Divergent Connectional Asymmetries of the Inferior Parietal Lobule Shape Hemispheric Specialization in Humans, Chimpanzees, and Macaque Monkeys

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Introduction

The inferior parietal lobule (IPL) is involved in the human specialized functions including language and complex tool use, which show considerable lateralization in the human brain [1, 2]. Moreover, the IPL is one of the most expanded regions in humans compared with nonhuman primates[3]. Traditional anatomical descriptions of hemispheric specialization, which focused on hemispheric asymmetries of local characteristics of the IPL, cannot assess the neural connectivity architecture and are, thus, insufficient for establishing a complete explanation. Here, we used connectivity-based parcellations to subdivide the IPL and used vertex-, region of interest (ROI)-, and tract-wise analyses to examine connectional asymmetries of the IPL subregions to identify evolutionary changes.

Material and Methods

Human data, including T1w images (0.7mm isotropic) and diffusion-weighted images (DWI, 1.25mm isotropic; b-values: 1000, 2000, and 3000 s/mm2), from 40 right-handed healthy adults were randomly selected from the Human Connectome Project (HCP) database. Chimpanzee data, including T1w images (0.7x0.7x1mm), and DWI (b = 1000 s/mm2; 1.8 mm isotropic), from 27 adult chimpanzees were obtained from the National Chimpanzee Brain Resource. Macaque data, including T1w images (0.5 mm isotropic), and DWI (b = 1000 s/mm^2, 64 directions), from 8 male adult macaque monkeys (Macaca mulatta) were obtained from TheVirtualBrain [4]. The T1w images had been preprocessed following the HCP's or NHPHCP' minimal preprocessing pipeline [5]. FSL's DTIFIT was used to fit a diffusion tensor model for DWI data. Voxel-wise estimates of the fiber orientation distribution were calculated using Bedpostx. We used a connectivity-based parcellation framework modified from Fan et al[6](**Fig.1**). To map the whole-brain anatomical connectivity pattern for each cluster, we performed probabilistic tractography by drawing 5000 samples from each vertex in each cluster. The resulting tractograms were log-transformed, normalized by the maximum, and then projected onto surface space. The asymmetry index (AI) was defined as the difference between values for the left and right hemispheres according to the formula $AI = 2*(R−L)/(R+L)$. For the vertex-wise analysis, a one-sample t test was performed at each vertex for each species using PALM [7]. The significant level was set at FDR corrected $p < .05$. ROI- and tract-wise analyses was further performed with 11 cortical regions and 7 whiter mater tracts. Bonferroni correction was then used for multiple comparisons with statistical significance set at $p < .05$.

Results

Using connectivity-based parcellation, we revealed a consistent four-way rostral-caudal topological parcellation of the IPL in macaques, chimpanzees, and humans (**Fig.1**), which were consistent with cytoarchitectonic delineations of the IPL[8, 9, 10]. In terms of connectional asymmetries of the IPL subregions, humans showed the most widespread asymmetric connections in the frontal, parietal, and temporal cortices, chimpanzees showed some asymmetric connections in the anterior frontal cortex, superior parietal lobule, and anterior temporal lobe, and macaques showed no significant asymmetries (**Fig.2**).

Conclusion

Connectivity-based parcellation is a powerful tool to reveal internal organizations of the brain across species and can be used for cross-species comparisons. Compared with chimpanzees and macaque, human showed increasing asymmetric connections between IPL subregions and frontal, parietal, and temporal cortices, which are related to the human language and tool use and may underlie the human hemispheric specialization. The opposite asymmetric connection between the IPL and SPL in chimpanzees and humans may reflect evolutionary adaptation during the course of the human evolution.

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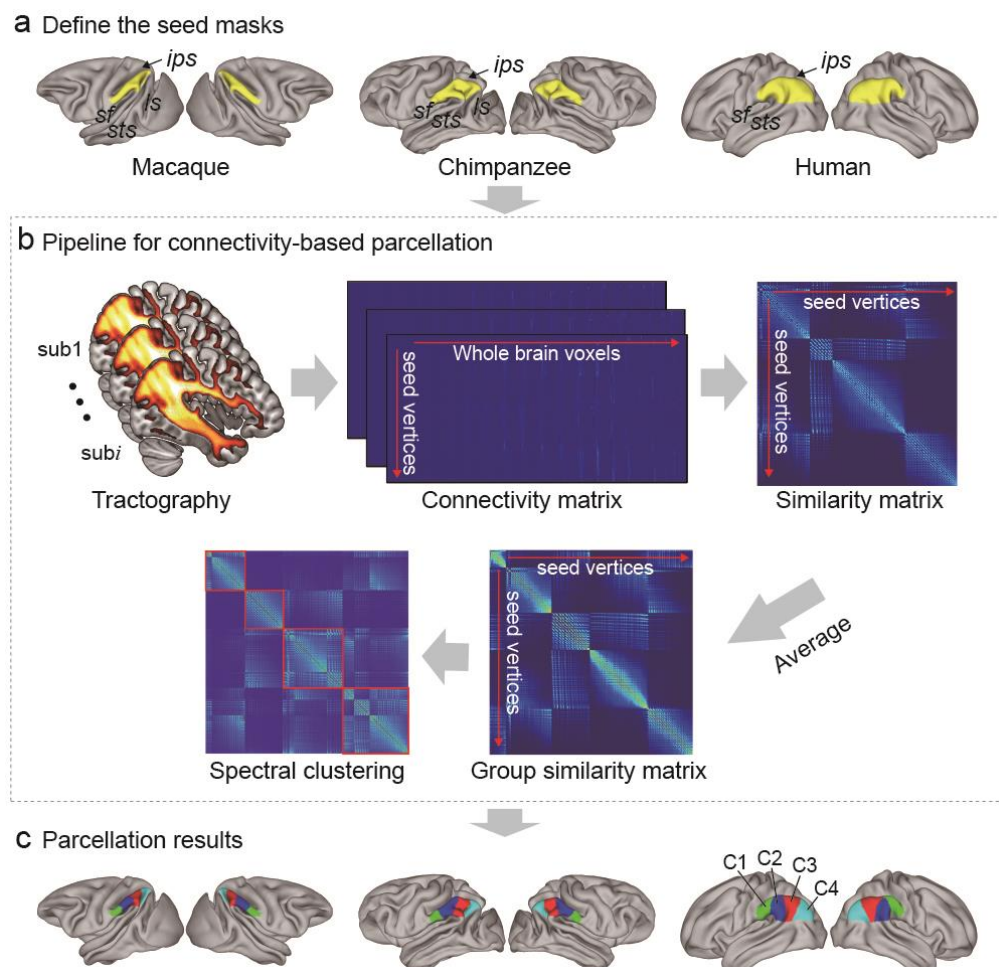**Fig 1.** Framework of the connectivity-based brain parcellation for macaques, chimpanzees, and humans.

Fig. 2. Connectional asymmetries of the IPL subdivisions across species.