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Delineating the human direct and indirect motor descending pathways using high-resolution tractography with diffusion imaging

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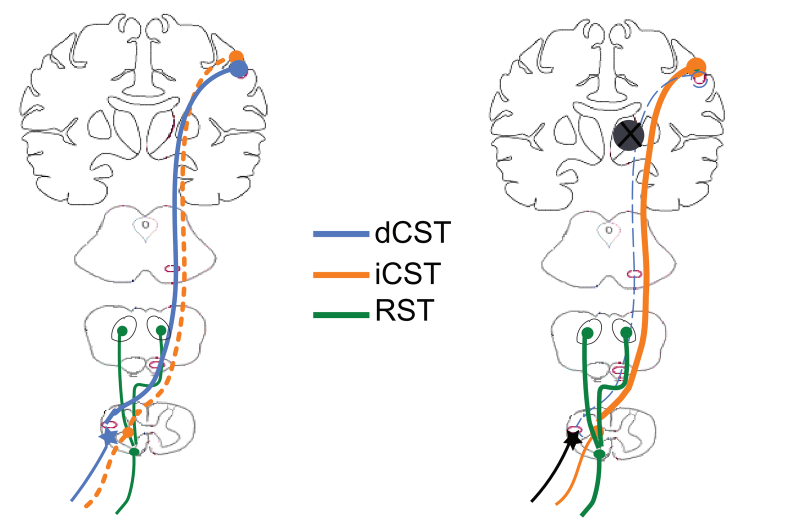
Introduction

Dexterous hands are essential in our daily activities. Previous studies have established that fine finger control and hand strength are supported by separate descending pathways, namely, the corticospinal (CST) and reticulospinal tracts (RST) (Lawrence & Kuypers, 1968a&b; Xu et al., 2017). Non-human primate research also suggests that after lesion of the direct, corticomotoneuronal projections within the CST (dCST), the indirect connections within the CST (iCST), specifically the propriospinal (PN) pathway, also contributes to the recovery of hand dexterity (Isa, 2019). Moreover, reticulospinal tract (RST) has also been found to particpate or set a limit to dexterity recovery (Zaaimi et al., 2012).

Delineating these descending pathways will be informative to functional recovery after neurological insult. Comparative fiber tracking studies across species suggests that the majority of the dCST in humans originates from M1 (Brodmann's area BA4) (Lassek & Rasmussen, 1940) and the PN pathway mainly originate from ventral premotor cortex (PMv) (BA6) (Pierrot-Deseilligny, E. & Burke, 2005).

Here we investigate the feasibility of using a recent ultra-high-resolution whole-brain atlas from the HCP data to separate dCST, iCST, and RST in healthy participants and stroke survivors.



Hypothesized Model

A hypothesized model of three descending pathways (dCST, iCST and RST) showing disruption of the neural pathway before and after the stroke incident.

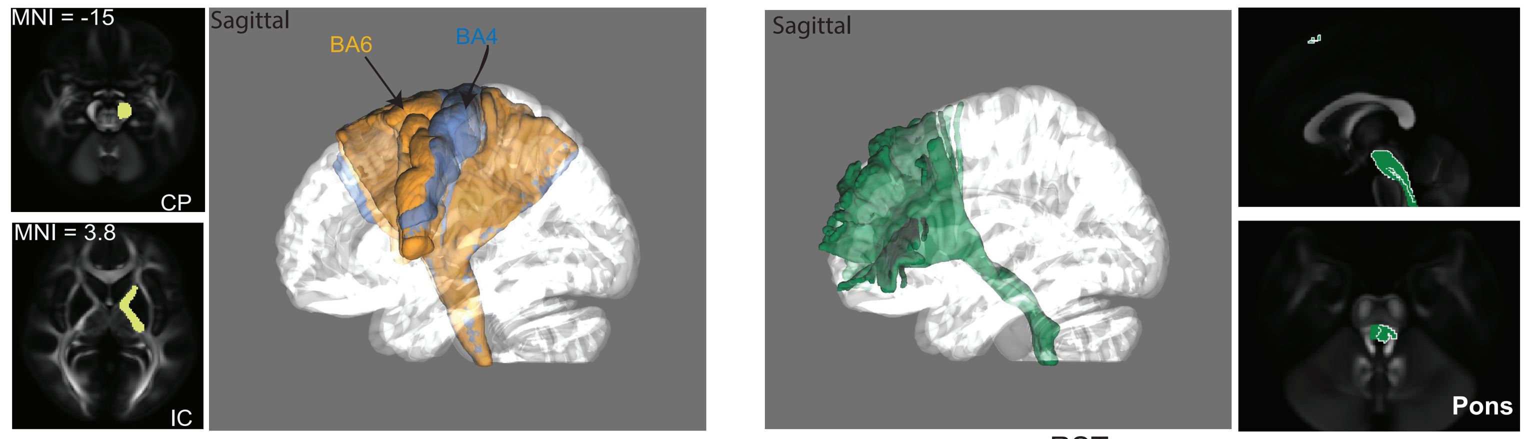
In stroke: after a disruption of the dCST, iCST and RST may be upregulated to compensate the loss of the direct pathway.

