Mapping hubs in the neocortical structural network of the human brain shows lateralization

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INTRODUCTION Mapping hubs as defined through graph theoretical measures, such as node degree and betweenness centrality in the neocortical structural network is a promising mean to locate critical areas in the human brain. In this paper we adopt an improved approach as described in [1] to create average neocortical hub maps for a cohort study of 46 young adults. The results provide to the best of our knowledge the first evidence through graph theoretical measures that neocortical network hubs show lateralization.

DATA 46 healthy subjects (24 females 22.38 ± 1.66y, 22 males 23.55 ± 3.14y) were scanned on a Siemens 3T TIM Trio system with a 32 channel head coil. *Anatomical scans* were acquired using a 3D MPRAGE sequence with TE=3.03ms, TR=2300ms, TI=1100ms, a flip angle of 8° with 1mm isotropic voxels. *Diffusion weighted imaging* volumes were acquired using a single-shot echo-planar imaging (EPI) sequence, with TE=101 ms, TR=13.0s, 2mm isotropic voxels and taken in 256 non-collinear directions at a b-value of 1500 s/mm^2. In addition, 28 volumes were acquired with b=0 s/mm^2.

METHODS The anatomical scans were analyzed using freesurfer to segment the brains into cortical and subcortical structures (step 1a). Each neocortical hemisphere was then parcellated into 500 ROIs using the k-means algorithm on the Euclidean distances of gray matter voxels (step 2a). The diffusion-weighted images were checked for motion, cardiac and table vibration-induced artifacts using the PATCH algorithm [2]. The volumes were then realigned and corrected for eddy current-induced distortions using the integrated approach described in [3]. Finally the volumes were unwarped in the phase encoding direction onto the anatomical scan to reduce the effects of phase evolution in the EPI read out direction [4]. We used the multifibre reconstruction PASMRI with 16 basis functions (step 1b) [5] and performed interpolated deterministic tractography with a 0.2mm stepping size (step 2b) [6] using the coregistered freesurfer white matter mask for seeding. For each brain a network was then reconstructed by defining the ROIs as nodes and the number of tracked fibers between ROIs as the edge strength (step 3). A network analysis was then performed to determine the node degree and betweenness centrality for each brain (step 4). The normalized results were then mapped back on the cortical surfaces (step 5) and finally registered onto the freesurfer average surface, where they were smoothed with a 10 mm full width at half maximum kernel.

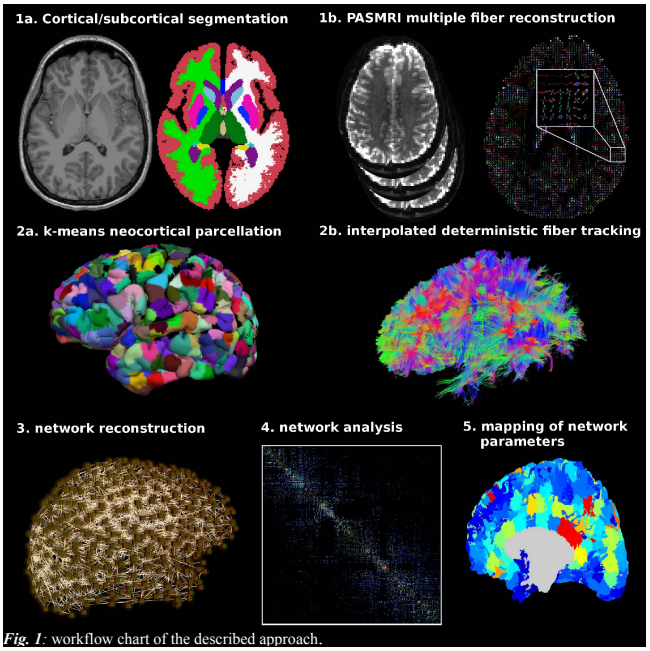

Fig. 1: workflow chart of the described approach.

RESULTS In fig. 2 and 3 the normalized outcomes of the betweenness and the node degree analyzes are displayed on the freesurfer average surface. We found that areas in the cingulate cortex are a prominent location for neocortical hubs with area **2** having the highest betweenness centrality within it. Another finding is that the hub areas **1**, **2**, **5**, **6** and **8** coincide with areas which are associated with the default mode network [7], while areas **3**, **4** and **7** play an important role in language processing. With our approach we have also demonstrated that neocortical network hubs are lateralized. E.g. areas **1** and **2** show a higher betweenness centrality on the right hemisphere, while areas **3-8** are lateralized to the left hemisphere. These hub areas on their more dominant hemispheres are therefore assumed to be more critical to the network structure than their contra lateral homologues.

