispheric fiber tracts is more closely related to developmental events and cortical differentiation than to "the sending of messages" between cortical functional "centers." This discussion is particularly relevant to our speculations concerning the function of the arcuate fasciculus. Since there are homologous structures in the chimpanzee brain, it is doubtful that man's capacity for language is in any important way related to the presence of this fiber tract. (1972: 526)

I agree that certain pathways and structures may play their crucial role in development, but disagree that homology disqualifies a tract from playing a distinctive role in language. For example, Rilling et al. (2008) used diffusion tensor imaging (DTI) to chart the very different structure of arcuate fasciculus in macaque, chimpanzee, and human (also see the discussion by Friederici, this issue). My own perspective is that arcuate fasciculus in monkey and chimpanzee serves fine manual motor control; and that its expansion in the human reflects the emergence of fine vocal control.

Returning us to developmental issues, Lenneberg adds that

> [t]hese facts lead to but one conclusion: There is some latitude and individual variation in the way neuroanatomical structures may mediate specific behavior types. These variations are not likely to be random but rather are governed by quite specific principles of the development of brain organization. The principles may have something to do with the concepts of critical age and sensitive period. (1972: 526–527)

3. Some Neuroembryological Principles

Given the lack of data directly linking human brain development to the general time course of language acquisition, it was thought valuable to explore in some detail what general neuroembryology could reveal as to developmental principles of brain organization—even though the behavioral aspects considered were far removed from humans and language. Marcus Jacobson (1972: 528–534) spoke on

"The Problem of Regulation: The Visual System in Amphibians." This has been of interest to me because, from the work of (Willshaw & Malsburg 1979) onward, the formation of retinotopic maps has been a major target for computational modeling as the best worked-out example of "how the brain wires itself up" (see Bednar's chapter in Arbib & Bonaiuto 2016 and Hjorth et al. 2015 for reviews). John Szentágothai (1972: 534–536) discussed "Plasticity in the Central Nervous System: Its Possible Significance in Language Mechanisms." Recent evidence of the role of plasticity in shaping language mechanisms is the finding that the brain of a literate person has distinctive brain regions adapted for reading, the visual word form area, for example. Dehaene & Cohen (2011) support the hypothesis that "reading acquisition partially recycles a cortical territory evolved for object and face recognition, the prior properties of which influenced the form of writing systems." This phenomenon has been the target of modeling by Behrmann & Plaut (2013), but will not be considered further here.

4. Language Properties of Special Interest to Neurobiology

As part of an attempt to understand the relationship between brain and language, the work session sought to assess the relevant properties of language by reviewing attempts (as available in 1972) to provide formal descriptions of grammar.

Terence Langendoen (1972: 537–539) asked "Is the Theory of Generative Grammar Relevant to Neurobiology?" and answered that Chomsky's (1957, 1965) competence theory is not of primary relevance—a conclusion I would agree with even today, despite Chomsky's major recasting of his theories across the decades (Arbib 2012: 47–71): rules of grammar should not be confused with the rules that govern the processes of comprehension and production. Langendoen outlined a long series of developmental stages in speech production that yields a set of highly specific phonological rules, while arguing that one should treat the syllable as the proper unit in phonology, not the phoneme.

Ed Klima and Ursula Bellugi (1972: 539–550) introduced "Language in Another Mode," their research on sign languages of the deaf, especially American Sign Language (ASL) and its acquisition as a first language by deaf children of deaf parents (for an updated overview see Bellugi et al., this issue). Following on Stokoe's argument (1960) that ASL was indeed a language rather than an unstructured collection of gestures, Klima and Bellugi showed that ASL had a grammar that shared certain properties with a spoken language like, for example, English but had certain distinctive properties exploiting the visuo-manual mode of communication, and explored the distinction between ASL and Chinese Sign Language (CSL; Klima & Bellugi 1979 presents the result of this research). (Note that we now accept sign languages as human languages in their own right—the grammar of ASL versus CSL does not reflect the differences between the grammars of spoken American English and Chinese.) Klima and Bellugi note that sign languages differ from spoken languages in the way the hands and face can exploit simultaneity:

