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LATERALIZATION, LANGUAGE LEARNING, AND THE CRITICAL PERIOD: SOME NEW EVIDENCE

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New evidence is presented that modifies Lenneberg's (1967) proposed critical period of language acquisition. The development of lateralization is complete much earlier than puberty and is thus not a barrier to accent free second language learning by adults. Rather, the development of lateralization may correspond to normal first language acquisition. Also, the case of Genie, a girl who endured 11 years of enforced isolation, shows that some first language acquisition is possible after the critical period, although mechanisms outside of the left hemisphere may be involved. Genie's slow but steady progress also implies that adult achievement in learning second languages should not be pre-judged.

In *Biological Foundations of Language*, Lenneberg suggests that natural language acquisition "by mere exposure" can only take place during a critical period, lasting from about age two to puberty. Before two, language acquisition is impossible due to maturational factors, while natural acquisition of language after puberty is blocked by a loss of "cerebral plasticity" supposedly caused by the completion of the development of cerebral dominance, or lateralization of the language function. It is this biologically based critical period, Lenneberg suggests, that is responsible for the fact that "automatic acquisition from mere exposure to a given language seems to disappear after this age (puberty)" and "foreign accents cannot be overcome easily after puberty" (Lenneberg 1967:176). Scovel (1969) has in fact suggested that if such a critical period exists, it is futile for foreign language teachers to attempt to rid their older students of their accents.

This paper will report on areas of current neurolinguistic research that modify and shed new light on Lenneberg's notion of a critical period. First, evidence will be presented that the de-

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velopment of language lateralization is complete far earlier than puberty, perhaps as early as age five. Thus, while a critical period may exist, its neurological substrata is not the development of lateralization. Second, the concept of cerebral plasticity and its relation to second language learning and lateralization will be re-examined. Finally, we will examine a striking test case of the critical period for first language acquisition, the case of Genie, a girl who is presently involved in first language learning at the age of 16.

THE DEVELOPMENT OF LATERALIZATION

The effect of unilateral brain damage in children

Lenneberg presents the following picture of the development of lateralization: cerebral dominance for language is first detectable between ages three and five and becomes gradually stronger, the right hemisphere performing less and less of the language function until puberty, by which time the degree of dominance of the left hemisphere is permanently established. Lenneberg cites two kinds of clinical data as evidence for the lateralization-by-puberty hypothesis, data from "transfer" of function, which will be dealt with below, and data from the effect of unilateral brain damage in children.

Lenneberg cites data from Basser (1962) to support the claim that injuries to the right hemisphere cause more language disturbance in children than adults (Table 1). This would indicate that the right hemisphere is more strongly involved in the language function during childhood. Table 1 indicates that in children injured "after the onset of speech and before age 10" (Lenneberg 1967:151) right sided lesions cause aphasia more often than in adults; of the twenty cases of speech disturbance reported by Basser, thirteen were from left lesions, or 65%. For adults, Russell and Espir (1961) found that 198 of 205 cases of aphasia were caused by left lesions, or 97%. This suggests that children 10 and under are less lateralized than adults.

TABLE 1*

Lesions after onset of speech and before age 10

	After catastrophe speech was normal	disturbed
Left Hemisphere	2	13
Right Hemisphere	8	7

*from Lenneberg 1967: 151.

On closer examination, however, this data is consistent with the hypothesis that the development of lateralization is complete by five. In all cases of injury to the right hemisphere resulting in speech disturbance, the lesion was incurred before five. There is just one case in Basser's study of a child who incurred a right lesion after five; case XV was injured at ten, but since no speech disturbance resulted, this case does not supply evidence for Lenneberg's hypothesis.

Studies that include descriptions of children injured after five indicate that the effects of right lesions in older children is the same as in adults. Table 2 summarizes these studies and includes Basser and Russell and Espir's data for comparison.

