of the correct object appears. If similar results are obtained for the two hands, i.e., a deficient performance by the right as compared to the left hand in non-euclidean tasks, then this would demonstrate the perceptual primacy of the problem, unless proponents of the manipulospatiality explanation want to argue that pressing a button with a fingertip makes it a manipulospatial one!

340

Cerebral hemispheres: Specialized for the analysis of what?

Michael Studdert-Kennedy

Queens College, City University of New York, Flushing, N.Y. 11367 and Haskins Laboratories, New Haven, Conn. 06510

What we miss in Bradshaw & Nettleton's (B & N's) target article is an approach to the biological functions of hemispheric specialization. Questions of mechanism cannot, or should not, be separated from questions of phylogenetic origin. Indeed, B & N do seem to have the question of origin in mind when they refer to ". . . a possible prior mode" and to ". . . a more fundamental, antecedent mode of specialization." But once they have characterized this mode as "analytic/holistic," their brief fling with biology is at an end. Presumably, behavioral modes do not evolve without a behavior to support, but the authors give no indication of what this behavior might be. They do not even ask. And so their conclusion is trivial, scarcely more illuminating and of no more heuristic value than if, following the mythological lead of Nietzsche and Freud, they had assigned the left hemisphere to Apollo, the right to Dionysus. In short, the target article lacks both depth and scope.

Consider its scope. From the grand title and from the authors' evident concern with cerebral specialization for language, we might expect them to assess studies of circumscribed unilateral lesions (the oldest and perhaps least problematic body of data bearing on the topic; Milner 1974), of unilateral sodium amytal injection (Milner, Branch & Rasmussen 1964; Milner 1974), of hemispherectomy (Dennis 1980), of brain stimulation (Penfield & Roberts 1959; Ojemann & Mateer 1979), of electrical response potentials (Desmedt 1977; Molfese 1979), of intracranial blood-flow (Lassen & Larsen 1980; Wood 1980). We might even look for some account of current work in neurolinguistics which, by means of a revitalized connectionist theory (Goodglass & Geschwind 1976), acknowledging local variation within as well as between hemispheres, is exploring aphasic patients' defects in lexical access and syntactic processing (e.g., Zurif & Blumstein 1978). We would surely expect a detailed critique of the commissurotomy studies, particularly the work of Zaidel (e.g., 1978) bearing on the linguistic capabilities of the right hemisphere. The piece might wind to its close with what we largely do get from the present target article, namely, a summary of laterality studies in normals. After such a review we might well be tempted to capture the *perceptual* capacities of the hemispheres with "analytic/holistic" (cf. Morais 1980), but we would surely also want to acknowledge their motor dissociation. And we might be struck by the fact that the two dissociations are at their most salient in language: The right hemisphere is mute, perceptually restricted to holistic lexical access and to a minimal syntax, while the left is skilled in the production and perception of both syntactic and phonological pattern. These facts might even lead us to suspect that the linguistic specialization was prior to the "analytic" rather than the reverse.

However, the actual strategy of the target article is to cast doubt on particular modes of specialization, such as those for face recognition and language. As far as language is concerned, the authors largely confine their doubts to what they perhaps suspect is the weakest area, namely, specialization for speech perception. Yet they misunderstand the nature of the claims that have been made. The general claims have been that speech is unique because it is the only effective acoustic carrier of language (Liberman, Cooper, Shankweiler & Studdert-Kennedy 1967) and that phonetic processes are integral to language.

Support for the claim that speech is unique comes, not as Cutting (1979), Schouten (1980), and B & N seem to suppose, from various laboratory oddities, such as categorical perception and selective adaptation, but from many years of attempts to construct alternative output codes for use in reading machines for the blind. These attempts have not yet yielded anything more efficient than Morse code (for which federal licenses are granted to operators able to transcribe 13 words a minute). This is hardly surprising (we certainly would not expect to find an effective acoustic substitute for the species-specific song of, say, the chipping sparrow), but it does challenge us to specify just how speech is peculiar. The concept of "encodedness" (Liberman et al., 1967) was, in fact, a first response to this challenge, an attempt to describe the relation between the speech signal and the phonetic segments of the language it conveys. The current literature of speech perception is replete with studies exploring this relation and the nature of the distinctively phonetic processes (e.g., Bailey & Summerfield 1980; Fitch, Halwes, Erickson & Liberman 1980; Liberman & Studdert-Kennedy 1978; Repp, Liberman, Eccardt & Pesetsky 1978; Tuller & Fowler 1980).