> Though sign language may well have its roots in pantomime, it is clear that internal pressures toward systematization have resulted in a reanalysis of what may have been highly iconic into what seems to have become increasingly arbitrary. (1972: 550)

Since 1972, sign languages have offered a strong counter-balance to spoken languages and have suggested to some (but perhaps still a minority of) researchers in language evolution the plausibility of a gestural role in language origins, with the path to speech being indirect (Arbib 2012, Armstrong et al. 1994, Armstrong & Wilcox 2007, Kendon 2002). But crucial data for Lenneberg's concerns come from post-1972 studies on development of gesture in relation to speech and sign (Caselli et al. 2012), sign language aphasia (Poizner et al. 1987) and fMRI studies (Emmorey et al. 2014, Emmorey & Özyürek 2014), to name just a few. Returning to the theme of neural plasticity, important information can be gleaned for how having a signed versus spoken language can differentially remodel the brain (recall the earlier discussion of Dehaene et al. 2010).

5. Language in the Clinic

Here the attempt was to revisit the then century-old study of aphasias from a modern perspective. Simeon Locke (1972: 551–555) gave "A Neurologist's Point of View." He raised two "ambitious, and perhaps unanswerable" questions: (1) What is the evidence that language in the human is "innate" (leaving open the possibility that instead of being preprogrammed, all that is there is the potential, which is then developed)? (2) In what sense is language an extension of preexisting systems, and in what sense does it exploit new principles?

> As the studies of Klima and Bellugi show, language can exist without speech. Speech, as distinguished from the speech act [...], functions at the level of acoustic percepts and can be looked at in the absence of its semantic load. (1972: 552)

Locke reported on comparative analysis of the amount of speech produced in light and dark by schizophrenics, aphasics and dements, concluding that schizophrenics speak far less in the dark, suggesting that for them at least visual perception is a key to language production. In fact, language production has been far less studied than comprehension in neurolinguistics, and I would suggest that we should look at the "action-perception cycle" generally to ground our understanding of how language emerged as a new medium of communication as compared with nonhuman primates.

Roch Lecours (1972: 555-564) took up "Linguistic Analysis of Paraphasias," focusing on the case in which words are transformed by replacement of a single linguistic segment, while considering a range of variations of what might broadly be called Wernicke's aphasia (i.e., with the emphasis on errors of production):

> One might suggest that the semantic incoherence of jargonaphasic material, which sometimes precludes all possibility of linguistic communication with subjects whose productions contain too many compounded and complex verbal transformations, is not necessarily the behavioral manifestation of a conceptual deficit. [...] [It is] the result of an expressive, rather than a conceptual, disorder. To the listener, the sequence is no doubt quite incoherent; but its significance for the speaker's linguistic deficit might indeed be of the same order as that of a mere phonemic paraphasia. (1972: 564)

The general notion here is that by seeing what may go wrong on the path from semantic structure to motor control, one might get a new handle on grammatical structure (cf. Langendoen's observations, informed by study of language acquisition).

6. Development of Motor, Language, and Cognitive Behavior

Building on Langendoen's work, there were five presentations on various forms of development in humans. Tom Twitchell (1972: 565-569) integrated this with brain damage in "Development of Motor Coordination in the Presence of Cerebral Lesions," demonstrating that it is easier to see how labyrinthine and proprioceptive mechanisms related to body posture and simple movements are acting than to envisage the role of cutaneous sensory-motor mechanisms in motor function in health and disease. Primitive ballistic movements of, for example, manual control provide the necessary interactions from which coordinated behavior can emerge. (Oztop et al. 2004 offered a computational model for how, over perhaps 9 months, the grasp reflex can be replaced by visually guided preshaping of the hand during reach.)

