Neurolinguistic Considerations on the Optimum Age for Second Language Learning
Author(s): Terence M. Walsh and Karl C. Diller
Proceedings of the Fifth Annual Meeting of the Berkeley Linguistics Society (1979), pp. 510-524

NEUROLINGUISTIC CONSIDERATIONS ON THE OPTIMUM AGE FOR SECOND LANGUAGE LEARNING

Terence M. Walsh, St. Paul's School
Karl C. Diller, University of New Hampshire

It is almost a generation, now, since Wilder Penfield's widely publicized writings (Penfield 1953, 1964) gave a neurosurgeon's authority to the proposition that the best period to begin second language learning is some time before age 6 or 8. Eric Lenneberg, in his Biological Foundations of Language (1967) also asserted that language learning ability deteriorates with age, especially after puberty.

But in recent literature on second language learning, we find overwhelming behavioral evidence that this view is not correct. If one disregards foreign accent phenomena, it is clear that young adults are more efficient language learners than adolescents, and that adolescents are more efficient than young children. For example, a recent study in Chicago of the sons and daughters of Japanese businessmen, university faculty, and graduate students, concludes that it takes about three and a half years for a Japanese child to equal his American peers in English reading ability regardless of age. Thus a five year old Japanese child in Chicago will read at an eight and a half year old level after 42 months, whereas his ten year old sibling can reach the proficiency of thirteen and one half year old Americans during the same 42 months (Walberg, Keiko, and Rasher 1978). In Britain it was found that there was very little difference between sixteen year olds who had studied French since age eight and those who had studied it since age eleven (Burstall, 1977). Roland Durette (1972) documents the fact that college students learn foreign languages twice as fast as high school students and that nine year olds need five years to accomplish what college freshmen learn in one year. The apparent counterexamples of some immigrant families in which children learn languages better than their parents and grandparents, are balanced by opposite cases in the American community overseas where parents use the foreign language fluently in their professional work and their children go to English-speaking schools and fail to learn much of the foreign language. Opportunity and motivation must be used to explain these cases (cf. Diller, 1978). Pronunciation may be the exception to adult superiority, but even in phonology there is evidence from a study by Susan Ervin-Tripp (1974) that older American children in Geneva, Switzerland, catch on to phonological rules faster than younger children do. For further evidence of the increasing ability to learn second languages with age, see numerous other studies referred to in the articles mentioned above and in a review of the literature on second language learning by McLaughlin (1977).

What, then, of the biological evidence? The earlier evidence from Penfield and Lenneberg, it seems, was partially correct but misleading. There is actually relevant evidence in recent neurodevelopmental research which corroborates the behavioral evidence in suggesting that adults may be better equipped for certain kinds of learning than children are. To explain biologically why children sometimes appear to be the better language learners when adults in fact are superior in most respects, we will need some preliminary remarks on the anatomy of the cerebral cortex, and discussion of neurolinguistic feature detectors, brain maturation, developmental and critical stages, and local neuronal circuitry. We can then distinguish lower order from higher order language processes, and explain some of the differences between adult and child second language learning.

1. Preliminary remarks on the anatomy of the cerebral cortex. At around the turn of the century, Brodmann (1909) found that he could distinguish various areas of the human cerebral cortex on the basis of microscopic structure. His mapping, as seen on the left side of figure 1, is based on the type of structure seen on the right side of the figure. The cortex, known as gray matter, is a thin surface mantle (about 1/6 of an inch thick) which contains nerve cells. The white matter below the cortex has no cell bodies, but is made up of heavily myelinated axons which form the intercellular connections. The basis of Brodmann's map is that the internal organization of the constituents of the cortex varies from area to area.

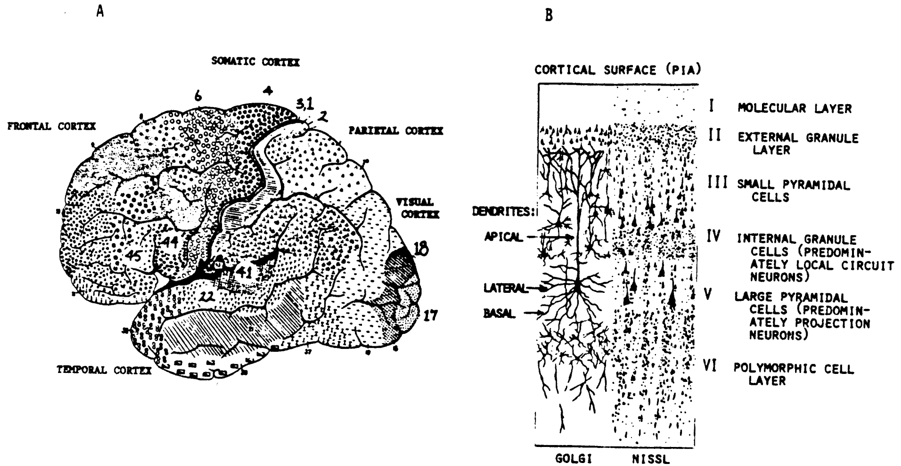

FIGURE 1.
A. CYTOARCHITECTURAL MAPS OF HUMAN CEREBRAL CORTEX BY BRODMANN (1914). TOPOGRAPHICAL REPRESENTATION OF DIFFERENT KNOWN REGIONS OF CORTICAL FUNCTION. B. LAMINAR STRUCTURE OF CEREBRAL CORTEX, SIX LAYERS. GOLGI - STAINS ALL OF NEURON (AXONS NOT SHOWN). NISSL - STAINS ONLY CELL BODY. EXCELLENT FOR SHOWING CELL DENSITY, LAYER THICKNESS.