Methods

Participants: Healthy younger adults (N=8; 6 females; 2 males; mean age 19), older adults (N=8; 4 females;4 male; mean age 71 years) and individuals with stroke (N=6; 3 females; 3 males; mean age 59 years).

Diffusion Imaging: The diffusion Magnetic Resonance images (dMRI; 60 directions, b=2000 and 4000 s/mm^2, slice thickness of 2 mm) was collected from each subject on a 3T GE scanner (Discovery MR750) at the University of Georgia. We used readout-segmented echo-planar imaging in conjunction with parallel imaging (Heidemann et al., 2010) and a multi-shell diffusion spectrum imaging sequence. The dMRI images were reconstructed to the MNI space using q-space diffeomorphic reconstruction (QSDR) at an output resolution of 2 mm isotropic in a standard atlas space for easy comparison across subjects using DSI studio (Yeh et al., 2010).

Fiber Tracking: To acess the tract integrity of different pathways affected by the lesion, we adopted the technique from previous studies and generated the three different ROI masks to approximate the direct, indirect CST and RST pathways in the HCP atlas.



ROIs masks were created in the MNI template space of the HCP data. The direct and indirect CST ROI masks were restricted by BA4 (direct), BA6 (indirect), starting from the internal capsule (IC) and between the cortex and cerebral peduncle (CP). Two ROI masks for the RST pathways

Atlas: dCST, iCST RST

The decending tracts, direct direct CST (dCST), indirect (iCST), and reticulospinal (RST) tracts are mapped in the HCP1065 average data as shown in coronal, sagittal and isosurface view.