> If one looks at the development of motor function following cerebral lesion at birth, the story is one of gradual improvement rather than gradual development of abnormalities. Often the improvement in function is so small over the life of the patient that it is of no use to him. One may see improvement occurring (provided it is not a learned type of utilization of the residual mechanism) in the same manner as in the normal infant. (1972: 569)

Lenneberg notes

> [...] that synergisms for sucking, mastication, and deglutition are physiologically separable from synergisms for speech articulation; the latter are later in development than the former. In abnormal development one may find normal anatomy and movements of oropharyngeal structures; the young patient has no difficulty in negotiating liquid or solid food.
>
> (1972: 569)

He then calls for studies akin to Twitchell's on motor control. (Interestingly, Lenneberg had at that time already sent off one of his graduate students to study the development of motor control, cf. Cohen, this issue).

Colwyn Trevarthen (1972: 570–585) offers an extended account of "The Psychobiology of Speech Development" in the only part of the Bulletin to be widely cited (over 100 times). He also discusses his commisurectomy studies with Roger Sperry. A diversity of studies with infants attest to his thesis that

> [t]he mechanism of intelligent action, employing a number of aimable and tunable receptors in unison for detection of structure in the world, is one in which a common space context, defined in innately wired circuits of the brain to represent the body's field of action, is used to obtain selective foci. [...] Separate focalizing and information-analyzing organs

> like eyes, hands, and mouth can pursue separate local goals individually, but all are periodically brought together and united in a common orienting field of behavior that shares one time base for its actions. This basic structure could not have been put together by learning or any process of association of initially free and independent parts. (1972: 570)

This then places language development firmly within the context of the child's interaction with the world. He discusses visual space in the neonate, voluntary reaching for objects, and (moving toward communication) prespeech in neonates to show that

> [...] the roots of social communication of experience and intention are well established at birth and that they begin to function before inanimate objects are perceived or used effectively. (1972: 579)

Prespeech is

> [...] a highly specific, quieter follow-up of the smile in which the baby, with gaze somewhat defocused from the mother's eye and often unsmiling, performs elaborate lip and tongue movements, sometimes with compressed breath. (1972: 581)

Trevarthen found

> [...] abundant evidence that speech has evolved out of the need for communication of intention and experience between beings of like psychological organization, with the same manner and cadence of attending to the events in the common environment, yet each with his own unique point of view on the world. (1972: 585)

This concept of intersubjectivity draws our attention to locate language within a context of social interaction. In recent years, Trevarthen has extended his study of intersubjectivity to include musicality (Malloch & Trevarthen 2009); whereas the relation between language and music poses a continuing challenge (Arbib 2013).

Tom Bever (1972: 585–588) addresses "The Relation of Language Development to Cognitive Development," starting by noting there are different types of linguistic knowledge such as grammatical knowledge, understanding of language, and speaking—and they interact. How do children perceive sequences of words? Bever demonstrates this by showing how at age two they have a stereotyped way of interpreting sentences that supports comprehension of parts of some sentences but not others, and observes how this changes by age four. The topic of language acquisition remains highly pertinent. A strict reliance on an innate Universal Grammar (e.g., Lightfoot 2006) seems mistaken (Arbib 2007), but computational modeling in concert with large databases seems to show real progress (Chang 2015, MacWhinney 2014).

Jonas Langer (1972: 588-596) discussed "The Ontogeny of Cognitive Functions." He posited three stages for the development of conceptual intelligence: presentational transformation upon objects, representational transformation upon objects, and operational transformation and assessed advances in symbolic systems of action that accompany conceptual progress. He argued that the evidence, though incomplete, seems to support the

> [. . .] working hypotheses that: (1) Conceptual activity defines the pace or sets the limits for symbolic development. (2) Conceptual development cannot be outstripped by symbolic development. [. . .] [He] summarized cognitive development as a shift from interaction and concern [. . .] with actual phenomena or objects located in the environment to a consideration [. . .] of possible phenomena located in his own thoughts. The character of the neural substrates that are necessary for such a shift is not at all clear. It seems reasonable to suggest, however, that such a cognitive shift is unlikely without a parallel inhibition of neural interaction with concrete external events accompanied by a relative activation of intraneural interaction. (1972: 595–596)

One may note here the concern with "mental time travel" that moves language and thought beyond the here-and-now (Suddendorf & Corballis 1997, Suddendorf & Corballis 2007)—but much remains to be done to secure the neural foundations for this expansion of cognitive perspective.