On the right side of figure 1 we see the typical six-layer organization of the cortex. Each section on the right hand figure shows the same tissue, using different staining techniques. The Nissl stain impregnates only the cell body while the Golgi method impregnates almost the entire neuron. Brodman found that the relative thickness of these six layers will vary from area to area with regard to the number and density of certain types of cells and other criteria.

There are essentially two principal types of cells in the human cortex: the pyramidal cells, and the star-shaped cells which for the most part are local circuit neurons. These two types, according to Sholl (1956), account for more than 97% of the 14 billion neocortical neurons. It is important for the argument of this paper to understand the distinction between these two types of cells. The pyramidal cell, the cortical "workhorse", is the most visibly distinctive type of cell in the cortex. It has the form of a pyramid, or triangle, whose upper end is continued toward the surface of the brain as the apical dendrite. Dendrites are also seen emanating from the side and base. Star shaped cells (principally the local circuit neurons) as seen for example in layer IV, figure 1B, are smaller, more polygonal, and perhaps rounder in shape. These cells have a number of dendrites passing in all directions and a short axon, which carries a propagated neural signal away from the main cell and typically arborizes close or locally to the region of the cell body. These star-shaped cells are the more important cells with regard to basic and long range learning, as we will see later.

2. Broca's and Wernicke's Areas. Using Brodmann's map, in figure 2, one can locate the various areas that have been found

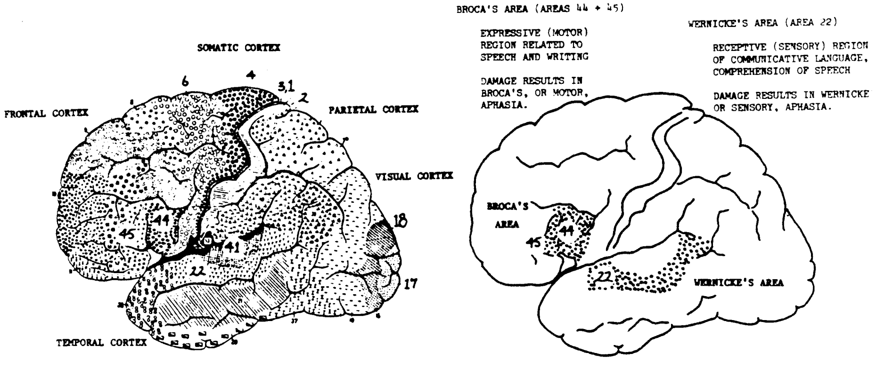

FIGURE 2.

CYTOARCHITECTURAL MAPS OF HUMAN CEREBRAL CORTEX BY BRODMANN (1914).
TOPOGRAPHICAL REPRESENTATION OF AREAS OF CORTICAL FUNCTION IN BROCA'S (AREAS 44 + 45) AND WERNICKE'S (AREA 22) AREAS.

to have special perceptual and behavioral functions. For example, the primary area for vision is area 17. The primary somatic cortex representing the so-called homunculus is located in areas 4, 6, 3, 1, and 2, and the primary auditory cortex in area 41. These functional areas are found in similar positions in all species of placental mammals.

In the human brain, several areas have evolved that have special importance for the learning and processing of language. The two classical areas known for more than a century, Broca's Area and Wernicke's Area, are shown on the right of figure 2. Paul Broca, in 1861, was the first to point out the special importance of the left hemisphere for language, and he placed special importance on the frontal region that can be seen in the figure as areas 44 and 45. Carl Wernicke, in 1874, pointed out the special importance of the posterior regions, especially Brodmann's area 22, for the auditory comprehension of speech.

The symptoms for Broca's and Wernicke's aphasias are strikingly different. If large frontal regions including Broca's area are destroyed (cf. Mohr, 1976) leaving the posterior language areas intact, the patient will typically have halting and effortful speech with special trouble using the grammatical function words. Comprehension in Broca's aphasics will be relatively good, but if you say that "The lion was killed by the tiger", they will usually think that the *tiger* was dead. Posterior lesions, including Wernicke's area but sparing the frontal language areas, will lead to severe comprehension problems accompanied by fluent grammatical speech which is rather empty in content. On the basis of this knowledge, Wernicke predicted that there should be a third type of aphasia: if the connection between posterior and frontal language areas is broken, then there should be patients who have fluent grammatical speech, and excellent comprehension, but who have extreme difficulty with repetition. It wasn't long before such patients with *conduction aphasia* were found. Other specialized types of aphasia are reviewed in Goodglass and Geschwind, 1976.

The important point for our purposes is that the different language areas have different functions in the use and in the acquisition of language. *Just as damage to different areas will result in specifiable types of aphasia, differing rates and types of maturation among these areas will result in specifiable and different acquisition patterns.*

3. Neurolinguistic Feature Detectors. A great deal of recent work by Eimas and others has shown that newborn infants only a few weeks old are able to perceive phonetic features of speech in a categorical manner, just as adults do, suggesting that we are dealing with innate neural detectors for phonological distinctive features. In one example, the infants responded to new stimuli by increasing their sucking rate on a pacifier nipple. Two synthesized /b/ sounds with slightly different voice onset times were regarded as being the same. But if this slight difference in voice onset time spanned the /b/ - /p/ boundary, the two sounds were perceived as being separate stimuli. The numerous studies which have refined and elaborated on this finding give persuasive behavioral evidence that infants are innately equipped for the analysis of speech (Eilers, 1977; Eilers and Minifie, 1975; Eilers, Wilson and Moore, 1978; Eimas, 1974, 1975a, 1975b; Eimas and Miller, 1977; Eimas, Siqueland, Lusczyk and Vigorito, 1971; Fodor, Garrett and Brill, 1975; Hillenbrand, Minifie and Edwards, 1977; Jusczyk, 1977; Jusczyk _et al_. 1977; Lasky, Syrdal-Lasky and Klein, 1975).