TABLE 2

Summary of studies of aphasia resulting from unilateral lesions

Study	Age range of subjects	Number of cases	Percent with right lesions
Guttman 1942	2 to 14	15	7%
Alajouanine and Lhermitte 1965	6 to 15	32	0%
McCarthey 1963	after language acquisition	114	4%
Basser 1962	before 5	20	35%
Russell and Espir 1961	adulthood	205	3%

These studies indicate that the strength or involvement of the right hemisphere in older children is the same as during adulthood, a conclusion consistent only with the hypothesis that lateralization is established around age five.

Data from psychological testing

Additional evidence that the development of lateralization is complete well before puberty comes from reports of psychological testing of children with unilateral brain damage, performed by MacFie (1961) and Fedio and Mirsky (1969). Both studies conclude that the effect of unilateral brain damage in children is the same as in adults; left lesions impair performance on verbal tests and do not affect performance on spatial and configurational tests, while right sided lesions impair performance on spatial and configurational tests and do not affect verbal scores.

Neither MacFie nor Fedio and Mirsky give the age at which the lesion was incurred for all subjects tested. MacFie comments only that his subjects were young children older than one while Fedio and Mirsky reported that their subjects' mean age of seizure onset was about six (the actual lesion may have been earlier). Thus, this data does not point to a specific age by which the development of lateralization is complete. It is, however, fully consistent with the clinical data presented above and is further evidence that lateralization is established well before puberty.

Dichotic listening

Dichotic listening has been used since 1961 (Kimura 1961) in the study of hemispheric asymmetry and has proven to be a safe and reliable procedure. In dichotic listening, subjects are presented with competing simultaneous auditory stimuli, one to each ear. In right handed subjects the right ear generally excels for verbal material, reflecting left hemisphere specialization. The left ear excels for certain non-verbal stimuli (environmental sounds, Curry 1967, and musical chords, Gordon 1970), indicating right hemisphere dominance.

The lateralization-by-puberty hypothesis predicts that in dichotic listening the degree of right ear superiority would gradually increase throughout childhood, reflecting the growing dominance of the left hemisphere, whereas the lateralization-by-five hypothesis predicts that the degree of right ear superiority would not change after age five. Published data from experiments using children as subjects (Kimura 1963, Knox and Kimura 1970, Geffner and Hochberg 1971) has been analyzed (Krashen and Harshman 1972, Krashen 1972) using a scoring procedure that is relatively free of the effects of accuracy variation and that corrects for the effects of guessing (Harshman and Krashen 1972). This procedure, termed the "percent of errors" method, consists of computing each ear's contribution to the total number of errors. Using data from adult tests Harshman and Krashen have demonstrated that percent of errors scores do not correlate with accuracy variations, while ear difference scores produced by other procedures are significantly biased by accuracy variations. No significant change in degree of lateralization or right ear advantage was found for the age range tested, from four to nine. In addition, the degree of lateralization exhibited by the children is the same as that shown by adults tested under similar conditions (Harshman and Krashen forthcoming). These results have recently been confirmed by Berlin, Lowe-Bell, Hughes, and Berlin (1972).

This result suggests that the development of lateralization may

even be complete by age four. This is consistent with most of the clinical data, except for Basser's cases 32 and XII, right lesions with resultant speech disturbance injured at five and one half years of age. Despite this conflict, the dichotic listening, clinical, and testing data all place the completion of the development of lateralization far earlier than puberty.

Transfer and cerebral plasticity

"Transfer" refers to the ability of the minor hemisphere to take over the language function in case of serious injury to the dominant hemisphere. Lenneberg (1967) and Scovel (1969) link this kind of interhemispheric plasticity with the plasticity necessary for natural and accent-free language acquisition. The theory of transfer assumed by Lenneberg and Scovel is that lateralization and the ability to transfer are linked; transfer consists of mobilizing those linguistic capacities of the right hemisphere which have not yet fully lateralized to the left hemisphere. This predicts that once the development of lateralization is complete, perfect transfer is no longer possible.