7. Neurobiological Aspects of Animal Communication

Three of the last four presentations asked what could be learned from the study of songbirds. In "Cerebral Lateralization in Birds" Fernando Nottebohm (1972: 597–602) discussed his seminal work on "Central Neural Mechanisms of Vocalizations in Birds," Juan Delius (1972: 602–607) reviewed "Central Neural Mechanisms of Vocalizations in Birds," while Mark Konishi explored "The Development of Auditory Sensitivity in Relation to Mother-Young Vocal Communication in Birds" (possibly an echo of Trevarthen's intersubjectivity?). The study of birdsong and its development, and speculation as to its relation to language, has been very active since these pioneering contributions and so I simply provide a few references to recent research (Berwick et al. 2011, Bolhuis & Everaert 2013, Fitch & Jarvis 2013, Petkov & Jarvis 2012). Since birdsong lacks semantics, it does not provide a model for the "compositional semantics" that language provides; it may better be regarded as exhibiting something akin to a "phonological syntax" (Yip 2010).

Finally, Detlev Ploog returned discussion to primates with his analysis of "Phylogenetic and Ontogenetic Aspects of Vocal Behavior in Squirrel Monkeys." An updated review is provided by (Jürgens 2002, 2009), whereas Aboitiz has placed monkey vocalization and human language within an evolutionary framework, while noting that voice and manual gesture may have played complementary roles in the evolution of the human language-ready brain (Aboitiz 2012, 2017). Thus, the study of ape gesture may be a valuable bridge in assessing how language evolved (Arbib et al. 2008, Rossano & Liebal 2014, Slocombe et al. 2011).

8. Epilogue

Lenneberg's epilogue to the collected presentations is divided into ten sections. Here are the key points that Lenneberg made in each section.

8.1. Language, Speech, and Speakers

Lenneberg states that

> [l]anguage is a system or a "structure" of relations. Relational features pervade every aspect—semantics, syntax, and phonology. [. . .] [A]nd the reality of these points was driven home to engineers in recent years when they discovered that no mechanical device can recognize speech sound patterns (or syntactic structures) unless it is capable of making elaborate computations of relations. (1972: 619)

A few years later, HEARSAY provided an example of a speech understanding system employing cooperative computation across the levels (Erman et al. 1980, Lesser et al. 1975); Arbib and Caplan (1979) offered initial ideas on the relevance of this to neurolinguistics.

Lenneberg then points out that

> [i]n order to assign phonemic values to sounds, the object [i.e. biological organism] must "compute" relationships between given acoustic heterogeneities [. . .]. Syntactic and semantic relationships [. . .] are "computed" in intimate connection with the organism's cognitive activities (including perception, memory, recognition—in short, knowledge) concerning the world around it. The computation of relationships is involved when relationships in the environment are assessed or verified, or when a speaker issues a statement or makes an assertion about relationships that supposedly hold for certain conditions. (1972: 619)

He continues by saying that

> [t]hese considerations should make it clear that language reception and language production are both dependent upon a common, unified mechanism [. . .]. (1972: 619)

Perhaps this is misleading. Thus, where Lenneberg asks "Where is language located, whatever it may turn out to be?" (p. 620), I would rather speak of "orchestrating" diverse mechanisms for production and comprehension, while noting that learning may have altered not only these mechanisms but their patterns of interaction with others (recall the earlier discussion of reading).

Next, Lenneberg goes on by discussing the explanatory value of association. He remarks that

> [f]or about a century we have been satisfied with the use of association as an explanatory concept. This has engendered the false impression that language knowledge is simply a collection of associative bonds that may be established within the organism by manipulations from the outside and, therefore, that language knowledge may be introduced into a basically passive recipient by any clever trainer. Linguists, especially Chomsky (1957) and his students, have argued compellingly against this view. Observations on clinical language disorders as well as on the normal ontogeny of language development similarly militate against the idea that language consists of immutable items (such as fixed associations) that are either present in an organism or not. (1972: 621)

The modern challenge, also discussed by Trettenbrein and Chomsky (this issue), then is to assess what notion of grammar may best support a study of language use—with perception and production providing occasions for learning and themselves changing (and changing in their relation to action, perception and cognitive processes) in the process. My own vote is to seek a neurologically constrained variant of construction grammar in which meaning and form are intertwined in each construction. Moreover, when we take a performance view, the elements of grammar may constitute dynamic schemas which differ between those available for comprehension and those for perception.