The actual neurophysiological operations leading to linguistic feature detection have not yet been distinguished within the brain, but research in the basic neurosciences in the last twenty years would tend to support the possibility of such a deducted claim. For example, Hubel and Wiesel (1959, 1969) demonstrated in the cat, and later in the primate, that the visual cortex contains neurons which are specialized in their detection of specific features in the visual world, such as contours, angles, illuminated lines, lines in certain orientations. Some visual cells excite only if a certain line appears in a precise part of the visual field; other cells are indifferent to location. These detectors are part of the innate neural arrangement and physiological function of the visual cortex.

In inframammalian animals such as the frog and the bullfrog, there is evidence that feature detectors are also found in peripheral neural systems. In their celebrated paper entitled "What

BROCA'S AREA

INTEGRATION OF ENCODED LINGUISTIC INFORMATION IN FRONTAL CORTEX. "PATTERNED" AND DELIVERED TO OTHER CORTICAL REGIONS.

WERNICKE'S AREA

FEATURE DETECTION OF LANGUAGE ELEMENTS.

NEURAL ANALYZERS.

NEURAL ENCODING AVAILABLE TO SENSORY AND INTEGRATIVE AND MOTOR-EXPRESSION REGIONS, (VISUAL, AND SOMATIC).

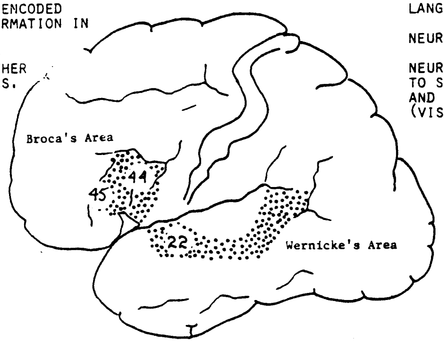

FIGURE 3.
NEUROLINGUISTIC ASSUMPTIONS RELATED TO WERNICKE'S AND BROCA'S AREAS. WERNICKE'S AREA, INNATELY RESPONSIVE TO SPEECH VERSES NON SPEECH SIGNALS. BROCA'S AREAS, INNATE PATTERNING OF ENCODED LINGUISTIC INFORMATION, EVENTUALLY PASSED ON TO SOMATIC SENSORY-MOTOR AREAS.

the Frog's Eye Tells the Frog's Brain" (1959), Lettvin and his collaborators reported that recording from single optic nerve fibers, the frog's retina performed four distinctive operations on the image. Groups of fibers were found which responded to edges, to the curvature of an object, to the movement of edges, and to a sudden reduction of illumination. These operations suggested to the authors "much more the flavor of perception than of sensation."

As investigators were quick to see, it makes sense to assume that in the course of evolution, neural systems have evolved for detecting elements and encoding information about visual input. It has become clear that the primary visual cortex possesses "wired in" detectors for the complex aspects of visual response to the environment.

Similar findings have been reported from the somatic sensory cortex of the cat and primate (Mountcastle, 1957, 1973), the auditory cortex of the cat (Abeles & Goldstein, 1970), and aspects of coding properties of the auditory system used to detect vocalization in the bullfrog (Capranica, 1965, 1966; Frishkopf *et al.*, 1968).

With regard to language, then, it seems quite likely that feature detectors and neural analyzers exist in the language areas of the cortex analogous to Hubel and Wiesel's feature detectors in the visual cortex, and that Wernicke's Area would have a certain priority of importance in the detection and analysis of language (cf. Walsh and Diller, 1978). It is not likely that such a long-term encoding mechanism would turn off at age 6 or 8, or at puberty; it would operate well beyond childhood in much the same way, say, as an ear for music persists through several decades.

4. *Brain Maturation: Neurodevelopmental progression.* The neocortex, as we see in figure 4, is to a large extent underdeveloped at birth. Human infants can distinguish speech sounds with phonetic features, as we have just seen, and, of course, they begin quite early to babble with speech-like sounds. They are not able at this early stage to do much mimicking or repetition. It is several months before infants understand their first words and even longer before they use their first word. The reason for the inability of infants to deal effectively with language in the first months is that the neural connections are not well established. Infants are like conduction aphasics to the extent that their repetition is poor. If the *arcuate fasciculus*, the pathway between Wernicke's and Broca's areas, were more highly developed at birth, one would hear mimickry much sooner in infants.