If transfer is linked to the development of lateralization, and if this development is complete by puberty, transfer ought to be possible until puberty. Actual data on transfer indicates that perfect transfer is definitely possible before five; Basser (1962) and White (1961) report a total of 66 cases of left hemispherectomy (removal of the entire left hemisphere) for lesions incurred before five with no resultant permanent aphasia. Lenneberg (1967: 152) notes that Basser's cases were injured "before teens" and uses this data as evidence that transfer is possible just up to puberty. Again, in all cases, the lesion was incurred before five. For lesions incurred during adulthood, complete transfer has not yet been reported (see Smith 1966 and Hillier 1954 for left hemispherectomies performed on adults and Kinsbourne 1971 for three cases of partial transfer, or aphasic right hemisphere speech, in adults detected by the Wada test, injection of an anesthetic to half the brain at a time).

Unfortunately for our discussion, there is little data on transfer associated with lesions incurred between five and puberty. Gardiner, Karnosh, McClure, and Gardiner (1955) report a left hemispherectomy performed on a left-handed girl for a tumor whose onset was at age nine. There was some permanent aphasia after the operation. There is suspicion of earlier brain damage in this case ("general convulsions" at age three) and the handedness confuses the issue (about one-third of all left handers have reversed dominance, language in the right hemisphere and spatial

functions in the left). White (1961) mentions a left hemispherectomy performed on a young man who received "trauma" to the left hemisphere at nine. Apparently, removal of the left hemisphere did not affect language at all. No case history or handedness data was available, however.

In addition, Lansdell (1969) reported on 18 cases of right hemisphere speech preceded by left lesions; in 14 of the cases the injury clearly took place before age five. In one case the age of onset was six. In another, the only detail provided is that seizures began at sixteen (the injury could have been earlier), and in a third, childhood brain damage was suspected. Only one case out of 18 cannot be accounted for by the lateralization-by-five hypothesis—a case of right hemisphere speech with lesion at ten (who might have been originally right dominant).

Striking evidence that transfer may be impossible after five is provided by Rasmussen in discussion following Zangwill (1964). Five cases of left damage in right handed (and thus most probably left dominant) children are reported. Each child experienced and recovered from aphasia. Transfer of dominance, revealed by right hemisphere performance on the Wada test, occured in the three children who were five or under at the time their lesion was incurred (two, three, and five), but not in the children who were seven and eight years old at the time of the lesion.

While transfer seems to be at best rare after five, data is scarce and the possibility still remains that complete transfer is possible until puberty; the plasticity necessary for successful language acquisition may be connected to interhemispheric plasticity. Note, however, that the lesion, dichotic listening, and testing data place the completion of the development of lateralization much earlier than puberty. If transfer were possible until puberty, this would imply that lateralization and transfer are not directly related. It is logically possible that the right hemisphere can retrain itself to do language despite its full specialization for other functions (this possibility was independently suggested by Richard Harshman and Eric Lenneberg).

The relationship of lateralization and language learning

If the development of lateralization is complete by around five and is thus not connected to Lenneberg's critical period, does it have any relationship to language learning? Krashen and Harshman (1972) (also Krashen 1972) argue that first language acquisition itself, also complete by around five, may be related to the development of lateralization. See Chomsky (1969) and Hatch (1969) for evidence that the five year old has not yet attained full competence in his language. Note that fairly subtle testing procedures were necessary to expose these previously undetected gaps, which for the most part involve exceptions to rules. The fact remains that the five year old has certainly mastered the fundamentals of his language. Either the two processes may go hand-in-hand, or, as Krashen and Harshman suggest, language acquisition may involve and depend on the previous lateralization of certain functions (this view is explicated and supported in Krashen 1972). Thus, the development of lateralization may represent the acquisition of an ability rather than the loss of an ability.

