TONE PROCESSING AND THE BRAIN

Wolfgang Woerner
Central Institute of Mental Health and
University of Mannheim
P.O.Box 12 21 20, D-6800 Mannheim 1, Germany

One of the most intricate changes that occurred during the evolution of modern man is the development of highly sophisticated and differentiated language systems. Since the necessary hardware for processing language resides in the brain, evolution of the human brain and the development of language systems have gone hand in hand. Biologically, these two factors represent the most striking features distinguishing human beings from subhuman species.

A particularly challenging area of interest concerns the study of how language is processed by its user, including both the input side of comprehension of written or spoken speech, and the generation and production of linguistic output.
Partly due to the complexity and speed of ongoing processing, direct observation of the separate steps involved has proved extremely difficult. Thus, even within the behavioral sciences, most research has centered on indirect analyses of outcomes (i.e., products of processing), seeking to draw inferences about how linguistic processors might be organized in the brain in order to explain the observed results.
A somewhat different approach aims to relate individual linguistic or other cognitive functions to more or less circumscribed areas of the brain. Starting way back in the early 19th century, one method used in investigating such structure-function (i.e., brain-behavior) relations represented the systematic observation of the effects of brain lesions with different localization. Since then, a wide body of evidence has been collected on neurological and cognitive deficit correlates of open- or closed-head injuries. However, given the extreme complexity of the affected organ, the large variability in nature and extent of the individual damage, the high redundance present in brain circuitry, and the resulting potential strength of compensating mechanisms, this method provides somewhat vague information on how and where specific cognitive functions are localized in the healthy brain.

Nevertheless, one pattern that emerged very clearly concerned the dominant role of the left cerebral hemisphere (and, in particular, the left temporal regions) for language comprehension and production. Thus, it has long been established that the most complex and exclusively human cognitive abilities are lateralized, i.e., chiefly represented in one half of the cortex, in contrast to symmetrically organized elementary perceptual and motor functions.

Seeking to overcome the limited conclusiveness of lesion studies, a number of behavioral paradigms have been developed to determine which of the two sides of the brain is more strongly involved during the execution of a variety of cognitive tasks presented to normal subjects. Due to the preponderance of crossed neural pathways linking each perceptual hemispace with brain structures, differences in performance following presentation of stimuli on the left vs. right side reflect the use of lateralized cerebral functions and, thus, are regarded as evidence of lateralization of highly specialized processing activities.
In the visual modality, asymmetrical cerebral functions can be assessed by comparing performance measures following tachistoscopic presentation of stimuli in the right vs. left visual field. On the other hand, auditory processes have frequently been studied with the dichotic listening paradigm (Figure 1).
As shown in the illustration, monaural stimuli have

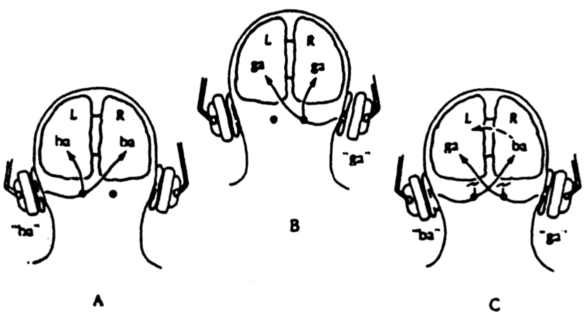

Figure 1: Access of auditory stimuli to the two cerebral hemispheres in (A) left or (B) right monaural, and (C) dichotic listening conditions (Springer & Deutsch, 1981)

direct access to both hemispheres by either ipsi- or contralateral pathways. In dichotic presentation, the efficiency of the weaker uncrossed pathways is suppressed, stimulus traces are propagated to the contralateral hemisphere. Linguistic stimuli presented to the left ear are channeled to the right hemisphere and then have to cross the corpus callosum in order to reach the left hemisphere specialized for linguistic processing. This extra step requires additional time and is associated with qualitative degradation, resulting in poorer identification performance. While representing a powerful tool for investigating cerebral lateralization of function in healthy subjects, great care must be taken in the preparation of dichotic stimulus material. One important requirement concerns the perfect temporal overlap between the two stimuli presented simultaneously. Other points include equivalence of amplitude and duration of the stimuli, as well as the perfect alignment of the two tracks of the dichotic stimulus tape (Porter & Hughes 1983). When adequate precautions are taken, the right-ear advantage (REA) found for linguistic stimuli represents a behavioral correlate of language processes lateralized to the left hemisphere. The magnitude of the REA for linguistic stimuli even appears to be associated with psychometric measures of verbal abilities, while left-ear advantage (LEA) for recognizing six-tone melodies in a musical task seems more strongly related to spatial abilities (Bryden 1986).
Visual half-field and dichotic stimulation studies both confirmed and further elaborated earlier notions that handedness is an important factor determining cerebral organization (i.e., direction and extent of lateralization of cerebral functions). As demonstrated by the large inter- and intraindividual variability in performance asymmetries, these methods have also shown that functional cerebral lateralization is not an all-or-none phenomenon, but is rather expressed as a relative preponderance of activity and/or superiority of performance of one hemisphere as compared to the other half-cortex while a person is solving a given task by using a particular strategy. Hence, observed asymmetries in performance may be influenced to varying degrees by stimulus and task properties, context, experience, practice, strategy, and other factors.

Mecacci (1981) considers the comparison of the degree of hemisphere specialization in different populations to be a highly promising line of investigation in the area of cross-cultural neuropsychology. By comparing information-processing phenomena and/or cerebral organization patterns among different cultures, one will eventually gain increasing knowledge about both cognitive processes (including linguistic ones) and the brain (Fabrega 1977).

The different language systems that evolved make use of varying dimensions and properties of the acoustical signal. While most Western languages utilize the same physical dimensions and draw their basic elements from very similar sets of phonemes, tone languages are unique in using levels and changes of pitch as phonemic attributes with highly salient semantic function (cf. Gandour 1978 for a review of tone languages). On a scale of levels of functional pitch in the speech signal, languages such as Chinese or Thai with their phonological tones on single segments or syllables would be placed at the "most systematically linguistic" end (Van Lancker 1980).

Obviously, linguistic and external context provide additional information in connected speech. In contrast, isolated presentation of otherwise identical monosyllabic (CV or CVC) tone words in a neutral setting creates a situation where a person must entirely rely on the tonal dimension in order to identify each stimulus. In speakers of a tone language, the distinction between different tonal patterns is thus one aspect of their language comprehension abilities. Hence, tone discrimination and identification tasks can be expected to activate those brain structures that are responsible for language processing (i.e., the left cerebral hemisphere), since this is where decoding and comprehension of the utterance takes place.

Several studies on tone production and comprehension in brain-injured tone language speakers were able to demonstrate such left-hemisphere processing of tone words (Gandour & Dardarananda 1983, Packard 1986, Gandour et al. 1988). However, perceptual studies using genuine words of a tone language as stimuli could always be expected to elicit a left-hemisphere advantage (=REA) in subjects with sufficient knowledge of the language, i.e., who "understand" the presented words and can link them to lexical elements. On the other hand, the same stimuli would represent meaningless sounds to persons who do not know the language.

In order to investigate the locus of processing of the tonal dimension (i.e., the tonal pattern itself), it is necessary to use otherwise non-linguistic, neutral tokens rather than words, thus presenting meaningless stimuli to all listeners studied. The tonal pattern superimposed on such synthetic sounds will constitute a