

Functional precursors to language and its lateralization

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MACNEILAGE, PETER F., MICHAEL G. STUDDERT-KENNEDY, AND BJORN LINDBLOM. *Functional precursors to language and its lateralization*. Am. J. Physiol. 246 (Regulatory Integrative Comp. Physiol. 15): R912-R914, 1984.—An adequate account of language evolution must reconcile the propositions that language is unique but has precursors. The paper of Bellman and Goldberg and that of Tzeng and Wang each neglects one of these propositions. We suggest that the uniqueness of language lies primarily in its dualistic structure which has a frame-content mode of organization: at the phonological level, consonant and vowel elements are inserted into syllabic frames; and at the morphological level, stem forms of content words are inserted into syntactic frames. We suggest that the morphological level evolved from the phonological level and that the frame-content mode of organization in phonology had a precursor in the form of bimanual coordination in which the nonpreferred (frame) hand holds an object operated on by the preferred hand (content). It is argued that lateralization of cortical function evolved first for bimanual coordination, then for language. Old World monkey hand preferences may be consistent with both the putative left-hemisphere specialization for bimanual coordination and the human right-hemisphere specialization for spatial functions.

frame-content mode of organization; Old World monkey; right-hemisphere specialization; left-hemisphere specialization

WE BELIEVE that an adequate account of language in the context of movement must reconcile the apparently conflicting propositions that language is unique yet must have evolved from functional adaptations, including motor adaptations, present in other animals. Consequently we find fault with two papers in this symposium, each of which neglects one of these propositions. We find fault with Bellman and Goldberg (1) for not coming to terms with the uniqueness of language and with Tzeng and Wang (12) for not providing a plausible functional progression for its evolution. Tzeng and Wang rightly point out that duality of patterning in language—the existence of both morphological and phonological levels with their own ordering rules—is the main basis for its uniqueness. However, Bellman and Goldberg do not even mention this property. They simply define language as a symbolic system in terms so general as to be unacceptable to the majority of those seriously interested in language. Their R912

definition certainly allows a common origin for linguistic and movement processes (and presumably perception and cognition as well) in intracellular communication of unicellular organisms but does not begin to address the origins of dual structure.

Curiously, Tzeng and Wang (12) also do not attempt to account for the origins of duality, nor do they consider the unique properties of the structures they deem so important. They propose that the left-hemisphere specialization for language is due to the evolution of a new type of timing ability in the left hemisphere of hominids, serving both our dualistic linguistic structure and our advanced voluntary movement capacity. This claim has a number of problems. 1) The timing specialization is considered to have evolved de novo. Yet the cat, the hawk, and even the fish, seizing their prey, surely require no less perceptuomotor coordination and timing control than the hominid throwing a rock at a running rabbit. Moreover the manual organization of a baboon opening a puzzle box at the rate of 7.5 acts per second, with the acts smoothly overlapping in time (“coarticulated”?) and little temporal variability from trial to trial (11), appears to share temporal precision with language acts. A precise timing mechanism is therefore not new, and this is as it should be, since the dominant mode of evolution is to capitalize on already existing adaptations. 2) We do not know of any evidence for the evolution of adaptive *metafunctions*, such as timing (or analyticity), rather than of adaptive *functions*: modes of behavioral control could hardly evolve without specific behaviors to control, but Tzeng and Wang do not suggest what these behaviors might be. 3) There is no rationale for the lateralization of the supposed metafunction: the fact that two hemispheres may differ in physiological design, as Semmes (9) argues, is not an explanation. On the contrary, it is precisely the differences in design that we have to explain. 4) There is no plausible explanation for why a lateralized specialization should have arisen in hominids but not in other primate species. As it happens, there is plausible evidence for a lateralized precursor of language in nonhuman primates, but it is not well described in terms of timing control.

Accordingly we wish to propose an alternative view of the evolution of language in the context of movement

that is consistent with its unique dual pattern, its lateralization, and the evolutionary principle of conservation of adaptive functions.

Our starting point, like that of Tzeng and Wang, is in the serial organization of speech. Of particular interest are segmental spoonerisms in which the dominant mode is for the exchanged vowels or consonants to move to a position in a syllable like the one from which they moved (e.g., pit bull → bit pull, fish and tackle → fash and tickle, and night life → knife light); vowels and consonants virtually never exchange. As Shattuck-Hufnagel (10) has pointed out, this demands a phonological device in which the syllabic structure of the output is specified independently of the segmental content elements: content elements are inserted into frames.

We believe this frame-content mode of organization in the time domain is unique to the motor control of language in that serial-ordering errors in other sequential motor tasks do not obey analogous structural restrictions. For example, in typing errors, vowels and consonants readily exchange with each other and exchanged letters do not preserve restrictions related to their position in higher-order units (6). In addition, informal consideration of music and the equivalent of the phonological level in the sign language of the deaf does not reveal any general pattern of serial structure constraints on errors.

The adaptive function of this mode is, of course, as Tzeng and Wang (12) remark, to permit the construction of a very large set of distinctive signals (words) by permutation of a small number of articulatory gestures.

We wish to argue that once the frame-content mode of organization evolved at the phonological level, it was used again (as is typical of evolution) at the higher level of the dualistic system, the morphological level. The occurrence of morphological spoonerisms, such as "McGovern favors busting pushers → McGovern favors pushing busters" suggests a mechanism whereby morphological content elements ("push" and "bust") are inserted into syntactic frames (3).

