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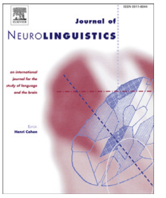

White-matter structure in the right hemisphere predicts Mandarin Chinese learning success

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ABSTRACT

Second language learning becomes increasingly difficult with age, but some adults learn more successfully than others. We examined whether inter-subject variability in the microstructure of white matter pathways, as measured by diffusion tensor imaging (DTI), would predict native English speakers' outcomes in learning Mandarin Chinese. Twenty-one adults were scanned before participating in an intensive 4-week Mandarin course. At the end of the Mandarin course, participants completed a final exam that assessed their skills in both spoken and written Mandarin. Individual participants' white-matter tracts were reconstructed from their native DTI data and related to final-exam performance. Superior language learning was correlated with DTI measures in the right hemisphere, but not in the left hemisphere. In particular, greater initial fractional anisotropy (FA) in both the right superior longitudinal fasciculus (parietal bundle) and the right inferior longitudinal fasciculus was associated with more successful Mandarin learning. The relation between white-matter structure in the right hemisphere of native English speakers and successful initial language learning may reflect the tonal and visuo-spatial properties, respectively, of spoken and written Mandarin Chinese.

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1. Introduction

In contrast to native language acquisition, which seems to be effortless during the first years of childhood, second language acquisition during adulthood is exceptionally challenging (Hull & Vaid, 2007; Johnson & Newport, 1989; Kuhl, 2004; Perani et al., 1998, pp. 1841–1852; Sakai, 2005). Adults vary substantially in their second-language learning efficacy, with few learners achieving native-like fluency in either the spoken or written form of the new language. Little is known about how adult language learning capacities are represented in the brain, but neuroimaging studies have started to explore the structural and functional neural differences underlying individual variation in adult language learning. Here, we asked whether structural differences in white-matter pathways are related to differences among English-speaking adults in learning spoken and written Mandarin.

In studies of English and other alphabetic languages, two white-matter tracts have been most strongly associated with language: the left arcuate fasciculus (AF) component of the superior longitudinal fasciculus (SLF) and the left inferior longitudinal fasciculus (ILF). The SLF connects a dorsal language network (Hickok & Poeppel, 2004, 2007) and is thought to consist of a direct AF pathway connecting posterior (superior temporal gyrus/Wernicke's area) and anterior (inferior frontal gyrus/Broca's area) language cortices and an indirect pathway including the SLFp connecting the inferior parietal cortex and anterior language cortices (Catani, Jones, & Ffytche, 2005). The ILF connects a ventral language network that includes Broca's area and posterior occipitotemporal regions and, via another pathway, the anterior temporal lobe with the uncinate fasciculus (Anwander, Tittgemeyer, von Cramon, Friederici, & Knösche, 2007).

Among these language-related white-matter tracts, the left AF is most prominently implicated in language function; disruption of the left AF leads to impairment in speech production, auditory comprehension, and reading (Dronkers, Plaisant, Iba-Zizen, & Cabanis, 2007; Rauschecker et al., 2009; Vandermosten et al., 2012; Yeatman, Dougherty, Ben-Shachar, & Wandell, 2012; Yeatman et al., 2011). The left ILF has also been implicated more specifically in visual (orthographic) aspects of reading, perhaps by transmitting visual information about words between the fusiform gyrus at the temporal-occipital junction and anterior/interior temporal regions (Epelbaum et al., 2008; Yeatman et al., 2012).

Neuroimaging in relation to language learning has shown an association between individual learning performance and both structural and functional connectivity in the left hemisphere. In one study, diffusion measures of the left AF strongly associated with superior learning of English pseudowords (López-Barroso et al., 2013). Another study found a positive correlation between diffusion measures of the left ILF and the learning of associations between Mandarin tones and English pseudowords (Wong, Chandrasekaran, Garibaldi, & Wong, 2011). A resting-state functional magnetic resonance imaging (rsfMRI) study found that successful learning of foreign sound contrasts was associated with greater functional connectivity between Broca's area and the left superior parietal area, which are two regions connected by the left SLFp, a white matter tract in the dorsal pathway (Ventura-Campos et al., 2013). Bilingualism also affects the left inferior frontal-occipital fasciculus, an arguably indistinguishable tract from the left ILF (Wakana et al., 2007), such that fractional anisotropy (FA), one of the diffusivity measures indexing white matter microstructure, is highest in early bilinguals and lowest in monolinguals with late bilinguals being in between (Mohades et al., 2012).

In contrast to the attention given to the left hemisphere, only a few studies have explored relations between structural or functional connectivity in the right hemisphere and language learning, and even these studies have reported mixed findings. One study found diffusion measures in the right AF correlated with individual's performance in pitch-related grammar learning (Loui, Li, & Schlaug, 2011). Conversely, a study of Japanese speakers learning English found no association between the learning performance and the white-matter structure in either the left or right hemisphere before learning. Instead, learning proficiency correlated with the training-induced increases in the strength of the structural connectivity between the right inferior frontal gyrus and caudate (Hosoda, Tanaka, Nariai, Honda, & Hanakawa, 2013).

Because Mandarin differs from English and other alphabetic languages in both spoken and written forms, the neural bases that support learning Mandarin may be different from those that support learning European (alphabetic) languages. For spoken language, Mandarin has four lexical tones (high-