FIRST LANGUAGE ACQUISITION AFTER PUBERTY: THE CASE OF GENIE

The case of Genie, an adolescent girl who endured 11 and a half years of extreme social and experiental deprivation, is the most direct test of the critical period seen thus far. Genie emerged from isolation at the age of 13 years, eight months, with little if any linguistic competence and no linguistic performance, and was thus faced with the task of first language acquisition with a post pubescent brain (for details concerning Genie's personal history and the conditions of her confinement see Curtiss, Fromkin, Krashen, Rigler, and Rigler forthcoming). Despite this, and despite previous negative reinforcement for speaking (the result of her having been punished for making any noise whatever), Genie has shown slow but steady progress in language learning over the past two years. At the time of this writing, Genie can understand and produce three and four word sentences expressing negation, locative relations, SVO relations, possessives, and modification (for details of Genie's syntactic and phonological competence, see Curtiss *et al.* forthcoming, and Curtiss, Krashen, Fromkin, Rigler, and Rigler 1973).

Neurolinguistic research with Genie has thus far revealed two related findings; dichotic listening tests have shown that Genie is processing language in her minor, right hemisphere, and psychological testing, conducted by Dr. D. Rigler of Children's Hospital, Los Angeles, has shown that she performs surprisingly well in tests that involve skills that are normally dependent on right hemisphere mechanisms.

With the assistance of Lloyd Rice and Sarah Spitz of the UCLA Phonetics Laboratory, special dichotic tapes were prepared for Genie, one consisting of words familiar to her and the other consisting of familiar environmental sounds.

Genie was first tested monaurally (one ear at a time) and

scored 100% in each ear. As is reported elsewhere (Krashen, Fromkin, Curtiss, Rigler, and Spitz 1972), Genie manifested an extreme *left ear* advantage for verbal material, the left ear doing perfectly and the right ear performing at a chance level. Both the direction and degree of ear difference are very unusual. Since Genie is right handed, a right ear advantage was expected. Also, the ear difference usually found in dichotic listening is not large and statistical tests are generally necessary to show significant differences. Ear differences as extreme as found with Genie have been found thus far only in split-brain subjects (subjects who have undergone surgery for the control of epilepsy that involved cutting the nerve fibers connecting the two hemispheres—Milner, Taylor, and Sperry 1968) and in hemispherectomized subjects (Berlin, Lowe-Bell, Porter, Berlin, and Thompson 1972, and Curry 1968).

For environmental sounds Genie showed the expected moderate left ear advantage, pointing to right hemisphere processing. In a recent study, Krashen and Spitz have shown that environmental sounds may yield a right ear advantage when presented under certain conditions to male subjects and no ear difference for female subjects. This result is not inconsistent with the hypothesis that Genie is using her right hemisphere for both verbal and nonverbal processing, since she did show a left ear advantage. Nevertheless, efforts are now being made to determine cerebral localization of other functions in Genie.

TABLE 3

Comparison of Genie's results with other dichotic studies

Subjects	stimuli	RE	LE	study
normals	words	60%	52%	(Curry, 1968)
Genie	words	16%	100%	
split-brains	words	91%	22%	(Milner *et al.* 1968)
hemispherectomies (right)	words	99%	24%	(Berlin *et al.* 1972)
normals	env. sds.	27%	29%	(Curry, 1968)
Genie	env. sds.	65%	93%	

In other reports (Krashen *et al.* 1972, Krashen, Fromkin, and Curtiss 1972), it is argued that Genie may have begun language acquisition (before her confinement) with her left hemisphere. Through disuse the left hemisphere is now no longer able to fulfill its

original linguistic function, and Genie may now be using her right hemisphere to learn language. This explains the direction of her results, the left ear advantage. The degree of ear difference may be due to the "atrophied" left hemisphere language areas preventing the flow of impulses arriving at the right ear from reaching the right hemisphere (Figure 1).

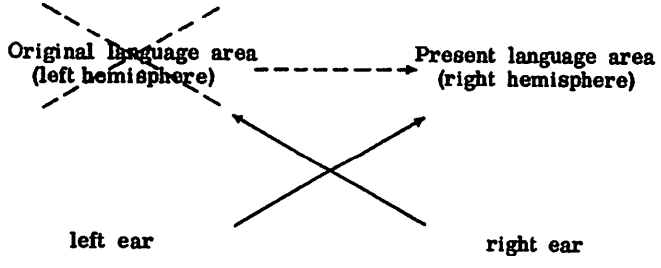

Figure 1. Dichotic listening model for Genie.