Support for the second claim, namely, that phonetic processes are integral to language, comes from many directions (e.g., Lindblom 1980; Liberman & Studdert-Kennedy 1978), including studies demonstrating lateralization of phonetic analysis. Here, too, B & N seem to have missed the point. For, although Liberman et al. (1967) do attribute the consonant-vowel difference in ear advantage to a difference in degrees of "encodedness," Studdert-Kennedy and Shankweiler (1970, p. 592, section F) explicitly reject that interpretation. They regard "encodedness" as relevant only insofar as "encoded" segments tend to be brief, and they treat all variations in ear advantage among phoneme classes as due to variation in transcallosal loss and in consequent access to the left hemisphere. They conclude that ". . . while the general auditory system common to both hemispheres is equipped to extract the auditory parameters of a speech signal, the dominant hemisphere may be specialized for the extraction of linguistic features from those parameters" (p. 579). They attribute the right hemisphere's rudimentary capacities to repeated association of its auditory analysis with the outcome of the left hemisphere's linguistic analysis. Subsequently, the commissurotomy studies have led Levy (1974, p. 149) and Zaidel (1978, p. 196) to essentially identical conclusions. Perhaps B & N missed all this because they deliberately eschew discussion of factors affecting hemispheric access, without which many dichotic studies are simply uninterpretable (Studdert-Kennedy & Shankweiler, in press).

The question that these conclusions raise is the one with which we began. What biological functions supported the evolution of this hemispheric dissociation? Perhaps we can approach an answer if we hew to the axiom that every semiotic system must be constrained, in some degree, by its medium of expression (cf. Bellugi and Studdert-Kennedy 1980; Studdert-Kennedy 1980b). The most striking property of the left hemisphere is, in fact, its preeminence in the motor control of speech. If we add to this its dominance in manual praxis for some 95% of the population, and the recent demonstration of the linguistic status of the manual system of American Sign Language (Stokoe, Casterline & Croneberg 1965; Klima & Bellugi 1979), we may reasonably hypothesize that language was drawn to the left hemisphere because the left hemisphere already possessed the neural circuitry for unilateral coordination of the two hands, which is precisely the type of circuitry needed for control of the bilaterally innervated vocal apparatus (cf. Levy 1969; Liberman 1974; Studdert-Kennedy 1980a). Some such hypothesis underlies the work of Kimura (e.g., 1973) and Semmes (1968). B & N discuss this work, but seem not to have understood that its intent is to develop an account of possible evolutionary connections between the linguistic and motor specializations of the left hemisphere.

We should clearly distinguish this approach from a type of view that B & N sometimes seem to favor: for example, that speech laterality effects can be derived from one or another of the left hemisphere's supposed specializations for auditory analysis. Neither speech nor language can be reduced to a mere collection of auditory and motor functions (cf. Marshall 1980). Nonetheless, many such functions must have combined to build the perceptuomotor foundations of speech and language, and the nature of these functions is of great interest. That is why study of the connections between manual control and speech, with the evolutionary question in mind (e.g., Kimura 1979; Kinsbourne & Hicks 1978; Shankweiler & Studdert-Kennedy 1975), is a promising direction of research into the biology of language.

ACKNOWLEDGMENTS

I thank Donald Shankweiler for very helpful discussion and advice, and Alan Bell, Alvin Liberman, and Scott Kelso for thoughtful comments. Preparation of the commentary was supported in part by NICHD Grant HD 01994 to Haskins Laboratories.

