## Introduction

My research focuses on the link between perception and action in the language system. In order for language communication to work, there must exist a rough parity between the speech that a person can ***perceive*** and the speech that a person can ***produce***. Human communication is a two-way street: a hearer must also be a speaker for conversation to occur. But this means that the problem for the hearer/speaker is two-fold: he or she must be able to analyze the acoustic signals that arrive from the environment and recognize them as speech and he or she must be able to generate the motor commands necessary to control the oral articulators to produce those very same acoustic signals. How does the brain manage this double problem? Does it solve the problem with two independent, non-overlapping systems -- one on the sensory (input) side and one on the motor (output) side? Or does it use a single system that is shared between overlapping perception and production systems? How does a person repeat a stream of auditory-verbal information and in what form is the information temporarily stored (and how is it buffered across a short delay?). These questions all relate to how sensory and motor systems interact during language perception and production, but also how memory (short-term and long-term) is used to bridge the sensory and motor poles of cognition in the service of complex human behavior.

## Research

Language requires a strong link between perception and production. In a series of functional neuroimaging studies, I have shown that a region in posterior superior temporal lobe – area Spt (Sylvian-parietal-temporal) – may serve as a sensorimotor interface that binds or transforms sensory representations of speech to their corresponding motor forms. I have hypothesized that Spt is a major processing component in what has been called the ***auditory dorsal stream***, a functional-neuroanatomical system that constitutes the primary pathway for linking the perception and action systems in the context of language and other auditory-motor processes (e.g. music). My research has focused on studying the contribution of this perception-action pathway to perceptual-motor mapping (perception and production of visual/textual, auditory, and sign language), verbal working memory, and, most recently, verbal sequence learning.

## Perceptual-Motor Mapping

As noted above, a sensorimotor integration system is required to be able to map different sensory inputs or stimulus classes to their appropriate motor analogues. I have shown that the functional anatomical processing pathways that underlie the perception of visual- and auditory-verbal stimuli converge in area Spt (Buchsbaum et al., 2005a), and that the region is just as engaged during speech production as it is during perception (Buchsbaum et al., 2001). I have also shown this same region is recruited during the perception and covert production of sign-language stimuli in a sample of congenitally deaf subjects

(Buchsbaum et al., 2005a), and in a task requiring the rehearsal of short musical melodies (Hickok, Buchsbaum, Humphries, and Muftuler, 2003), indicating that Spt may act as an interface system not only across visual and auditory modalities *within* a language (read and heard), but also across visual and auditory modalities *across* languages (e.g. spoken, signed, and melodic). The discovery and characterization of the functional properties of Spt has important implications for understanding the neural organization of language and explaining how disparate systems of communication (such as speech, music and sign) may depend on a similar computational mechanism for the transformation and binding of sensory and motor representations of symbolic gestures.

**Verbal Working Memory**

Models of verbal short-term memory often place an emphasis on "inner speech" as a means of maintaining speech-based information in memory across a short delay. This has often been conceptualized as a "phonological loop" in which articulatory rehearsal is used to cycle through the contents of memory and "refresh" decaying traces that reside in an amodal "phonological store". I have argued that such a mechanism cannot adequately explain modality-specific "echoic" memory, and have shown in an fMRI study (Buchsbaum, 2005b) that there is a functional neuroanatomical dissociation between a short-lived auditory-sensory memory ("echoic") trace in the lateral superior temporal gyrus and a rehearsal-based memory system in area Spt and the auditory dorsal stream (Buchsbaum et al., 2005c; Buchsbaum & D'Esposito, submitted). In a recent review (Buchsbaum and D'Esposito, in press) I proposed a new functional anatomical framework for understanding verbal working memory as emerging from the interaction of auditory perceptual systems in the lateral temporal lobe and the speech production system of the auditory dorsal stream, with Spt acting as a bi-directional interface system for the temporary binding of sensory and motor representations of speech.

**Verbal Sequence Learning**

The ability to learn new words in one's own or in a foreign language depends on the formation of new mappings between auditory and motor representations of sound sequences. I have previously argued that the *temporary* binding of auditory and motor representations of speech – as is required during tasks of phonological short-term memory -- is mediated by area Spt and the auditory dorsal stream. As one builds up experience with a particular sequence, such as a word, a phone number or street address, a "long-term" or structural memory trace may be formed, and less reliance is placed on auditory-motor bindings processes. The extent to which such long-term learning occurs, however, may depend on the efficiency of auditory-motor binding that occurs during the first few experiences with a new verbal sequence. In an fMRI study using the classic Hebb repetition paradigm with supraspan (9 letter) auditory-verbal sequences, we have shown that as a subjects' performance improves after repeated experience with a particular sequence, we observe a qualitative shift from regions in the auditory dorsal stream memory to a cortical network more typical of long-term memory retrieval – i.e. with limbic, anterior prefrontal and lateral parietal regions becoming more active as learning progresses (Buchsbaum et al, Society for Neuroscience Abstracts, 2007). This research begins to elucidate the difference between long-term learning and phonological short-term memory; as a sequence becomes crystallized in memory, the brain resources that would ordinarily be deployed the service of verbal memory maintenance (or auditory-motor binding), are freed up for other processing. Current work in collaboration with developmental psychology lab at UC Berkeley[1] aims to understand how children, who have smaller working memory capacity, are nevertheless proficient at certain kinds of implicit learning tasks. Thus, understanding how children and adults differ at a simple sequence learning task such as the Hebb repetition paradigm can provide clues to the apparent superiority of children at learning new languages.

**Future Directions**

I plan to continue and expand my program of research in the domain of language perception and production and the neural organization of language. A major goal of future work will be to develop a better understanding of how psychological models of speech perception and production – with the representational stages and architectural constraints that they imply – can be better integrated with the functional neuroanatomy -- in terms of its systems, circuits, and hierarchies – of sensorimotor processes in language. In addition, the study of clinical disorders such as developmental dyslexia where a disturbance of sensorimotor interface system may be implicated, or in schizophrenia, where one of the cardinal symptoms – auditory hallucinations – suggests a breakdown between self-awareness and the link between speech production and perception processes, may provide valuable insight into the machinery of the language system. Finally, I am dedicated to a research style that values information from all quarters -- including cognitive psychology, neuroscience, computational modeling, neuropsychology, and neurology – and I strive to arrive at an understanding of human behavior that transcends a particular paradigm or methodology.

**References**

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