The environmental sounds results indicates that for Genie *both* linguistic and non-linguistic processing is taking place in the right hemisphere; thus Genie is not merely one of those individuals with "reversed" laterality (language in the right and non-language in the left).

Dr. D. Rigler has observed that Genie's behavior on psychological tests can be meaningfully comprehended when performance on two kinds of tests is distinguished: those that involve analytic or sequential use of symbols, such as language and number, and those that involve perception of spatial configurations or Gestalts. On the first group of tasks (Peabody Picture Vocabulary Test, Columbia Mental Maturity Test) Genie's performance is consistently in the low range, presently approximating an age of two and a half to three years. Compared with her behavior on admission to the hospital, this represents a growth of about one and a half years over a two year period. On configurational tests (the Street Test, the WISC Performance Tests) her performance lies somewhere between eight years and the adult level, depending on the test. The rate of growth on these tests has been very rapid.

Both the dichotic listening and psychological testing results are consistent with the hypothesis that Genie is using her healthy right hemisphere for both verbal and nonverbal functions; what are generally considered right hemisphere functions (perception of the environment, spatial relations) thrive quite well, while Genie's

hemisphere is not as successful with what are considered left hemisphere functions. Note that this is consistent with reports of existing but deficient right hemisphere speech in adults (Smith 1966, Hiller 1954, Kinsbourne 1971).

Thus, while the normal development of lateralization may not play a role in the critical period, lateralization may be intimately involved in a different way; the left hemisphere must perhaps be linguistically stimulated during a specific period of time for it to participate in normal language acquisition. If stimulation does take place during this time, any language acquisition must depend on other cortical areas and will proceed less efficiently due to the previous specialization of these areas for other functions.

SUMMARY AND CONCLUSION

The main points of this paper are (1) the developmental course of lateralization is not associated with Lenneberg's proposed critical period, since lateralization is complete far earlier than puberty. Available evidence does not as yet preclude the possibility that limitations of interhemispheric transfer are associated with the critical period (although the demonstration that transfer is possible until puberty does not demonstrate the existence of a critical period), and (2) first language learning is definitely possible after puberty, although this language learning may not be as rapid or efficient as normal first language acquisition and may depend on cortical mechanisms outside the left hemisphere.

Completion of lateralization thus does not mean the establishment of an absolute barrier to language acquisition. Hill (1971), for example, cites cross-cultural studies that question the inevitability of foreign accents in second languages learned after puberty. Genie's continuing progress in first language acquisition, moreover, should encourage second language learners, the vast majority of whom possess healthy left hemispheres. Until we see Genie's limitations, the capacity of adult second language learners should not be pre-judged.

REFERENCES

Alajouanine, T. and F. Lhermitte. 1965. Acquired aphasia in children. Brain 88.653-662.

Basser, L. 1962. Hemiplegia of early onset and the faculty of speech with special reference to the effects of hemispherectomy. Brain 85.427-460.

Berlin, C., S. Lowe-Bell, R. Porter, H. Berlin and C. Thompson. 1972. Dichotic signs of the recognition of speech elements in normal, temporal lobectomies, and hemispherectomies. Proceedings from the International Conference on Speech Communication and Processing. Boston, Mass.: April 24-26, 1972.

Berlin, C., S. Lowe-Bell, L. Hughes and H. Berlin. 1972. Dichotic right ear advantage in males and females - ages 5 to 13. Journal of the Acoustical Society of America 53.368. (Abstract)

Chomsky, C. 1969. The Acquisition of Syntax in Children from 5 to 10. Cambridge, Mass.: MIT Press.

Curry, F. 1967. A comparison of left-handed and right-handed subjects on verbal and nonverbal dichotic listening tasks. Cortex 3.343-352.

Curry, F. 1968. A comparison of the performance of a right hemispherectomized subject and twenty-five normals on four dichotic listening tasks. Cortex 4.144-153.

Curtiss, S., S. Krashen, V. Fromkin, D. Rigler and M. Rigler. 1973. Language acquisition after the critical period: Genie as of April, 1973. Proceedings of the ninth regional meeting of the Chicago Linguistic Society (in press).