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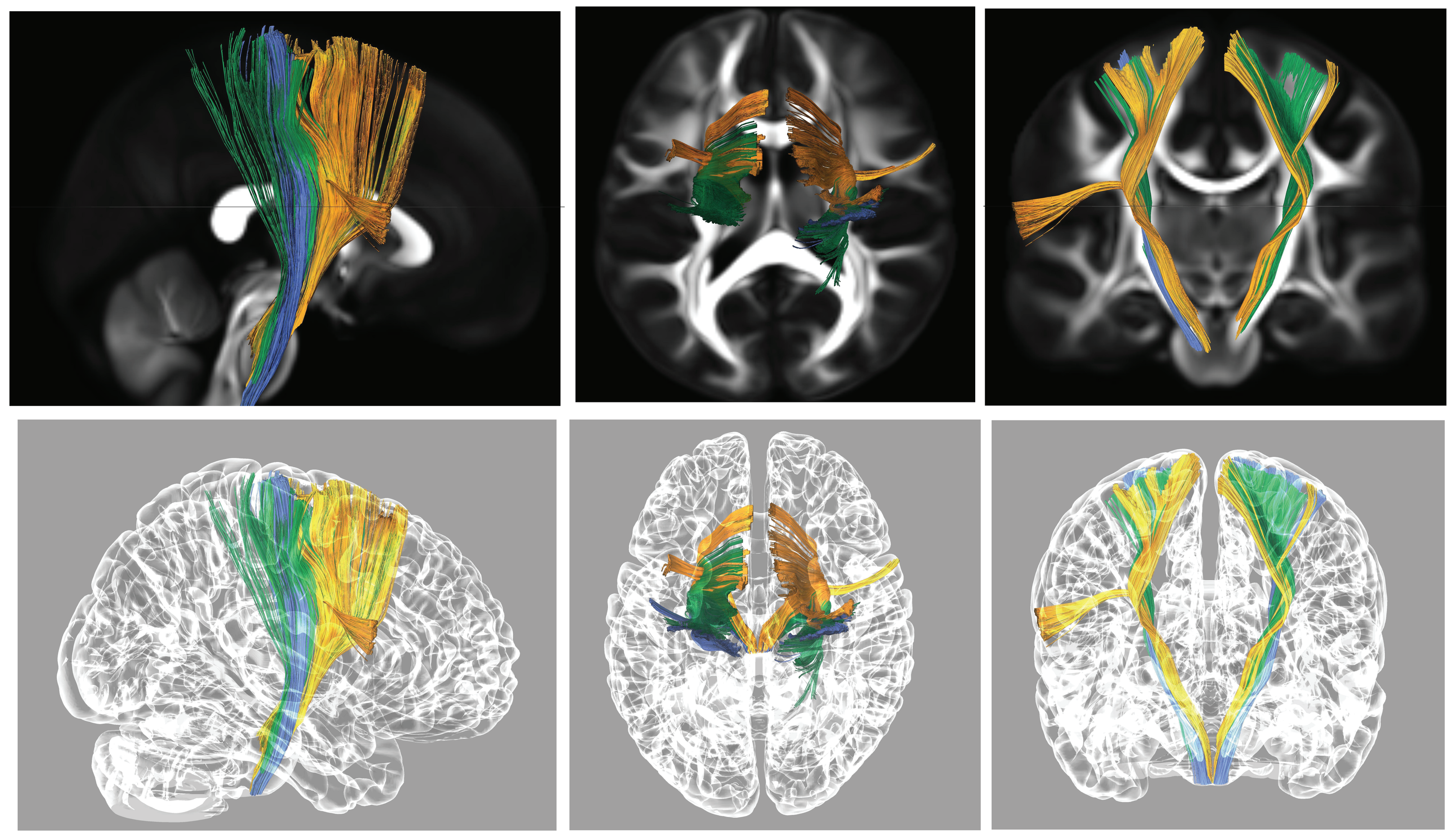
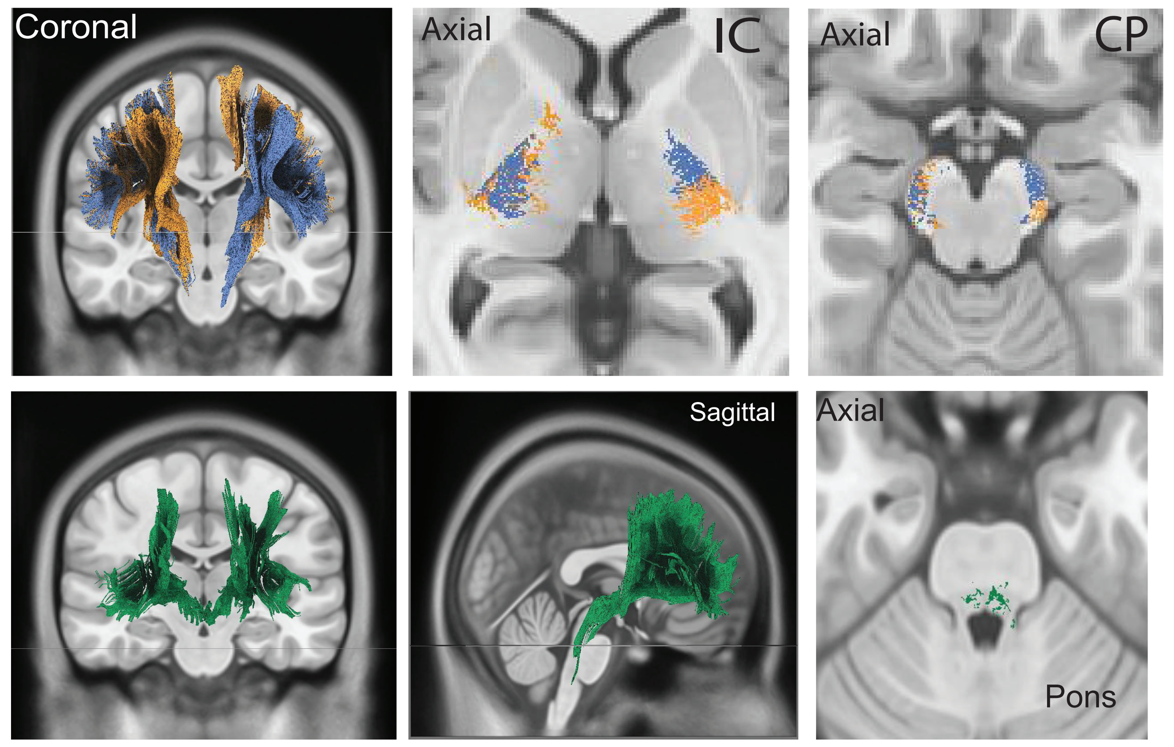