There is a double reason why Wernicke's area is most important in the early stages of language acquisition. The first reason is that by being adjacent to the primary auditory cortex, it is the first language area to receive linguistic input from the environment. Secondly, because the *arcuate fasciculus* and other pathways out of Wernicke's area are slow to develop, the

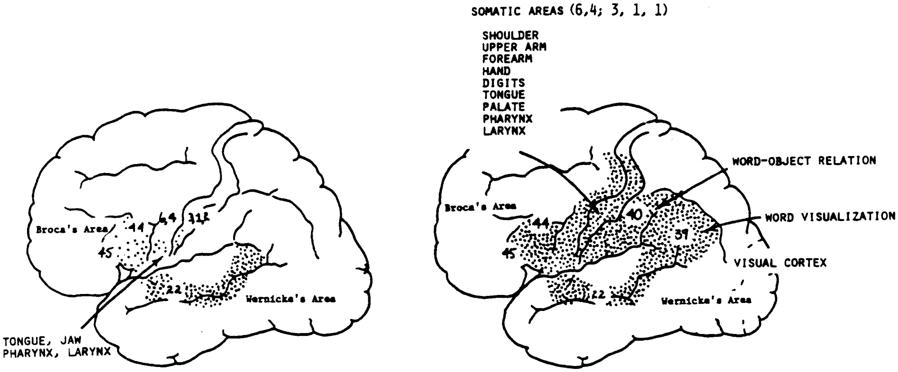

FIGURE 4.
NEURODEVELOPMENTAL PROGRESSION RELATED TO THE INNATE RESPONSIVENESS OF WERNICKE'S AND BROCA'S AREAS AND EARLY REGIONS OF EXPRESSION. LATER DEVELOPMENT OF SENSORY AND MOTOR AREAS TO LANGUAGE ACQUISITION. HIGHER CORTICAL PROCESSES OF COGNITIVE AND INTELLECTUAL FUNCTIONS BECOME ELABORATED DURING FIRST LANGUAGE ACQUISITION; TOWARD LANGUAGE ACQUISITION SYSTEMS AVAILABLE FOR LATER LANGUAGES.

infant cannot direct the production of the words that he hears, but must be content with processing the words in a receptive manner.

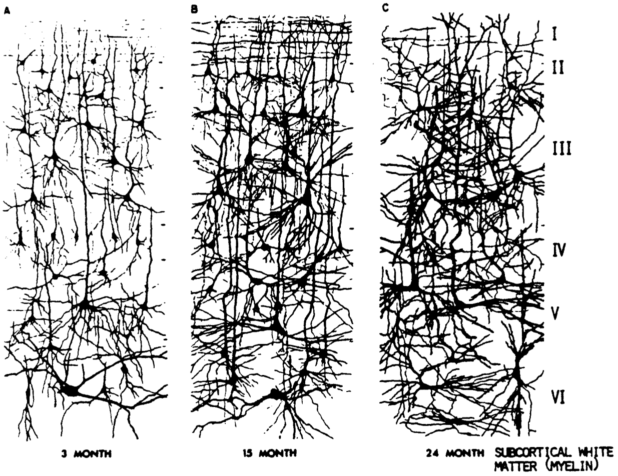

FIGURE 5.
CAMERA LUCIDA DRAWINGS OF GOLGI IMPREGNATED SECTIONS FROM THE SUPERIOR TEMPORAL CORTEX IN HUMAN CHILDREN AGED 3, 15, 24 MONTHS. NOTE INCREASED ARBORIZATION OF NEURONS, AND DENSITY OF DENDRITIC SPINES, WITH INCREASING AGE (CONEL, 1947, 1955,1959). AXONS FROM PYRAMIDAL CELLS PASS TO HOMOLATERAL AREAS, CONTRALATERAL AREAS, AND SUBCORTICALLY.

Human brain weight increases almost fourfold from birth to adulthood (from about 335 grams to 1300 grams). In figure 5 we see the radical increase that occurs in the human brain in the first two years from birth. These drawings are from sections taken from the superior temporal cortex in human children aged 3 months, 15 months, and 24 months (Conel, 1939-63).

Notice that in the brain of the newborn, the ascending (apical) dendrites of pyramidal cells are bare shafts with very few branches. There is gradual growth in the next two years in the arborization of the ascending and basal dendrites and in the number of spines (postsynaptic receptor sites) on the ascending dendrites. By the age of about two years, the brain has matured enough so that serious language learning can begin.

5. Developmental stages, not critical stages. By all neuroanatomical accounts, pyramidal axon connections are reasonably well established early in the period of language development, certainly by age 6 to 8, especially for axons which pass the longer distances. This consolidation of anatomical connections presumably explains the difficulty that older children and adults have in establishing new language centers in the right hemisphere when they develop left hemisphere damage. It also explains the difficulty in conquering foreign accents after childhood. When a child learns a second language right along with the first, pronunciation for both languages procedes authentically at the same pace. But once the pronunciation pattern of the first language is established in normal monolinguals, it becomes easy to use these patterns as first approximations to new sounds when learning a second language. With regard to foreign accents, then, Penfield does have some neural evidence for his insistence that early childhood is the best time for second language learning. On the other hand, foreign accents are overcome to a reasonably large extent with proper instruction or with an optimal natural environment. From the standpoint of learning a second language, then, early childhood should not be seen as a critical stage in which it is necessary to start learning a second language. It is, rather, a developmental stage, in which the learning of a second language is somewhat different from learning a second language in later developmental stages. As we shall see, there is good reason to support the view that except for pronunciation, the later developmental stages are better.

