

Chimpanzees' primary motor cortex asymmetry and its association with handedness – a combined T1- and diffusion-weighted magnetic resonance imaging (MRI) study

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Introduction: Recent studies indicate that chimpanzees, like humans, show a population-level bias for the use of the right hand for fine manipulation, although the degree of handedness is less than that of humans. In addition, it is reported that chimpanzee brains show gross anatomical correlates of handedness, the central sulcus (CS) being deeper in the region of the motor hand representation in the dominant hemisphere [1]. Here, we used *in vivo* diffusion-weighted and T1-weighted magnetic resonance imaging (MRI) in 36 adult female chimpanzees to study the organization of the chimpanzees' precentral corticospinal tracts (pCST) and its relationship to handedness. Specifically, we examined (i) whether chimpanzees exhibit interhemispheric differences in the pCST at the levels of microstructure and macrostructure, (ii) whether these features vary systematically with handedness, and (iii) whether interhemispheric differences in fractional anisotropy are related to variations in CS depth.

Methods: Subjects: Thirty-six female chimpanzees (age: 26.7±13.24 yrs) were included in this study. **Behavior measures:** Handedness index (HI = (R - L)/(R + L), where R and L represent the use of right and left hand) were measured for coordinated bimanual actions (TUBE) [2]. **Image acquisition:** MRI images were obtained using a 3T Trio scanner (Siemens Trio, Pennsylvania, US). T1-weighted images were acquired with 3D MPRAGE sequence with the following parameters: FOV=204×204 mm², matrix size: 256×256, 0.8 mm isotropic voxel. Diffusion MR data were acquired with the following parameters: segmented dual spin-echo diffusion echo-planar imaging sequence (seg=4), FOV=230×230 mm, matrix size: 128×128, 41 slices covering the whole brain, 1.8 mm isotropic voxels, two averages with opposite phase encoding directions to remove the susceptibility distortion [3]. **Data analysis: Probabilistic tractography:** probabilistic tractography implemented in the FSL package was used to track the pCSTs originating from the precentral gyrus. The locations of the seed mask, waypoint mask and the grey matter/white matter boundary cortical mask in the probabilistic tractography study (Fdt toolbox, FSL, <http://www.fmrib.ox.ac.uk/fsl/>) are shown in Fig. 1A. The pathways of pCSTs for each chimpanzee were normalized by the waytotal number and then nonlinearly transformed to a common anatomical template, averaged and interpreted as the probability map of the pCSTs from the population. The pCST probability map was further thresholded (> 0.2%) and binarized to generate a pCST mask, both as a whole or divided into five equal sections for calculating the mean FA from within each mask. **Depth of Central Sulcus (CS):** The depth of the CS was measured in the axial plane of the T1-weighted images, and divided into ten equally spaced sections (see Fig. 1B). For both pCSTs and depth of CS measures, asymmetry quotients (AQ=(L - R)/(L + R), where L and R represent the measures from the left and right hemispheres), were calculated.

Results: Tractography of pCST and tract-based ROI: The center of mass for the sample's right precentral corticospinal tract was located more anteriorly than the left-sided one, consistent with the findings in humans [4] (Fig.1C). No significant correlation was found between handedness (HI) and brain asymmetries (AQ) for the tract-based ROIs (i.e., the mean FA from within the whole or from the five equally spaced pCSTs sections). Post-hoc univariate tests of FA values revealed hemispheric effects (L>R) at the mean FA from within the whole pCST mask (p<0.002), and at CST2 (p<0.006), CST4 (p<0.001), and CST5 (p<0.000) (Fig.1C). No effect of handedness or hemisphere-by-handedness interaction was detected for pCST-based ROIs. **Measurement of the CS depth:** Significant correlations between HI and AQ were found for the depth of the CS at CS1 (r=0.424, p<0.01), CS2 (r=0.444, p<0.007), CS7 (r=0.293, p<0.083). A hemisphere-by-handedness interaction was detected at CS1 (p<0.029), CS2 (p<0.063) and CS7 (p<0.035) (see Fig.1D), with a deeper central sulcus in these sections in the left hemisphere for right-handers than for non-right-handers. We found no significant correlation between the AQ of the depth of the CS and the AQ of the mean FA from within the pCST masks.