Temporal processing as related to hemispheric specialization for speech perception in normal and language impaired populations

Paula Tallal

Department of Psychiatry, University of California, San Diego, La Jolla, Calif. 92093

That the left cerebral hemisphere subserves verbal processing and the right nonverbal acoustic processing, for most people, has come to be the foundation upon which our understanding of cerebral organization of higher cortical function lies. However, data contrary to this traditional verbal/nonverbal dichotomy have been chipping away at this basic foundation for well over a decade. These data have been systematically organized and reviewed in detail by Bradshaw & Nettleton (B & N) and provide a much needed reevaluation of the nature of hemispheric specialization in man. It can only be hoped that the synthesis of evidence so carefully compiled in this review will have the impact on the behavioral and brain sciences that is needed to move beyond the simple verbal/nonverbal dichotomy underlying hemispheric specialization to a more thorough understanding of the precise mechanisms underlying these processes.

One of the main difficulties encountered in attempting to analyze the mechanisms underlying lateralized cortical functions has resulted from the assumption that these functions were divided along nonverbal and verbal lines. Thus, different techniques were used to assess the mechanisms underlying the nonverbal and verbal functions in the two cerebral hemispheres. For example, psychoacoustic techniques were generally employed to advance our understanding of nonverbal auditory perception, as presumed to occur in the right cerebral hemisphere in man. On the contrary, cognitive and linguistic techniques were often employed to assess the mechanisms underlying verbal functioning in the left hemisphere. These differences in the types of questions asked and the techniques used to assess functioning in the two cerebral hemispheres may have, in and of themselves, contributed to the vast body of literature supporting the verbal/nonverbal dichotomy of hemispheric specialization.

We encountered precisely this dilemma when first attempting to study the possible auditory perceptual prerequisites to developmental speech, language, and reading disorders (Tallal & Piercy 1973a,b). We had demonstrated that developmentally language impaired children (dysphasics) were deficient in their ability to respond correctly to rapidly presented nonverbal stimuli. Our interest was in whether this highly significant and specific deficit in temporal acoustic analysis of nonverbal stimuli was related to the severe developmental speech perceptual impairments in this population. In order to investigate this question, it seemed essential to view the speech signal as an acoustic, rather than merely a linguistic event. In other words, it seemed necessary to understand the central analysis of the acoustic wave form, regardless of whether the stimuli to be analyzed were nonverbal or verbal in nature.

Based on the results of our psychoacoustic studies, we hypothesized that the inability of dysphasic children to respond correctly to rapidly changing nonverbal stimuli should result in an inability to discriminate between speech sounds that incorporate rapidly changing acoustic spectra. Conversely, these children should not be impaired in their ability to discriminate between speech sounds that are characterized by slower frequency changes over time, or steady-state stimuli. If, on the other hand, these children's speech discrimination deficits were related to primary linguistic rather than acoustic mechanisms, then we might predict a more general deficit in speech discrimination, or at least a pattern of discrimination deficit that could not be related to the rate of acoustic change within syllables (Tallal & Piercy 1974).

We tested this hypothesis using synthetic speech, which enabled us to maintain precise control over the rate of change of acoustic information within specified syllables. The results of the study demonstrated that, in fact, language-impaired children's speech discrimination was poorest for stop consonant stimuli, which are characterized by very rapid frequency changes over time, and best for steady-state vowels, whose spectrum does not change over time. In subsequent studies (Tallal & Piercy 1975), we were able to demonstrate conclusively that it is the rate of change of the critical components within the acoustic spectra of speech, rather than the verbal nature of these stimuli per se, that results in the grossly impaired discrimination performance of language-delayed children. Using the computer once again to control the acoustic spectra of syllables, the same consonant-vowel syllables were synthesized, but with varying duration transitional components. It was found that there was a highly significant difference in the performance of the language-impaired children in their ability to discriminate between the same speech sounds with different duration transitions. These children were significantly better in discriminating between consonant-vowel syllables incorporating longer duration transitions than they were in discriminating the same syllables synthesized with shorter duration transitions. Similar results were found in subsequent studies using the same stimuli with aphasic patients with acquired left-hemisphere damage (Tallal & Newcombe 1978).

We have recently taken a similar approach to investigating the possible mechanisms underlying hemispheric specialization for speech perception in normal adult listeners. Using the dichotic listening test paradigm, college students with normal hearing were presented with two sets of synthetic speech stimuli comprising the six stop consonant vowel syllables (/ba/, /da/, /ga/, /pa/, /ta/, /ka/) presented randomly. In