

Frontiers of Brain Mapping of Speech Prosody

Jack Gandour

Purdue University

A key issue for the study of language and the brain in the twenty-first century is the delineation of the neural substrate underlying the perception and production of prosody in relation to linguistic and affective components of the speech signal. The notion of *speech prosody* dates back to Monrad-Krohn's (1947) case study of a woman who was unable to produce the phonemic tone contrasts in her native Norwegian dialect even though she retained considerable musical ability. Because of its multiple functions (e.g., linguistic, attitudinal, affective) and its multiple phonetic cues (e.g., pitch, duration, loudness), the neural substrate of speech prosody remains elusive and controversial to the present day (Baum & Pell, in press).

During the second half of the twentieth century, two major, competing lines of investigation have emerged concerning hemispheric specialization for speech prosody. One emphasizes task-dependent or domain-specific effects (e.g., Van Lancker, 1980; Ross & Mesulam, 1979), and the other cue-dependent effects that cut across task domains (e.g., Robin, Tranel, & Damasio, 1990; Ivry & Robertson, 1998). In speech perception, for example, task-specific hypotheses assume that unique, neural mechanisms are recruited for the speech domain, whereas cue-dependent hypotheses claim that speech processing is subserved by neurobiological mechanisms specialized for particular aspects of the acoustic signal, irrespective of communicative or linguistic relevance. Evidence for or against these hypotheses has been drawn primarily from neurologically impaired populations with unilateral lesions to the left (LH) or right hemisphere (RH) as well as from studies using dichotic listening procedures or the Wada technique. Within the past decade, empirical evidence has also begun to appear from functional neuroimaging studies.

Address correspondence and reprint requests to Jack Gandour, Ph.D., Department of Audiology and Speech Sciences, Purdue University, West Lafayette, IN 47907-1353. E-mail: gandour@purdue.edu.



For example, PET (positron emission tomography) studies have shown that pitch in linguistic and nonlinguistic contexts, respectively, activates homologous, inferior frontal regions in the LH and RH (Gandour, Wong, & Hutchins, 1998; Gandour et al., in press; Zatorre, Evans, Meyer, & Gedde, 1992). Such findings argue in support of Zatorre et al.'s view that auditory information undergoes discrete processing stages, each of which depends on separate neural subsystems. Whether linguistic or nonlinguistic, perceptual analysis of auditory stimuli occurs in the temporal lobe. However, when a phonological decision is to be made, whether it be segmental or suprasegmental, subjects must further access articulatory representations involving neural circuits that include Broca's area. This finding conflicts with the classical view that speech production is mediated exclusively by anterior brain structures and speech perception by posterior. Instead, a mosaic view is supported that postulates common neuroanatomic sites subserving both production and perception. Indeed, a recent PET study has demonstrated a direct interaction between motor (speech) and sensory (auditory) regions (Paus, Perry, Zatorre, Worsley, & Evans, 1996). fMRI (functional magnetic resonance imaging) studies (e.g., Binder et al., 1997) similarly show that LH frontal areas are engaged in receptive language tasks. In an magnetoencephalography (MEG) study of Japanese pitch accents, Imaizumi et al. (1998) have demonstrated that the LH is responsible for linguistic information irrespective of acoustic cues, whereas those in the RH are prosody specific.

ERP (event-related brain potentials) measures offer promise for showing the time course of the relationship between prosody and sentence processing. Intonational phrasing appears to guide the initial analysis of sentence structure. A positive shift in ERP at intonational boundaries suggests a specific on-line brain response to prosodic processing (Steinhauer, Alter, & Friederici, 1999).

In the twentieth century, the primary focus has been on hemispheric dichotomies in the processing of speech prosody. In the twenty-first century, the major focus will shift to the development of neural networks subserving speech prosody. Data from both lesion-deficit and functional neuroimaging studies are crucial for this purpose. Lesion studies tell us what areas are necessary for normal functioning, while imaging studies tell us what areas participate in that function. The former date back almost 150 years, while the latter go back only about a decade or so. It is only the latter, however, that give us a window on language processing *in vivo* in the normal functioning human brain. The advantages and disadvantages of both approaches notwithstanding, we can look forward to the application of a variety of imaging techniques that promise to illuminate both the functional neuroanatomy and the time course of speech prosody.

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