Conclusions: The fact that handedness measure was correlated with the depth of CS, instead of the hemispheric asymmetries in FA at the pCST, suggests that – perhaps both for chimpanzees and for humans—that the asymmetries of central sulcus depth and of corticospinal FA are largely functionally independent. If asymmetries of the CS depth reflect differences in the precentral gray matter volume, as seems likely, then hand dominance in chimpanzees is related more strongly to interhemispheric differences in cortical gray matter volume than to interhemispheric differences in the microstructural features of the corticospinal tract white matter indexed by FA. **References:** [1]. Hopkins, W.D., Behavioral Neuroscience, 118, 1176-1183, 2004; [2]. Tagliabata, J.P., et al., Behavior Brain Research, 184, 185-191, 2007. [3]. Andersson, J.L., et al., NeuroImage, 20, 870-888, 2003. [4]. Rademacher, J., Brain, 124, Pt1, 2232-58, 2001. [5]. Smith, S.M., NeuroImage, 31(4), 1487-505, 2006. **Grants:** This work was kindly supported by NIH 5P01 AG026423-03 and RR-00165.

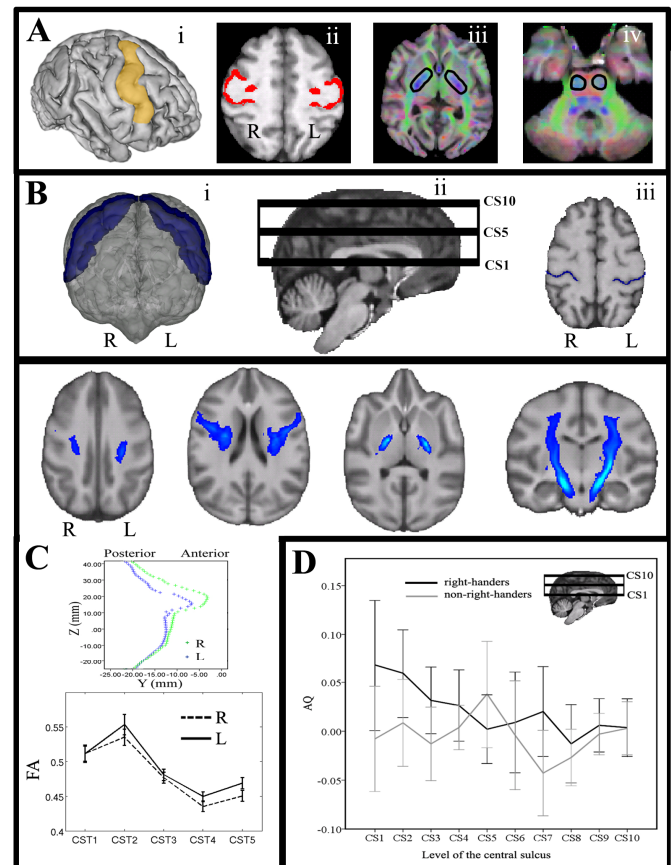


Fig. 1. **A:** The gross coverage of the cortical target mask in a 3D render view (lateral) (i), the grey matter/white matter cortical target masks (ii) and the locations of the waypoint mask at the posterior limb of internal capsule (iii) and of the seed mask at the basilar pons (iv). **B:** The 3D render view (front) of the CS (i), the volume coverage for the analysis of the depth of the CS (ii) and an example drawing of CS on an axial slice (iii). **C:** The probability map of the pCST (top figures) and the plot of the anterior-posterior position of the gravity center of the pCST (middle plot). The mean FA from within the five equally spaced sections of the pCST masks, showing a hemispheric effect on FA in the pCST (bottom). **D:** the hemisphere-by-handedness interaction on the depth of the CS divided by the ten equally spaced sections (see results for details).