Auditory tracts identified with the combined use of fMRI and DTI

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Introduction. The auditory system contains both ascending and descending projections linking auditory cortex with sub-cortical structures: ascending projections connect the inferior collicular nuclei (ICN) with the primary (PA), secondary (SA) and association (AC) auditory cortices via the medial geniculate body (MGB), while descending projections connect the auditory cortex directly to the ICN. However, these tracts are difficult to identify due both to their small size and their intersection with numerous other fibres in the vicinity of ICN and MGB (e.g. the optic tract and the optic radiation). Furthermore, while anatomical identification of ICN and MGB is relatively straightforward, anatomical parcellation of auditory cortices is difficult in the absence of functional information, due in part to intersubject variability of anatomical landmarks. The combination of fMRI and DTI was previously used to investigate connections between auditory cortices, but not between these and sub-cortical structures (1). We used diffusion tensor imaging (DTI) with a large number of diffusion directions, high b-values and high spatial resolution, combined with 2-tensor probabilistic tractography, which is the most promising presently known method to identify auditory fascicles. We also adopted auditory functional MRI (fMRI) to help localize auditory cortices based on their functional properties.

Methods. Structural, fMRI and DTI data were acquired from 14 healthy subjects (median age 24 years; 5 men) at 3T (Siemens Trio). Protocol: a) anatomical 3D T1-weighted image, TI=900ms, 1.1mm isotropic resolution; b) EPI DTI, 2 acquisitions, TE/TR= 90/7900ms, 64 gradient directions with b-value=1400 s/mm^2, 10 acquisitions with b=0 s/mm^2, 2.3mm isotropic resolution, 64 contiguous axial slices tilted by 30° from AC-PC line; c) 3 sparse fMRI runs (2): gradient-echo EPI, TR/TE= 11000/30ms (EPI acquisition = 3s; inter-scan interval=8s), 48 slices tilted by 30° from AC-PC line, slice/gap=2/1mm, in-plane resolution=2x2mm^2, 13min 47s acq. time per run; d) field-maps: 64 slices tilted by 30° from the AC-PC line, slice/gap=3/0mm, TR=688ms, TE1/TE2=4.92/7.38 ms, resolution 3mm isotropic. fMRI paradigm: During each run, subjects listened passively to four 3min 18s duration stimulus blocks: noise with no pitch; iterated rippled noise (IRN) fixed pitch; IRN varying pitch; and silence (rest) (adapted from (3)). The order of the 4 conditions was different in each of the 3 runs. In summary, a total of 216 functional image-volumes were acquired, each condition comprising 54 trials. During the experiment the scanner room lights were dimmed and subjects were asked to pay attention to the sounds while looking at a fixation cross. Auditory stimuli were presented via an Esys fMRI system (Invivo Corporation, FL, USA) equipped with: a 30" LCD display in the scanner room; pneumatic headphones embedded in ear-defenders (~25dB passive noise attenuation); and a computer running E-prime® (Psychology Software Tools Inc, PA, USA). Data processing: DTI was analyzed with probabilistic tractography, 2-tensor model (FSL; www.fmrib.ox.ac.uk/fsl/). fMRI was analyzed with SPM8 (www.fil.ion.ucl.ac.uk/spm/). Contrasts of interest were: all sound versus silence (brain regions with sensitivity to sound, PA); all sounds with pitch versus noise (regions with sensitivity to pitch information, SA); varying pitch versus fixed pitch (regions with sensitivity to pitch pattern, AC). Spheres of 6mm radius centered on the center of gravity of the activations were used as seed and target ROIs for the tractography, together with anatomically identified ICN and MGB ROIs.

Results and Discussion. Auditory fMRI, based on a previously published paradigm (3), successfully identified PA, SA, and AC in both hemispheres. Auditory association cortex in the right hemisphere comprised 2 areas, one in the planum polare and one in the planum temporale, while on the left hemisphere only the area in the planum polare was detected. Auditory fascicles were successfully identified in all subjects (an example in figure), with the percentage of success over the number of subjects reported in the table. It was not possible to discriminate between ascending and descending pathways, probably due to their close proximity.

PA-ICN	PA-MGB-ICN	SA-ICN	SA-MGB-ICN	AC-ICN	AC-MGB-ICN	PA-SA	PA-AC	L PA-R PA
L R	L R	L R	L R	L R	L R	L R	L R	
57 79	100 93	64 93	86 86	93 86 a 93 p	79 86 a 86 p	100 100	100 100 a 100 p	86

Auditory cortices: PA = primary, SA = secondary, AC = association, ICN = inferior collicular nucleus, MGB = medial geniculate body, L (R) = left (right) hemispheres, a (p) = anterior (posterior) AC.

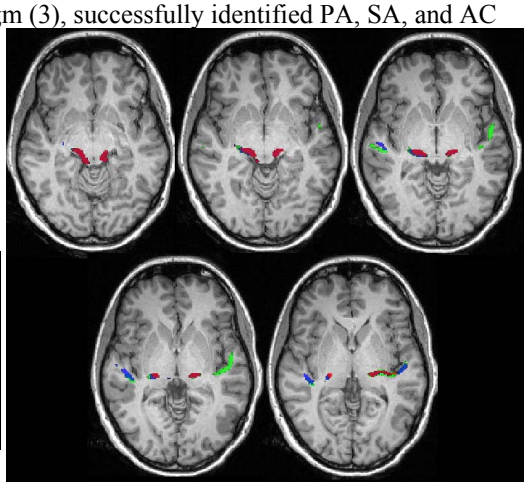

Fig. Ascending projections to PA (red), SA (blue) AC (green)

Conclusions. This study is, to our knowledge, the first combining fMRI, DTI and anatomical landmarks to successfully study the functional information and anatomical connectivity between sub-cortical structures and cortex in the human auditory system. Auditory fascicles were successfully identified in fourteen healthy subjects. Combining these methodologies can facilitate improved understanding of the function and anatomy of the auditory system, and may be of value in future clinical applications such as providing improved support for neurosurgical planning and aiding in the identification of patients most suitable for cochlear implant procedures.

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