Temporo-Parietal White Matter Pathway Asymmetry Underlies Functional Laterality

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Introduction

Structural and functional asymmetry of the human brain has been well documented using techniques such as magnetic resonance imaging (1,2,3). However, asymmetry of underlying white matter connections is less well understood. We applied diffusion tensor tractography to reveal the morphology of the white matter in vivo by mapping directions of maximum water diffusion in brain tissue. In particular, white matter pathway asymmetry was investigated in a normalised image dataset of 30 right handed young healthy individuals for pathways passing between the temporal and parietal lobes. We identified, for the first time, a rightwardly asymmetric pathway connecting the posterior temporal lobe to the superior parietal lobule that is in correspondence with functional evidence for lateralisation of auditory-spatial function (4,5).

Method

MRI data acquisition: 30 healthy right-handed subjects (15 male, 15 female: mean age 27.2±5.2) were scanned on a 1.5T GE Signa MRI system (max. field gradient strength 22mTm^{-1}). Diffusion tensor imaging (DTI) was achieved using a single shot echo planar sequence with 12 diffusion sensitised directions as described previously (6). Two interleaved acquisitions comprising 25 slices each provided whole brain coverage (resolution: in plane 2.5mm; through plane 2.8mm). Each subject's DTI was normalised to standard space by affine transformation and a normalised mean DTI computed (7).

Lobe segmentation: Temporal and parietal lobes in the left and right cerebral hemispheres were segmented from the normalised DTI data by application of the Talairach Daemon (8). These segmentations were used to determine the streamlines that terminate (i.e. start or end) in the lobes of interest using the coordinates of their start and end points.

Tractography: Subvoxel streamline tractography was performed as described previously (6). Streamlines (vector step length 1.0mm, termination criteria FA > 0.08) were initiated from the centre of every voxel in the normalised mean DTI and each individual normalised DTI dataset. Only streamlines passing between and terminating in the temporal and parietal lobes were retained. These streamlines were coloured according to their termination points using a Symmetrical Streamline Colour (SSC) map that identifies pathways with identical start and end points by colouring their streamlines similarly in the opposite cerebral hemispheres (see Figure 1).

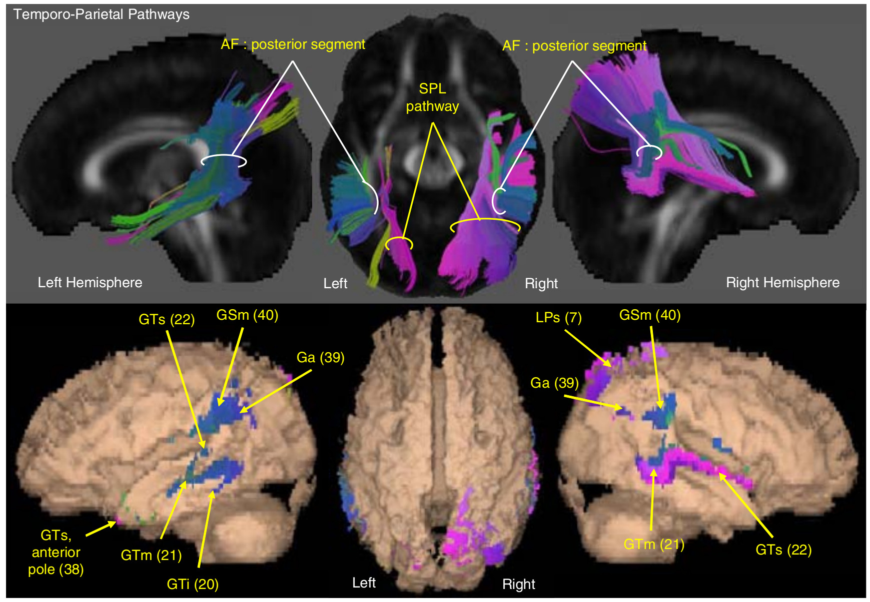

Figure 1

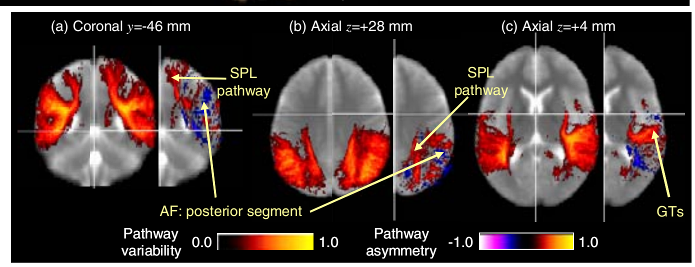

Figure 2 White Matter: AF = arcuate fasciculus
SPL = superior parietal lobule
Grey Matter: GTs = superior temporal gyrus
GTm = middle temporal gyrus
GTi = inferior temporal gyrus
GSm = Supramarginal gyrus
Ga = angular gyus
LPs = superior parietal lobule

Pathway variability and asymmetry maps: A pathway variability map was generated by computing the mean (across the entire dataset) of binary images representing whether streamlines pass between the temporal and parietal lobes in each individual subject. This provides an image with values between 0 (black) and 1 (yellow) where each voxel represents the normalized frequency for the presence of white matter pathways (see Figure 2). A pathway asymmetry map was computed from the pathway variability image. This was generated by reflecting the pathway asymmetry image in the mid-sagittal plane (x=0) and subtracting on a voxel-by-voxel basis the reflected from the unreflected image. This provides an image with values between -1 (leftward asymmetry: cold colourmap) and 1 (rightward asymmetry: hot colour map), see Figure 2. Note that as the asymmetry map has opposite asymmetry on both sides of the mid-sagittal plane only the right hemisphere is shown.

Results and Discussion: Two large pathways were found to pass from the posterior temporal to the parietal lobe. SSC maps indicating the average asymmetry of reconstructed temporo-parietal pathways (Figure 1, top row) and pathway termination coordinates rendered on the white matter surface (Figure 1, bottom row) are illustrated. Because each pathway is coloured according to its start and end coordinates in standard space, symmetrical pathways will have the same colour whereas asymmetrical pathways will have different colours in the left and right hemispheres. Inter-subject pathway variability and asymmetry maps of the temporo-parietal pathways are shown in Figure 2. The first pathway (highlighted by yellow arrows in Figure 1, top row), connecting the superior temporal gyrus to the superior parietal lobule was clearly present in the right hemisphere, with the pathway shown to exist in both hemispheres as indicated by the pathway variability maps in Figure 2. This pathway, referred to here as the superior parietal lobule pathway, has not been reported in previous tractography studies and exhibited a large rightward asymmetry at its superior (Figures 2a and 2b) and inferior limits (Figure 2c).The second pathway (highlighted by white arrows in Figure 1, top row) connected the superior, middle and inferior temporal gyri (Brodmann Area (BA) 21, 22 & 37) bilaterally to the inferior parietal lobule (Figure 1).This pathway, recently referred to as the posterior segment of the arcuate fasciculus (9), has been implicated in semantic processing in the left hemisphere whilst the inferior parietal lobule is activated by functional imaging tasks accessing the phonological store (10). In the present study, the posterior segment of the arcuate fasciculus was found to have a leftward asymmetry (Figures 2a and 2b). We identified, for the first time, a rightwardly asymmetric pathway connecting the posterior part of the temporal lobe to the superior parietal lobule. This pathway may be related to auditory-spatial function for which there is evidence for a rightward laterality from functional imaging studies (4,5) and may also be implicated in verbal (11) and auditory spatial working memory function (12).

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