We believe this frame-content mode of organization of language is a major source of its uniqueness but that it nevertheless did not evolve de novo. We suggest that this frame-content mode in phonology had a precursor in bimanual coordination, particularly the mode in which an object in the nonpreferred hand (the frame) is operated on by the preferred hand (content). Note, however, that serial-ordering errors in bimanual coordination are not subject to the structural restrictions observed for speech, because unlike speech the manual frame is not differentiated in time in a single stereotyped manner. This difference makes it less obvious that bimanual

coordination could be a precursor to speech.

One might expect that a consistent simultaneous division of labor between a more-skilled and a less-skilled hand acting in coordination would require a single controller, and because of the relatively great learning component in bimanual coordination tasks, one might expect the control to be situated in cerebral cortex. Consequently lateralization of the control function to one hemisphere, presumably the one contralateral to the preferred hand, would be expected. In accordance with this expectation, Trevarthen (11) concludes from a study of bimanual coordination in baboons, using a split-brain paradigm, "The schema governing the serial and spatial ordering of both hands . . . was laid down at the end of learning the skill in one side of the brain more fully than the other" (11, p. 37).

The evolution of hemispheric specialization for bimanual coordination may have paralleled the evolution of the opposable thumb in Old World monkeys (7). Structural asymmetries between the hemispheres analogous to those in humans have been shown in Old World monkeys (2) and great apes (4). We believe these to be more related to the evolution of bimanual coordination than to language. In a recent review of primate handedness (MacNeilage et al., unpublished observations), we found that, contrary to accepted belief (e.g., 13), there is evidence of a right-hand preference for object manipulation in Old World monkeys. There is also evidence for a concurrent left-hand preference for visually guided movements in extrapersonal space which may be a precursor to the human right-hemisphere specialization for spatial functions.

In summary we suggest that the unique dualistic structure of language and its functional lateralization in the brain had an important precursor in the frame-content mode of bimanual coordination, with its associated hemispheric specialization. This development made possible the separation of frame and content in language, at the phonological level, which in turn made the same mode of function possible at the morphological level. Obviously a precise chronology of the supposed stages of this evolutionary progression is not available. But the finding of Peterson et al. (8) of left-hemisphere specialization for perceptual processing of conspecific calls in Old World monkeys suggests that specialization for vocal communication and bimanual coordination may already coexist in this infraorder. An extended treatment of the views summarized here is presently being prepared (5).

Preparation of this paper was supported by Grant NS-15336-05 from the National Institute of Neurological and Communicative Disorders and Stroke.

REFERENCES

1. BELLMAN, K. L., AND L. J. GOLDBERG. Common origins of linguistic and movement abilities. *Am. J. Physiol.* 246 (*Regulatory Integrative Comp. Physiol.* 15): R915-R921, 1984.
2. FALK, D. External neuroanatomy of Old World monkeys (Cercopithecoidea). In: *Contributions to Primatology*. Basel: Karger, 1978, vol. 15.
3. GARRETT, M. The analysis of sentence production. In: *Psychology of Learning and Motivation*, edited by G. Bower. New York: Academic, 1975, vol. 9, p. 133-177.
4. LEMAY, M. Morphological cerebral asymmetries of modern man, fossil man, and non-human primate. In: *Origins and Evolution of Language and Speech*, edited by S. R. Harnad, H. D. Steklis, and J. Lancaster. *Ann. NY Acad. Sci.* 280: 349-366, 1976.
5. LINDBLOM, B., P. F. MACNEILAGE, AND M. G. STUDDERT-KENNEDY. *Biological Bases of Spoken Language*. New York: Academic, In press.

6. MACNEILAGE, P. F. A comparison of speech and typing errors. In: *Linguistic Phonetics*, edited by V. A. Fromkin. New York: Academic. In press.
7. NAPIER, J. R. The evolution of the hand. *Sci. Am.* 227: 56-62, 1972.
8. PETERSON, M. R., M. D. BEECHER, S. R. ZOLOTH, D. B. MOODY, AND V. C. STEBBINS. Neural lateralization of species-specific vocalization by Japanese macaques (*Macaca fuscata*). *Science* 202: 324-326, 1978.
9. SEMMES, J. Hemispheric specialization: a possible clue to mechanism. *Neuropsychologia* 7: 11-26, 1968.
10. SHATTUCK-HUFNAGEL, S. Speech errors as evidence for a serial ordering mechanism in sentence production. In: *Sentence Processing: Psycholinguistic Studies Presented to Merrill Garrett*, edited by MACNEILAGE, STUDDERT-KENNEDY, AND LINDSAY, W. E. Cooper and E. C. T. Walker. Hillsdale, NJ: Erlbaum, p. 297-342.
11. TREVARTHEN, C. Manipulative strategies of baboons and origins of cerebral asymmetry. In: *Asymmetrical Functions of the Brain*, edited by M. Kinsbourne. Cambridge, UK: Cambridge University Press, 1978, p. 329-391.
12. TZENG, O. J. L., AND W. S.-Y. WANG. Search for a common neurocognitive mechanism for language and movements. *Ann. N.Y. Acad. Sci.* 415: 1-15, 1983. *Physiol.* 246 (*Regulatory Integrative Comp. Physiol.* 15): 1-15, R911, 1984.
13. WARREN, J. M. Handedness and laterality in humans and other animals. *Physiol. Psychol.* 8: 351-359, 1980.