8.2. Language Development

Lenneberg starts out by saying that

> [t]he general trend [of language development] is always from a global, undifferentiated whole towards greater and greater specificity. One is reminded of Coghill's (1930) concept of individuation in the development of motor coordination, which has been mentioned by Twitchell.
>
> (1972: 621)

This sets the stage for what may be read as Lenneberg's manifesto for the work session's overall theme of "Language and Brain: Developmental Aspects:"

> The phonemic structure develops as a system of contrasts and relations (as Jakobson, 1941, showed [...])—not as a linear augmentation of a speech sound repertoire. In syntax, the first joining of words represents an undifferentiated, primitive predicative relation; one word seems to be a comment on the other, but at first it is often not clear which of the words is the topic and which the comment. As sentences increase in length and syntactic complexity, the syntactic relations become more specialized and differentiated; words begin to function more and more clearly as specific syntactic categories. Likewise, in the realm of semantics, the child's usage of words is at first global and, to the adult observer, sloppy. Gradually the primitive semantic fields contract, and more and more precise semantic relationships emerge. This general trend suggests that the underlying neuronal activities responsible for language go through a developmental history themselves, starting from a maturationally undifferentiated stage and moving towards an ever-increasing degree of specialization and differentiation. (1972: 622)

He goes on to say that

> [w]hat is maturing is a capacity for computing special kinds of relations and relations between these relations. (1972: 623)

8.3. Biological Aspects of Language Development

Here, Lenneberg starts by saying that

> [...] one of the most general principles of embryogenesis may also be active in the specific (biological) maturational processes underlying language development. I should like to call this principle morphogeny, the embryological trend of local accumulation of anatomical structure and of physiological order. Developing organisms are morphogenic systems. (1972: 623)

(Compare his note on Waddington on his page 631.)

> But perhaps it is not quite so obvious that the development of behavior is actually an extension of embryogenesis. [...] An animal's behavior is but the outward manifestation of physiological and anatomical interactions under the impact of environmental stimulations. (1972: 624)

This integration of function and development sits well with the notion of evo-devo (also discussed by Piattelli-Palmarini in this issue), that evolution yields developmental systems rather than directly specifying adult forms. Extending Trevarthen's intersubjectivity, we may now place increasing emphasis on evo-devo-socio—since human language is indeed a primary shaper and shapee of sociocultural evolution.

Next, Lenneberg takes up the now familiar distinction between internal and external language:

> [...] [L]anguage may develop at the normal chronological age in children with peripheral handicaps that block the normal outward expression of language. Studies have been made of several children with motor deficits due to fixed CNS [central nervous system] lesions who have never been able to make speech sounds but who have developed language knowledge normally by listening to and interacting with speaking adults. This illustrates that the "mental" exercise of language may be distinguished from the physical output of language, i.e., from speech [...] (1972: 625)

Lastly, he concludes the section by noting that

> The idea that the exercise of language itself contributes to and alters the structural complexity of the language system is, incidentally, argument against regarding the brain as a finite-state computer. Though the argument here is based on different considerations from those used by Chomsky (1957), the conclusion is the same as his. (1972: 625)

But such agreement does not endorse a competence theory of generative grammar as the "solution." A rich learning theory of the child's language use while interacting with the physical and social environment is the goal of Lenneberg's enterprise.

