Probabilistic tractography analysis of superior temporal gyrus connectivity to Wernicke's and Broca's areas

H. A. Haroon[1], S. Luzzi[2], D. C. Alexander[3], O. Ciccarelli[4], C. A. Wheeler-Kingshott[4], M. A. Lambon-Ralph[5], G. J. Parker[1]

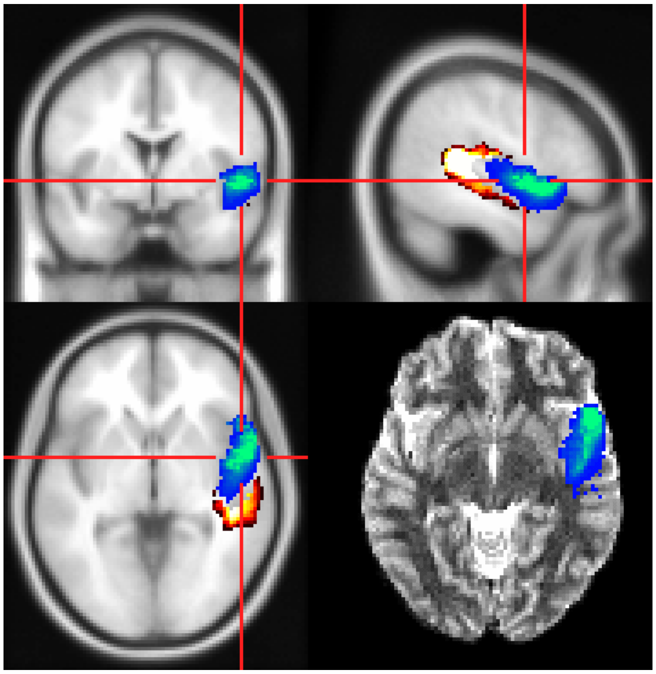
[1]Imaging Science & Biomedical Engineering, University of Manchester, Manchester, United Kingdom, [2]Department of Neuroscience, University of Ancona, Ancona, Italy, [3]Department of Computer Science, University College London, London, United Kingdom, [4]NMR Research Unit, Institute of Neurology, University College London, London, United Kingdom, [5]Department of Psychology, University of Manchester, Manchester, United Kingdom

Introduction Evidence from invasive tracer studies in monkey brains suggests dual streams for auditory-prefrontal pathways[1-3]. The classical picture is of connection via the arcuate fasciculus between Wernicke's area (WA) in the posterior superior temporal gyrus (STG) and Broca's area (BA) in the inferior frontal lobe. The second stream is likely to involve pathways emanating from the auditory association cortex in the anterior STG that reach the frontal areas via a ventral route, but has not to date been demonstrated anatomically in humans[4,5], although functional imaging and lesion studies imply its existence[3]. We use probabilistic tractography, incorporating crossing fibre information, in a group of 9 healthy subjects to assess STG connectivity internally to WA and externally to BA. We provide evidence for parcellation of the left STG into regions connecting largely to BA and regions connecting largely to WA, and provide anatomical evidence for the ventral auditory processing stream in humans.

Methods MR diffusion weighted data were acquired in 9 right-handed healthy volunteers. Imaging was carried out on a GE Signa 1.5 Tesla scanner with a standard quadrature head coil. Sequence parameters were: cardiac gating (TR = 20 RR ~ 20 s); TE = 95 ms; 60 axial slices; 54 non-collinear diffusion-weighting directions with a *b*-factor of 1156 s/mm^2; 6 acquisitions with a *b*-factor ~ 0 s/mm^2; δ = 34 ms; Δ = 40 ms; gradient strength G = 22 mT/m; 96 × 96 acquisition matrix, interpolated during reconstruction to 128 × 128; FOV = 220 mm, generating 2.3 × 2.3 × 2.3 mm^3 voxels as acquired, reconstructed to 1.72 × 1.72 × 2.3 mm^3. Eddy current-induced image distortions in the diffusion sensitised images were removed using affine multiscale 2D registration. High resolution EPI images were acquired at the same location as the diffusion data to aid anatomical localisation.

The anatomical images for each individual were transformed into standard space, where volumes of interest (VOI) were defined to delineate the STG, BA (Brodmann area 44), and WA (Brodmann area 22) in the left hemisphere[4,5] (with WA forming a sub-volume of the STG). VOIs were defined to encompass the grey matter relating to each area and neighboring gyral white matter. All VOIs were transformed back into acquisition space for each individual, where probabilistic fibre tracking was performed from every voxel in the STG VOI using the PICo software package[6,7]. Probability density functions (PDF) of cerebral fibre orientations were estimated for the presence of one or two fibres by modeling water diffusion in a single fibre by a single Gaussian density and in multiple fibres by a mixture of Gaussian densities[7]. The tracking process generated maps of connection probability to every voxel in the brain from each voxel within the STG. The connection probability of each STG voxel map within BA and WA was then used to determine the probability of connection of each STG voxel to either BA or WA[8]. Each individual STG-BA and STG-WA map was then transformed into standard space and combined to provide the voxel-wise group mean connection probability.

Results The figure shows the population averaged maps of the left STG regions that connect to BA (cold colour scale) and WA (hot colour scale), and the localization of the BA-STG connectivity in a single individual. The anterior STG (Brodmann area 38 or temporopolar region) showed the highest probability of connection to BA, while the region posterior to area 38, which includes the primary auditory cortex (area 41), the posterior transverse temporal area (area 42) and the parainsular cortex (area 52), showed slightly lower connection. Most of WA (area 22) was not connected to BA with high probability. BA-STG Connections appear to run via the uncinate fasciculus and/or the external capsule. The densest area of high connection probability to Wernicke's area is within the WA VOI itself and extending anteriorly to encompass the parts of Brodmann area 22 not within the VOI. A diffuse area of low-probability of connection to WA was found overlapping with the regions connecting to BA.



Group average WA VOI (hot colour scale) and BA VOI (cold colour scale) connectivity to the STG VOI. Bottom right: Pattern of BA connectivity to STG in a single individual.

Discussion The STG mapping presented here demonstrates the specificity of WA and BA connecting regions observable using probabilistic DWI tractography. The area connecting WA with high probability is likely to define the extent of WA (area 22) itself, and little more. The more extensive low probability connection to WA along the STG may represent evidence for low density connectivity along the posterior-anterior extent of the STG. We identify the BA-connecting region as a combination of Brodmann areas 38, 41, 42, and 52, with a small degree of overlap with the anterior part of area 22. Area 38 (the temporopolar cortex) is a multimodal area in which sensory modalities, including audition, are represented[3], and is well-connected to the orbitofrontal and prefrontal cortex via the uncinate fasciculus. The regions with high connection probability identified as being area 52 (the parainsular cortex), area 42 (implicated in speech recognition), and possibly the anterior part of area 22 may be analogous to the anterior association auditory regions identified in monkeys that project to the frontal lobe via the ventral auditory processing stream[2,3], indicating a similar mapping in the human brain. The use of DWI tractography allows the non-invasive definition of this pathway in the human brain.

References

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