Language Circuits of Human Brain: an integrated study of fMRI and probabilistic DTI

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Introduction

Neuroanatomical connection is crucial to the understanding of brain function. The language anatomical model proposed that Broca's area located in the inferior frontal lobe and Wernicke's area located in the superior temporal gyrus were connected through the arcuate fasciculus (AF). Hickok and Poeppel [1] and others recently proposed a dual stream model for auditory language processing. From the superior temporal gyrus, which is engaged in early cortical stages of speech perception, the system diverges into two processing streams. The dorsal stream is involved in auditory-motor integration by mapping acoustic speech sounds to articulatory representations. The other one, the ventral stream, serves as a sound-to-meaning interface by mapping sound-based representations. The aim of this study is to examine the language circuits of the dual stream model using visual perception by an integrated functional MRI (fMRI) and probabilistic diffusion tensor imaging (pDTI) method.

Methods

(**1**) The 8 healthy volunteers (right-handed, 5 male, mean age=26.5±3.0) participated in this research. All the patients took fMRI [Bruker 3T system, echo planar images (EPI), 64x64 matrix, slice thickness/gap =5/1mm, 20slices, repetition time (TR) = 2000 milliseconds (ms), echo time (TE) = 50 ms, flip angle = 90 degree], anatomical MRI [GE SignaExcite 1.5T system, T1-weighted, 3D spoiled gradient echo (SPGR) pulse sequence, TR=8.548ms, TE=1.836ms, matrix size=256x256x124, voxel size = 1.02 x 1.02 x1.5mm], and DTI [1.5T SignaExcite, spin- echo-based diffusion-weighted EPI sequence, TR=17000 ms, minimal TE, matrix size = 128x128, NEX= 6, b-value=1000sec/mm^2, 13 directions, voxel size = 2.03x2.03x2.2mm]. (**2**) The central neural correlates of language circuits were identified by event-related fMRI tasks of overt Chinese word and picture naming [trial number=155, mean internal stimulate interval (ISI)= 3.09 sec and repetition number (NR) =484]. During fMRI scanning session, they were asked to read out the given stimuli. (**3**) fMRI data were analyzed with Statistical Parametric Mapping 5 (SPM5) using standard procedures for preprocessing, single-subject (first level), and random-effect group analyses (second level). (**4**) Two regions of interest (ROIs) were derived from group result for DTI probabilistic tractography algorithm via FSL ProbTrack [FMRIB's Software Library , version 4.1.4 [2], including eddy current correct, fitting of diffusion tensors, modelling of diffusion parameters]. In ROI of the dorsal pathway, we apply a fMRI cluster [Seed of brodmann area 6&9 (BA6&9), the center of mass=-50,-8, 34 (MNI coordinate system)]. In ROI of the ventral pathway, we enlarged to a sphere with a radius of 10 mm [Seed of BA13, the center of mass=-32, 20, 8 (MNI coordinate system)]**.** All ROI was processing via MarsBaR region of interest toolbox for SPM (http://marsbar.sourceforge.net/).(**5**) During the DTI probabilistic tractography, we applied exclusion mask (including corpus callosum and inter hemisphere) in dorsal and ventral pathway pathway; termination mask (including BA22) in dorsal pathway.(**6**) Group analysis of DTI probabilistic tractography, we combined individual probabilistic tractography map to from 8 volunteers, and made a probabilistic penetration map [Preprocessing criteria: The number of sample was set to 5000 and step length to 5mm; Probabilistic threshold (p_{rob}) = number of hit /number of ROI volume×5000×100%].

Results

Two regions of significant activation, identified by picture naming task [t=3.85 p=0.001 (uncorrected), voxel extension=0], one ROI located in premotor and prefrontal areas in the left frontal lobe [seed of BA 6&9]. The other ROI located in the anterior of the insular cortex, BA13, which was close to the extreme capsule (Emc). Penetration maps of 2D/3D probabilistic tractography were generated for examing reproducibility (Figure 1). One of the model, the dorsal pathway [p_{rob}= 3000/1.93×10^6×100%=0.155%], premotor seeds (BA 6&9) extensions to temporal lobe (BA22) via the AF/SLF system. The other one connects temporal and frontal nodes via a ventral pathway [p_{rob}= 5000/2.55x10^6× 100%=0.196%] running through the extreme capsule (EmC) and entering medially to the insular into the orbitofrontal cortex.

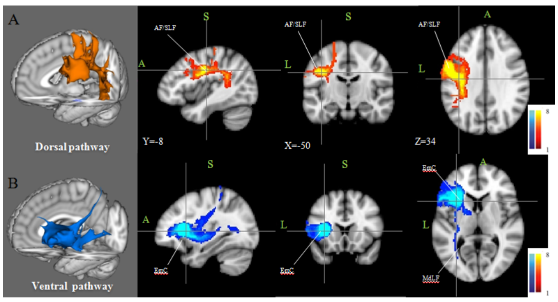
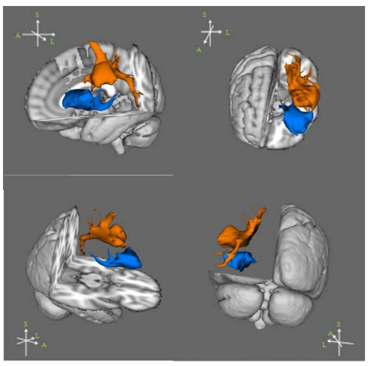


Figure 1. Dual pathway network for language. (A) Dorsal pathway (orange) and (B)Ventral pathway (blue). EmC, extreme capsule; AF/SLF, arcuate and superior longitudinal fascicle; MdLF, middle longitudinal fascicle .

Discussion



The 3D-probabilistic penetration map presented the dual system was actually independent of each other at the prefrontal lobe (Figure 2). That can support the dual stream model for language. One of the model, the dorsal pathway, which connects temporal (BA22) and premotor seeds (BA 6&9) via the AF/SLF system. The other one connects temporal and frontal nodes via a ventral pathway running through the extreme capsule (EmC) and entering medially to the insular into the orbitofrontal cortex. The individual subjects of results were consistent with previous researches [3]. However, the study still has a lot of individual variability. Combining functional MRI and probabilistic DTI tractography study is a powerful technology platform. But that still had many limits, especially in DTI tractography, which is often unable to reconstruct correct trajectories, such as axonal crossings.

Figure 2. Dual pathway network for language. Composite fiber network ventral pathway (blue) and dorsal pathway (orange).

Acknowledgment

This study was supported by grants of NSC.96-2321-B-075-003; Taipei VGH V98c1-112; NSC-97-2752-B-010-001-001-PAE

References

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