8.4. Maturation of the CNS and Language

Here, Lenneberg's key point is that

> [...] normal histological and functional development of the mammalian brain is dependent both on the availability of certain sensory stimulation and on the opportunity or processing such information and engaging in correlated behavior. The meager evidence concerning language

> capability in criminally deprived (or wolf-)children seems to support the view that man, too, must be exposed to language during the last stages of brain development or else suffer irreversible language deficits (Lenneberg, 1967). The experiments reported by Szentágothai stress the importance of the interaction between environmental input and maturationally developing patterns, especially of synaptic arrangements. [...] The most dramatic maturational event of clearcut relevance to language is the hemispheric specialization for language that occur largely during the most active period of language acquisition. (1972: 626)

8.5. *The Localization Issue*

Lenneberg already provided a modern way of thinking about the question of localization of language functions. He says:

> In my opinion [...] the cortical loci in question gradually come to be specialized [...] to contribute in a particular physiological manner to those activity patterns that form the neuronal basis or behavior [...]. Behavior such as language is not the product of one particular spot either in the cortex or in any of the subcortical nuclei. Very many parts of the brain must contribute to the proper function or a behavior that is as inseparable from perception, memory, concept formation, and every other cognitive process as is language. (1972: 627)

And, we may add, the different motor demands of spoken and signed language. Indeed, Lenneberg continues with examples from motor coordination and its impairment.

Lenneberg rejects the

> [...] notion of centers with principal control over any particular kind of circumscribed behavior. The brain is not a loose aggregate of autonomous organs, but a single organ (Locke and Trevarthen, this Bulletin). Its anatomical subdivisions undoubtedly have their own specific physiological functions, contributing to various types of behavior in different ways. But, so far we know of no behavioral entity that is the exclusive product of just one brain region alone. (1972: 628–629)

Again, I would rather speak of distributed or cooperative computation across diverse subsystems rather than speak of "a single organ," since this draws attention from the way the overall system changes with development and can reconfigure itself to meet the needs of different situations. I think Lenneberg would be content with this reformulation.

8.6. *Ontogeny of Behavior*

Here, Lenneberg says the following:

> Denny-Brown's concept of amorphosynthesis (Denny-Brown et al., 1952) foreshadowed a new interpretation of the interrelation between the two hemispheres, which has been most lucidly presented by (Kinsbourne,

> 1974). [...] He postulates, as Denny-Brown had done before him, a state of functional balance between the hemispheres that continues throughout life, even though the compensatory capacities are lost at the termination of the maturational phase of the brain. [...] [But] differentiation that takes place between birth and adolescence and that results in hemispheric functional specialization does not turn one side of the brain into an independent language organ. It causes physiological functions to be more selectively distributed between the left and the right side; it does not abolish all interdependence. [...] Twitchell's and Trevarthen's presentations [...] [illustrate] how original primitive reflexes (or, perhaps better, "prototype acts") gradually come to be transformed into effective motor patterns, resulting in new capabilities in motor control. As brain tissues become more and more differentiated, they [...] transform the previous types of functions into newly integrated patterns. (1972: 630)

8.7. *The Embryological Concept of Regulation Applied to Language Development*

Lenneberg begins this section by saying that

> [t]he compensatory powers of the infantile human brain with respect to language-relevant brain regions may be [...] [an] example of [...] [the] regulatory phase of ernbryogenesis. When this period comes to a close, the second phase, one speaks of determination of tissues. [...] [T]he organism can no longer rearrange itself to reconstitute the original manner of function or shape. However, even then there are mechanisms in certain animals that may compensate for loss. Regeneration is one such mechanism, though it is irrelevant to language and its biological substrate. (1972: 639)

Given the discovery of formation of new neurons in adult hippocampus, it may be time to see to what extent this may provide new mechanisms for language plasticity even long after key "critical periods" have long since passed.