6. Local Circuit Neurons. In 1967, Lenneberg stated that the maturation of the central nervous system was virtually complete by puberty (Lenneberg 1967, 181). Work published since that time has shown that this is not necessarily true of the final development of local circuit neurons, called variously microneurons, stellate or star-shaped cells, Golgi type II cells, and interneurons (see figure 6). Classical concepts of neuron function and development are being completely revised as a result of a

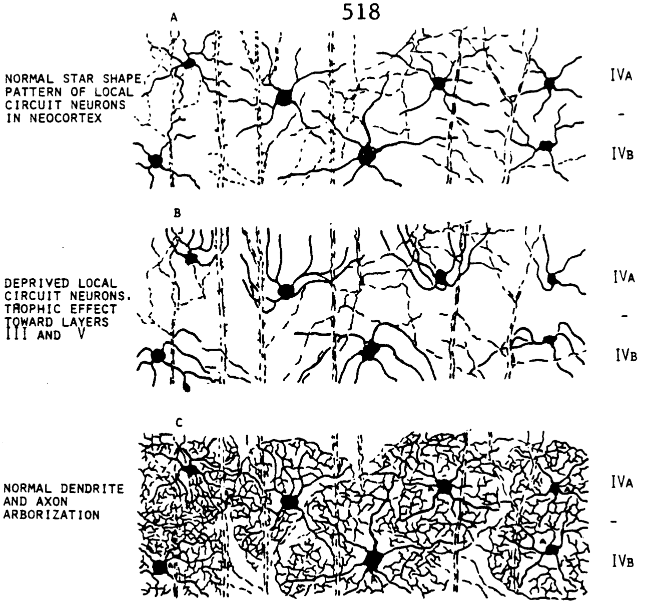

FIGURE 6.
REPRESENTATION OF LOCAL CIRCUIT NEURONS IN LAYER IV OF PARIETAL CORTEX. A. SHOWS NORMAL STAR SHAPE FORMATION OF DENDRITES. IN THIS LAYER DENDRITES RECEIVE INPUT MAINLY FROM THALAMUS, ALONG WITH CONTRALATERAL AND HOMOLATERAL AFFERENTS. B. DEPRIVATION OF THALAMIC INPUT LEADS TO ELONGATION OF DENDRITES AND THEIR DIRECTION TOWARD APPARANT SYNAPTIC ACTIVITY. C. NORMAL DENDRITIC AND AXONAL PLEXES. PRESUMABLY INCREASE AND DECREASE OF AXONAL ARBORIZATION RELATES TO NEURAL USE.

wide range of studies including recent intracellular recordings of postsynaptic patterns traced to local circuit neurons (Rakic, 1975). Other studies indicate that neuronal synaptic arrangements may be as modifiable at different postnatal stages as during formative stages (Valverde, 1967; Globus and Schiebel, 1967; Chan-Palay, 1973; Wiesel and Hubel, 1974; Rakic, 1974). Local circuit neurons seem to have a continuous role in the establishment of new connections, and appear to be the fundamental cells underlying neuroplasticity. As suggested by Jacobson (1970, 1974, 1975), they bear the brunt of environmental impact pertinent to learning. It would appear that they are the "fine tuning" neurons which modulate on a local level the input and output circuits formed by the pyramidal cells and other macroneurons.

Unlike pyramidal cells, which are well in place in the brain at birth, local circuit neurons appear to develop to a great extent after birth. Altman (1967, 1972), using a radioactive tracer technique for tagging proliferating cells suggests that these neurons are, in large bulk, undifferentiated at birth, still migrating as neuroblasts within the cerebral cortical tissue. It seems evident that these neurons should be characterized by their distinctive postnatal growth and slower differentiation in the brain, and that cortical maturation (contrary to traditional views) is a long term process in humans, ranging over two to possibly three decades or more.

LOWER ORDER CORTICAL FUNCTIONS
(BASIC COGNITIVE OPERATIONS)

WERNICKE'S AREA:

DETECTION OF LINGUISTIC INFORMATION (AREA 22)
NEURAL ANALYZERS (AREA 22)
NEURAL ENCODING (AREA)
GRAMMATICALITY -- RECEPTIVE (AREA 22)
MACRONEURONS (PRINCIPALLY PYRAMIDAL NEURONS): NARROWLY GENETICALLY SPECIFIED AND CONSOLIDATED EARLY.

BROCA'S AREA:

RETRIEVAL OF LINGUISTIC INFORMATION (AREAS 44+45)
PATTERNING OF ENCODED INFORMATION (AREAS 44+45)
GRAMMATICALLY -- EXPRESSIVE (AREAS 44+45 WITH SENSORY-MOTOR AREAS 6,4,;3,1,2.
SENSORY-MOTOR SKILLS WITH AREAS 4,6,;3,1,2 WITH NUMEROUS REGIONS.
MACRONEURONS (PRINCIPALLY PYRAMIDAL NEURONS): AREAS 44+45, PATHWAYS TO AREAS 4,6,;3,1,2. NARROWLY GENETICALLY SPECIFIED AND CONSOLIDATED EARLY.

LOWER PARIETAL CORTEX:

AREA 39. PERCEPTUAL ORGANIZATION OF LINGUISTIC VISUAL INPUT.

HIGHER ORDER CORTICAL FUNCTIONS
(VERBAL COGNITION; VERBAL CONSTRUCTION; ABSTRACTION)

WORD-OBJECT RELATION(AREA 40)
COGNITIVE NETWORKS RELATED TO PARIETAL CORTEX AREAS: RECRUITMENT OF INTRA AND INTER-HEMISPHERIC INFORMATION IN ASSOCIATION WITH LINGUISTIC RELATIONS.
LOCAL CIRCUIT NEURONS AND LOCAL NEURONAL CIRCUITS (AREAS 22; 44+45; 4,6,; 3,1,2; 39; 40).
NEUROPLASTICITY - ADAPTIVE TO DEMAND IN CORTICAL AREAS.
LONG RANGE IN DEVELOPMENT, POSSIBLY 2 TO 3 DECADES.