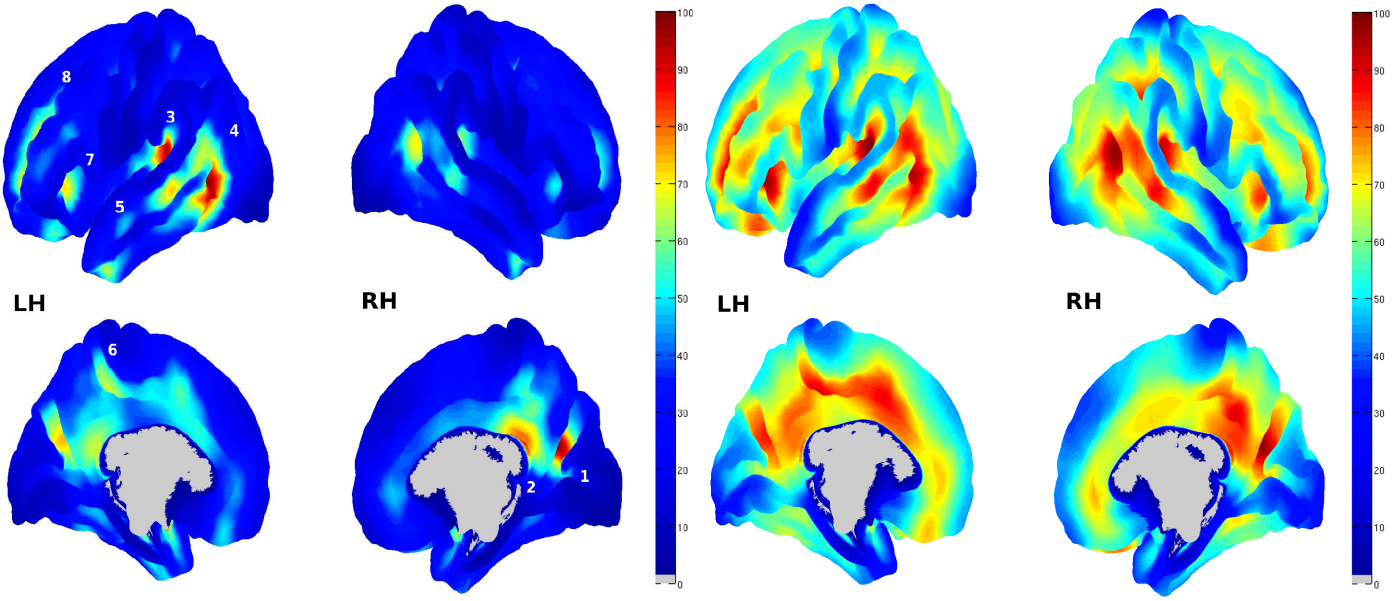

Fig. 2 (left half)*:* shows the average betweenness centrality map. Labels indicate hub loci. **1**: parieto-occipital sulcus, **2**: isthmus cingulate, **3**: posterior lateral sulcus, next to Wernicke's area and supramarginal gyrus,, **4**: cortices related to auditory comprehension, **5**: (not visible) medial temporal lobe, lateral sulcus, **6**: marginal sulcus, **7**: Broca's area, **8**: dorsal medial prefrontal cortex. ***Fig. 3*** (right half)*:* shows the average node degree surface map.

REFERENCES **[1]** *P. Hagmann et al*, PLoS Biol 6, 1479 (2008); **[2]** *M.P. Zwiers*, Proc. ISMRM, 1423 (2009); **[3]** *E. Visser et al*, Proc. ISMRM, 3459 (2010); **[4]** *J.L.R. Andersson et al* Neuroimage 16 (1), 177-99 (2002), **[5]** *P. Cook et al*, Proc. ISMRM, 2759 (2006); **[6]** *T.E. Behrens et al*, Magn. Reson. Med. 50, 1077 (2003); **[7]** *D.A. Gusnard and M.E. Raichle*, Nat. Rev. Neurosci. 2, 685 (2001)