8.8. *Stability of the Course of Development*

Here, Lenneberg says that

> [t]he tendency for a growing organism to follow a fairly narrowly defined trajectory of development and to be able to return to that trajectory even if it is temporarily deviated from its prescribed path has [...] been the subject of much discussion in theoretical biology, particularly by Waddington, who refers to the phenomenon as homeorhesis, and by the biologists who have joined him in a series of study groups (Waddington, 1968, 1969, 1970, 1972) [of which I (MAA) was one]. Formative principles of this sort are by no means restricted to biological growth. [...] There is no way for a system to reach any one given stage without having first traversed the stages that led to it. [...] [But] there are also examples in the experimental animal literature and in human embryology in which fetal or perinatal lesions seem at first to leave the infant

> unharmed but produce symptoms at a later stage of development. [. . .] At first these findings may appear to be paradoxical. However, we may yet learn to fit them into a consistent model if we try to explain them in terms of morphogeny and homeorhesis. In cases where the animal preparation or the patient gradually grows into the symptoms, the developmental preconditions for future pattern formation have been interfered with. (1972: 631–632)

He continues as follows:

> It is in these terms that we should also look at language development. [. . .] One of the most intriguing aspects of comparisons between human language and animal communication is precisely the various courses of development of these species-specific behavior types. The work of Konishi and of Nottebohm is especially a propos here. (1972: 632)

8.9. Brain Stimulation Data

Regarding the means for studying the neural substrates of language processing at the time Lenneberg says that

> [o]ur theories for brain mechanisms of language are based, essentially, on two types of evidence: electrical brain stimulation in unanesthetized man, as discussed by Schaltenbrand, and postmortem examination of brain lesions. (1972: 633)

Here, as noted earlier, the relevant database has expanded dramatically (or even overwhelmingly?) to include a wealth of data gained used EEG, PET, fMRI, and other techniques, and these are complemented by comparative neurobiology with other primates as well as further developments in the study of birdsong. Very much as Lenneberg notes with reference to Ploog's presentation, there are

> fundamental, physiological differences between brain correlates of vocalization in man and in so-called lower primates, as well as important similarities and homologies relevant to the correlates of vocalization. (1972: 634)

Aboitiz (2017) offers a perspective on the evolution of brain mechanisms for speech rooted in comparative neuroanatomy of monkeys and humans; see also my call for a (computational) comparative neuroprimatology (Arbib 2016).

8.10. Clinico-Pathological Correlations

Lenneberg turns finally, to the "morbid anatomy" giving rise to language disturbances and summarizes

> the consensus of the neurologists present [at the Workshop] as follows. There is no lesion that is capable of totally abolishing language capabilities (more specifically, language knowledge) without at the same time interfering dramatically with many other cognitive functions. Clinical

> speech and language disorders that are acquired in adult life present as both reduction and distortion of normal language patterns. [...] Perhaps the most important suggestion for future work in the area of aphasia that issued from the interaction with developmental biologists at this Work Session is the analysis of language disorders in their developmental perspective: the consequence of lesions in childhood and the course and progress in the formation of symptoms or recovery from symptoms.
>
> (1972: 635)

9. Conclusion

Lenneberg stated that at the time of the Work Session, there was

> only one type of scientific theory of language structure available, generative grammar, and this was never intended to serve as a model for biological language mechanisms. [...] What is most urgently needed is a theory of sentence production and comprehension that has the formal precision of Chomsky's approach but is explicitly intended to explicate the psychobiological underpinnings of language capabilities.
>
> (1972: 635)

Elsewhere, I have argued that computational construction grammar may provide such a framework, while stressing that the very diversity of formulations for such a grammar requires a synthesis of the lessons to be learnt from diverse approaches such as those of Embodied Construction Grammar (Bergen & Chang 2005, Feldman 2010), Template Construction Grammar (Arbib 2017, Arbib & Lee 2008), Fluid Construction Grammar (Steels 2004, Beuls & Steels 2013), and Dynamic Construction Grammar (Hinaut et al. 2015). However, what is striking about Lenneberg's Work Session is the relative unimportance of linguistic analysis and the emphasis on seeking insights from neuroembryology and from the development—and disorders—of motor and perceptual skills and the diverse breakdowns of language function in aphasia. These insights—and those that have extended them in the last 45 years—remain crucial, even as we seek new computational models of language comprehension and production and link them to new sources of data on the human brain and the comparative study of other species.

Appendix

The Supplementary Material contains scans of the original article Lenneberg (1972), prefaced with a republication note that also addresses the copyright situation. It is available for download here: `https://biolinguistics.eu/index.php/biolinguistics/article/downloadSuppFile/507/84`

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