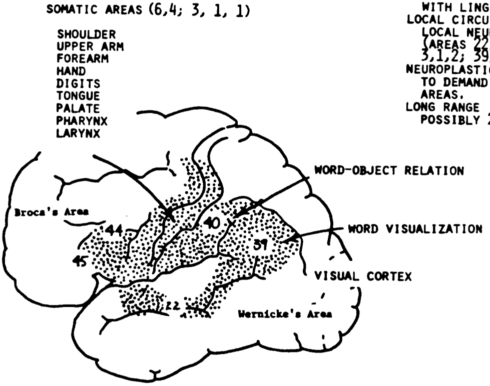

FIGURE 7.

SUMMARY OF LOWER AND HIGHER ORDER CORTICAL AREAS ASSOCIATED WITH LINGUISTIC FUNCTIONING. LOWER ORDER AREAS DEVELOP EARLIER AND ARE MINIMALLY NEUROPLASTIC (APTITUDES). HIGHER ORDER AREAS FUNCTION DEVELOPMENTALLY OVER SEVERAL YEARS AND ARE REGARDED AS NEUROPLASTIC TO LINGUISTIC DEMAND. LOWER AND HIGHER SYSTEMS ARE SEPERABLE IN FUNCTION.

There is an aphasic syndrome called "Isolation of the Speech Area" in which the lower-order speech processes of Broca's and Wernicke's areas are isolated from meaningful higher order processes of language, and in which the language areas serving these higher order semantic functions are damaged or cease to function. These patients exhibit echolalia--that is, they repeat anything that is said directly to them ("What's the weather like today?" --"What's the weather like today?"). They also sing along with the radio and learn the words to new songs. But they never show any sign of understanding any of this speech and, except for some swearing, they never utter any meaningful sentences (cf. Geschwind, Quadfasel, and Segarra, 1968; Whitaker, 1976). What is preserved is speech, the lower order language processing, but language in the broader sense is lost.

We have placed the basic grammatical processes of Wernicke's and Broca's areas as lower order processes. A current trend in syntax, however, is to place a large and sophisticated part of the grammar in the lexicon. This lexical grammar is presumably higher order. It is not surprising, then, that measured grammatical sensitivity continues to rise with age.

We are able, now, to explain the seemingly contradictory evidence on the optimum age for second language learning. Lower-order processes such as pronunciation are dependent on the early maturing and less adaptive macroneural circuits, which makes foreign accents difficult to overcome after childhood. Higher order language functions, such as semantic relations, are more

Various aspects of learning, memory, integration, and plasticity have been attributed to local circuits and local circuit neurons (Young, 1966; Gardner-Medwin, 1969; Jacobson, 1970; Cragg, 1972; Rakic, 1975). Indeed, even at the turn of the century, Cajal (1899) pointed out the apparent strong relationship of these "short axon cells" in the role they seem to play in complex animal behavior and human intelligence.

We have seen, in figure 4, how the neural systems subserving the vast range of human cerebral functions continue to develop over a period of years. We are coming to suspect that the functional capacity of these cortical regions may never be fully fixed. What we regard in psychology as cognitive development, as in the work of Piaget (1926), can be seen as the developing expression of an underlying maturation process. Cognitive development in adults is not yet fully adequately studied, but certain cognitive aptitudes continue to rise markedly after puberty (Bloom, 1964), especially scores on language aptitude tests which continue to rise at least into one's mid thirties (Carroll and Sapon, 1959; Pimsleur, 1966; Wells, 1974). Grammatical sensitivity or grammatical reasoning in particular, seems to develop into a new stage at puberty. This was known to such educators as Emile de Sauzé, who pioneered in the teaching of foreign languages in the elementary schools as an enrichment program for selected students in Cleveland. He never tried to extend this program to the general curriculum because he found that it was so much more effective to start second languages after students had reached about age twelve and had reached this developmental stage (de Sauzé, 1959).

The assumption to make is that plasticity of local neuronal circuitry is the factor which enables cognitive development to continue into adulthood.

7. Lower Order and Higher Order Language Processes.

In figure 7, we represent the cortical areas associated with what we would call "lower order" and "higher order" linguistic functioning. The lower order functioning is narrowly genetically specified and consolidated early in development. It includes the basic analyses of speech in Wernicke's area and the patterning of encoded information and the expressive speech of Broca's area. It also includes visual perception of area 39 leading to reading and writing.

The higher order functioning develops later and appears more adaptive to complex linguistic demand. It includes semantic processing and word-object relationships (area 40). This less specialized higher order linguistic functioning seems to utilize intra- and inter-hemishpere information. The essential nature of this cortical integration process is linguistic.

The distinction between lower order and higher order processes is illustrated by the similar distinction between "speech" and "language," in which we may include speech as a part of language.

dependent on the late maturing neural circuits, which may explain why college students can learn many times the amount of grammar and vocabulary than elementary school students can learn in a given period of time. As people grow older and cognitively more mature, their increasing higher order cortical functions allow them to do more than they could before with their lower order aptitudes and functions. From an understanding of the neural substrates involved in the development and differing strategies for learning language, we can understand how different aspects of language are learned optimally at different ages. Methods of teaching and strategies of learning vary predictably according to the developmental stage of the learner.

We conclude that though there may be certain neurolinguistic advantages of early bilingualism, the evidence does not support the strong claim that the best age for second language learning is necessarily the first decade; indeed, in important respects adults have superior language learning capabilities.