Fedio, P. and A. Mirsky. 1969. Selective intellectual deficits in children with temporal lobe or centrenchephalic epilepsy. Neuropsychologia. 7.287-300.

Gardiner, W., L. Karnosh, C. McClure and A. Gardiner. 1955. Residual function following hemispherectomy for tumor and infantile hemiplegia. Brain 78.487-502.

Geffner, D. and I. Hochberg. 1971. Ear laterality performance of children from low and middle socioeconomic levels on a verbal dichotic listening task. Cortex 7.193-203.

Gordon, H. 1970. Hemispheric asymmetries in the perception of musical chords. Cortex 6.387-398.

Guttmann, E. 1942. Aphasia in children. Brain 65.205-219.

Harshman, R. and S. Krashen. 1972. An "unbiased" procedure for comparing degree of lateralization of dichotically presented stimuli. UCLA Working Papers in Phonetics 23.1-13. Abstract in Journal of the Acoustical Society of America 52.174.

Hatch, E. 1969. Four experimental studies in syntax of young children. Technical Report 11. Los Alamitos, Calif.: Southwest Regional Laboratories.

Hill, J. 1971. Foreign accents, language acquisition, and cerebral dominance revisited. Language Learning 20.237-248.

Hillier, W. 1954. Total left hemispherectomy for malignant glioma. Neurology 4.718-721.

Kimura, D. 1961. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology 15.166-171.

Kimura, D. 1963. Speech lateralization in young children as determined by an auditory test. Journal of Comparative and Physiological Psychology 56.899-902.

Kinsbourne, M. 1971. The minor cerebral hemisphere as a source of aphasic speech. Archives of Neurology 25.302-306.

Knox, C. and D. Kimura. 1970. Cerebral processing of nonverbal sounds in boys and girls. Neuropsychologia 8.227-237.

Krashen, S. 1972. Language and the left hemisphere. UCLA Working Papers in Phonetics 24.

Karshen, S., V. Fromkin and S. Curtiss. 1972. A neurolinguistic investigation of language acquisition in the case of an isolated child. Paper

presented at the 47th meeting of the Linguistic Society of America. Atlanta, Ga.: December, 1972.

Krashen, S., V. Fromkin, S. Curtiss, D. Rigler and S. Spitz. 1972. Language lateralization in a case of extreme psychosocial deprivation. Journal of the Acoustical Society of America 53.367. (Abstract)

Krashen, S. and R. Harshman. 1972. Lateralization and the critical period. Journal of the Acoustical Society of America 52.174. (Abstract). also in UCLA Working Papers in Phonetics 23.13-21.

Lansdell, H. 1969. Speech and age at brain injury. Journal of Comparative and Physiological Psychology. 734-738.

Lenneberg, E. 1967. Biological foundations of language. New York: Wiley and Son.

MacFie, J. 1961. Intellectual impairment in children with localized post-infantile cerebral lesions. Journal of Neurology, Neurosurgery and Psychiatry 24.361-365.

McCarthey, quoted in Osgood and Miron (eds.). 1963. Approaches to the study of aphasia. Urbana, Ill.

Milner, B., L. Taylor and R. Sperry. 1968. Lateralized suppression of dichotically presented digits after commisural section in man. Science 161. 184-186.

Russell, R. and M. Espir. 1961. Traumatic Aphasia. Oxford: Oxford University Press.

Scovel, T. 1969. Foreign accents, language acquisition, and cerebral dominance. Language Learning 19.245-254.

Smith, A. 1966. Speech and other functions after left (dominant) hemispherectomy. Journal of Neurology, Neurosurgery and Psychiatry 29.467-471.

White, H. 1961. Cerebral hemispherectomy in the treatment of infantile hemiplegia. Confinia Neurologica 21.1-50.

Zangwill, O. 1964. The current status of cerebral dominance. Research Publications—Association for Research in Nervous and Mental Disease. 42.105-113. Baltimore: Williams and Wilkins.