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Towards a functional neural systems model of developmental stuttering

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Abstract

This paper overviews recent developments in an ongoing program of brain imaging research on developmental stuttering that is being conducted at the University of Texas Health Science Center, San Antonio. This program has primarily used $H_2{}^{15}O$ PET imaging of different speaking tasks by right-handed adult male and female persistent stutterers, recovered stutterers and controls in order to isolate the neural regions that are functionally associated with stuttered speech. The principal findings have emerged from studies using condition contrasts and performance correlation techniques. The emerging findings from these studies are reviewed and referenced to a neural model of normal speech production recently proposed by Jürgens [Neurosci. Biobehav. Rev. 26 (2002) 235]. This paper will report (1) the reconfiguration of previous findings within the Jürgens Model; (2) preliminary findings of an investigation with late recovered stutterers; (3) an investigation of neural activations during a treatment procedure designed to produce a sustained improvement in fluency; and (4) an across-studies comparison that seeks to isolate neural regions within the Jürgens Model that are consistently associated with stuttering. Two regions appear to meet this criterion: right anterior insula (activated) and anterior middle and superior temporal gyri (deactivated) mainly in right hemisphere. The implications of these findings and the direction of future imaging investigations are discussed.

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Educational objectives: The reader will learn about (1) recent uses of $H_2{}^{15}O$ PET imaging in stuttering research; (2) the use of a new neurological model of speech production in imaging research on stuttering; and (3) initial findings from PET imaging investigations of treated and recovered stutterers.

Keywords: PET brain imaging; Persistent; Treated and recovered stutterers; Jürgens Model

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In recent years positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magnetoencephalography (MEG) studies have provided converging evidence regarding the neural regions that are implicated in speech production. For the most part this research has served to verify some of the classic models of the neural regions involved in speech production—models that were largely derived from lesion studies. The origin of many models of the regional interaction system supporting speech production can be traced to Wernicke's (1874) observations on aphasia. These observations were ultimately extended by Geschwind (1979) and formed the basis of the Wernicke–Geschwind Model—arguably, the most influential model of speech production. This model identified a sequence of brain regions that play a critical role when, for example, individuals read aloud single words [primary visual area (V1) → angular gyrus → Wernicke's area → Broca's area → M1-mouth]. Inevitably, increasing knowledge about the neural regions and structures associated with speech production, especially subcortical structures, meant that this basic model had to be expanded in a number of important ways. An especially important expansion occurred when it was established that cerebral cortex links with the basal ganglia via input structures that receive direct input from the cerebral cortex, and via output structures that project back to the cerebral cortex via thalamus (Alexander & DeLong, 1985a, 1985b). These multiple loops, which came to be known as cortico-basal ganglia–thalamo–cortical circuits (see Alexander, DeLong, & Strick, 1986), have been found to be involved in speech production. Indeed, certain speech–motor disorders, such as dysarthria, appear to reflect a dysfunction in that loop (Crosson, 1985; Penney & Young, 1983). Not surprisingly, therefore, there is interest in determining if other speech disorders, such as developmental stuttering, are byproducts of a fundamentally dysfunctional neural system.

Major improvements to the understanding of the regions and systems that participate in speech production occurred in the mid-1980s with the arrival of PET imaging of the brain (Ter-Pogossian, Phelps, Hoffman, & Mullani, 1975; Ter-Pogossian, Raichle, & Sobel, 1980). The subsequent groundbreaking $H_2{}^{15}O$ PET experiments by Petersen, Fox, Posner, and Raichle (1988) and Petersen, Fox, Posner, Mintun, and Raichle (1989) yielded the first distinctive images of neural activity during reading and during the production of single words. Other researchers using PET in conjunction with various speech tasks soon replicated and refined Petersen et al.'s findings, identifying a group of regions that were generally active during speech