BIBLIOGRAPHY

Abeles, M. and Goldstein, M. H. (1970). Functional architecture in cat primary auditory cortex: Columnar organization and organization according to depth. J. Neurophys. 33:172-187.

Altman, J. (1967). Postnatal growth and differentiation of the mammalian brain, with implications for a morphological theory of memory. In: The Neurosciences: A Study Program, eds. Quarton, G. C., Meinechuk, T., and Schmitt, F. O. New York: Rockefeller University Press, pp. 723-743.

Altman, J. (1972). Experimental reorganization of the cerebellar cortex. I. Morphological effects of elimination of all microneurons with prolonged x-irradiation started at birth. J. Comp. Neurol. 146, 355-406.

Bloom, B. S. (1964). Stability and Change in Human Characteristics New York: Wiley.

Broca, P. (1861). Perte de la parole, ramollissement chronique et déstruction partielle du lobe anterieur gauche du cerveau. Bull. Anthro. de la Soc. Anthro., 2, 235-238.

Brodmann, K. (1909). Lokalisationslehre der Grosshirnrinde. Leipzig: J. A. Barth.

Burstall, C. (1977). Primary French in the balance. Foreign Lang. Annals 10:3, 245-258.

Cajal, S. Ramón y (1899). Comparative study of the sensory areas of the human cortex. In: Clark University 1889-1899 Decennial Celebration. Worcester, Mass. pp. 311-382.

Capranica, R. R. (1965). The evoked vocal response of the bullfrog, Res. Mon., No. 33, Cambridge, Mass.: MIT Press

Capranica, R. R. (1966). Vocal response of the bullfrog to natural and synthetic mating calls. J. Acous. Soc. Am. 40, 1131-1139.

Carroll, J. B., and Sapon, S. (1959). Manual, Modern Language Aptitude Test. New York: The Psychological Corp.

Chan-Palay, V. (1973). Neuronal plasticity in the cerebellar cortex and lateral nucleus. *Z. Anat. Entwicklungsgesch.* 142, 23-35.

Conel, J. L. (1939-1963). *The Postnatal Development of the Human Cerebral Cortex.* Vols. 1-6. Cambridge, Mass.: Harvard U. Pr.

Cragg, B. G. (1972). Plasticity of synapses. In: *The Structure and Function of Neuron Tissue*, vol. 4. Bourne, G. H., ed. New York: Academic Press, pp. 1-60.

de Sauzé, E. B. (1959). *The Cleveland Plan for the Teaching of Modern Languages with Special Reference to French.* New York: Holt, Rinehart, and Winston.

Diller, K. C. (1972). Is there an optimum age for foreign language learning? A paper presented to the Third International Congress of Applied Linguistics, Copenhagen. Chapter 10 of *The Language Teaching Controversy.* Rowley, Mass.: Newbury House, 1978.

Diller, K. C. and Walsh, T. M. (1978). "Living" and "Dead" languages--a neurolinguistic distinction. A paper presented to the Fifth International Congress of Applied Linguistics, Montreal.

Durette, R. (1972). A five year FLES report. *Mod. Lang. J.* 56:1, 23-24.

Eilers, R. E. (1977). Context-sensitive perception of naturally produced stop and fricative consonants by infants. *J. Acoust. Soc. Am.* 61, 1321-1336.

Eilers, R. E., Minifie, F. D. (1975). Fricative discrimination in early infancy. *J. Speech and Hearing Res.* 18, 158-167.

Eilers, R. E., Wilson, W. R., and Moore, J. M. (1978). Developmental changes in speech discrimination in three-, six-, and twelve-month-old infants. *J. Speech and Hearing Res.*

Eimas, P. D. (1974). Auditory and linguistic processing for cues for place of articulation by infants. *Percep. and Psychophys.* 16, 513-521.

Eimas, P. D. (1975a). Speech perception in early infancy. In: L. B. Cohen and P. Salapatek, eds., *Infant Percep.* 2, 193-231. New York: Academic Press.

Eimas, P. D. (1975b). Auditory and phonetic coding of the cues for speech: discrimination of the r - l distinction by young infants. *Percep. and Psychphys.*, 18, 341-347.

Eimas, P. D. and Miller, J. L. (1977). Perception of initial nasal and stop consonants by young infants. Unpublished study.

Eimas, P. D., Siqueland, E. R., Jusczyk, P., and Vigorito, J. (1971). Speech perception in infants. *Science* 171, 303-306.

Eimas, P. D. and Tartter, V. C. (1978). On the development of speech perception: mechanisms and analogies. In press.

Ervin-Tripp, S. M. (1974). Is second language learning like the first. *TESOL Quarterly* 8:2, 111-127.

Fodor, J. A., Garrett, M. F. and Brill, S. L. (1978). Pi ka pu: the perception of speech sounds by prelinguistic infants. *Percep. and Psychophys.*, 18, 74-78.

Frishkopf, L. S., Capranica, R. R., and Goldstein, M. H. (1968). Neural coding in the bullfrog's auditory system: a teleological approach. Proc. IEEE 56:6, 969-980.

Gardner-Medwin, A. R. (1969). Modifiable synapses necessary for learning. Nature 223, 916-919.

Geschwind, N., Quadfasel, F. A., and Segarra, J. M. (1968). Isolation of the speech area. Neuropsychologia 6:327-340.

Globus, A. and Scheibel, A. B. (1967). The effect of visual deprivation on cortical neurons: a Golgi study. Exp. Neurol. 19, 331-345.

Goodglass, H. and Geschwind, N. (1976). Language disorders (aphasia). Handbook of Perception, Vol. 7, Language and Speech, Carterette, E. T., ed. New York: Academic Press.

Hillenbrand, J. Minifie, F. D., and Edward, T. J. (1977). Tempo of format--frequency change as a cue in infant speech discrimination. Paper presented at the meetings of the Society for Research in Child Development, New Orleans.

Hubel, D. H., and Wiesl, T. M. (1959). Receptive fields of single neurons in the cat's striate cortex. J. Physiol. 148, 574-591.

Hubel, D. H., and Wiesl, T. N. (1969). An anatomical demonstration of columns in the monkey striate cortex. Nature 221, 747-750.

Jacobson, M. (1970). Development, specification, and diversification of neuronal connections. In: The Neurosciences: Second Study Program. Schmitt, F. O., editor in chief. New York: Rockefeller University Press. pp. 116-129.

Jacobson, M. (1974). A plentitude of neurons. In: Studies on the Development of Behavior and the Nervous system, vol. 2, Aspects of Neurogenesis. Gottlieb, G., ed. New York: Academic Press. pp. 151-166.

Jacobson, M. (1975). Development and evolution of type II neurons: conjectures a century after Golgi. In: Golgi Centennial Symposium: Perspectives in neurobiology. Santini, M., ed. New York: Raven Press, pp. 147-151.

Jusczyk, P. W. (1977). Perception of syllable-final stop consonants by 2-month-old infants. Percep. and Psychophys. 21, 450-454.

Jusczyk, P. W., Rosner, B. S., Cutting, J. E., Foard, C. F., and Smith, L. B. (1977). Categorical perception of nonspeech sounds by 2-month-old infants. Percep. and Psychophys. 21, 50-54.

Lasky, R. E., Syrdal-Lasky, A., and Klein, R. E. (1975). VOT discrimination by four and six and a half month old infants from Spanish environments. J. Exp. Child Psy. 20, 215-225.

Lenneberg, E. (1967). Biological Foundations of Language. New York: Wiley.

Lettvin, J. Y., Maturana, H. R., McCulloch, W. S., and Pitts, W. H. (1959). What the frog's eye tells the frog's brain. Proc. IRE 47, 1941-1951.

McLaughlin, B. (1977). Second-language learning in children. Psychological Bull. 84, 435-457.

Mohr, J. P. (1976). Broca's area and Broca's aphasia. In: *Studies in Neurolinguistics, Vol. 1,* Whitaker H., and Whitaker, H.A., eds. New York: Academic Press.

Mountcastle, V. B. (1957). Modality and topographic properties of single neurons of the cat's somatic sensory cortex. *J. Neurophys.* 20, 408-434.

Penfield, W. (1953). A consideration of the neurophysiological mechanism of speech and some educational consequences. *Proc. of the Am. Acad. of Arts and Sci. 82*:5, 201-214.

Penfield, W. (1964). The uncommitted cortex, the child's changing brain. *The Atlantic Monthly* 214:1, 77-91.

Piaget, J. (1926). *The Child's Conception of the World.* New York: Harcourt, Brace and World.

Pimsleur, P. (1966). *Manual, Pimsleur Language Aptitude Battery.* New York: Harcourt Brace and World.

Rakic, P. (1974). Intrinsic and extrinsic factors influencing the shape of neurons and their assembly into neuronal circuits. In: *Frontiers in Neurology and Neuroscience Research.* Sesman, P., and Brown, G. M., eds. Toronto: The Univ. of Toronto Press. pp. 112-132.

Rakic, P. (1975). Local Circuit Neurons. *Neurosci. Res. Prog. Bull.* 13:3.

Scott, D. T. (1977). The infant's perception of natural and synthetic vowels and consonants. PhD thesis, Yale Univ.

Sholl, D. A. (1956). *The Organization of the Cerebral Cortex.* London: Methuen and Co.

Valverde, F. (1967). Apical dendritic spines of the visual cortex and light deprivation in the mouse. *Exp. Brain Res.* 3, 337-352.

Walberg, H. J., Keiko, H., and Rasher, S. P. (1978). English acquisition as a diminishing function of experience rather than age. *TESOL Quarterly* 12:4, 427-437.

Walsh, T. M. and Diller, K. C. (1978). Neurolinguistic foundations to methods of teaching a second language. *IRAL* 41:1, 1-14.

Walsh, T. M., and Ebner, F. F. (1970). The cytoarchitecture of somatic sensory-motor cortex in the opossum (*didelphis marsupialis virginiana*): a Golgi study. *J.Anat* (London)107,1-18.

Wells, W. (1974). Données descriptive de la population étudiante en cours de langue. Unpublished study for the Bureau of Languages, Public Service Commission, Ottawa.

Wiesl, T. N., and Hubel, D. H. (1974). Reorganization of ocular dominance columns in monkey striate cortex. *Program and Abstracts, Soc. for Neuroscience*, 4th Ann. Mtg., 478.

Wernicke, C. (1874). *Der Aphasische Symptomkomplex: Eine Psychologishe Studie auf Anatomischer Basis.* Breslau: Cohn & Weigert

Whitaker, H. (1976). A case of the isolation of the language function. In *Studies in Neurolinguistics*, 2, 1-58, Whitaker H., and Whitaker, H.A., eds. New York: Academic Press.

Young, J. Z. (1966). *The memory System of the Brain.* Berkeley: University of California Press.