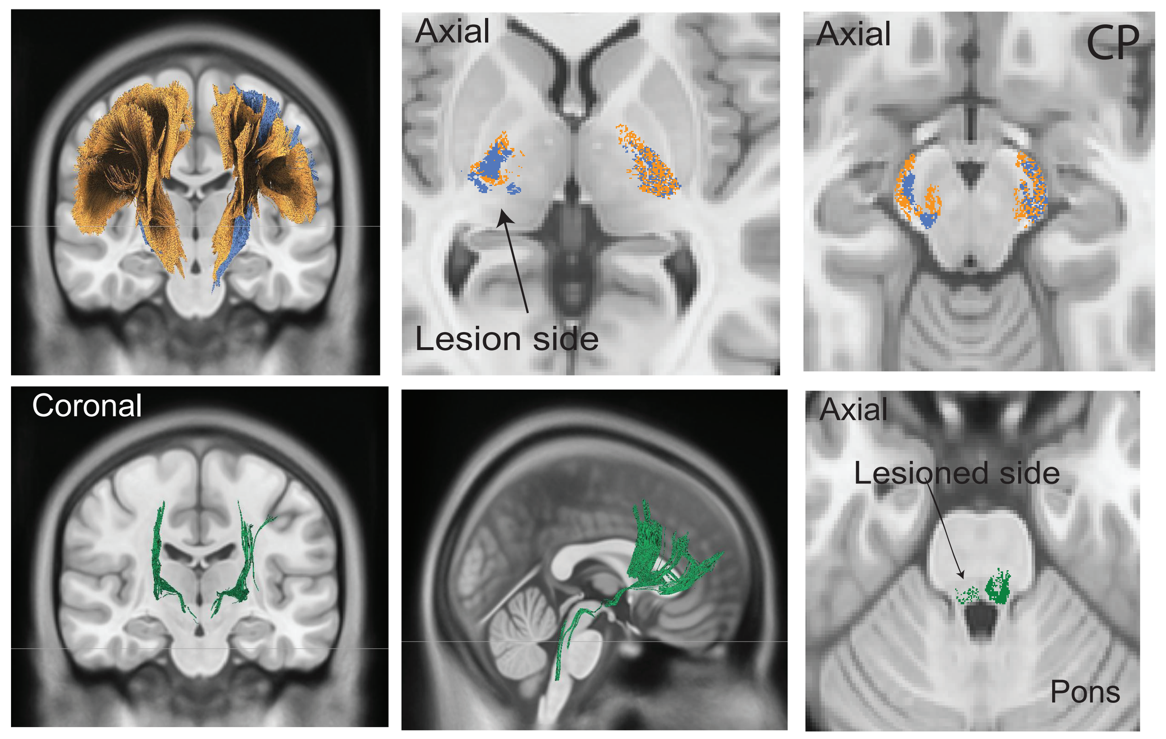


Tracking results (single subject)

Healthy



Patient

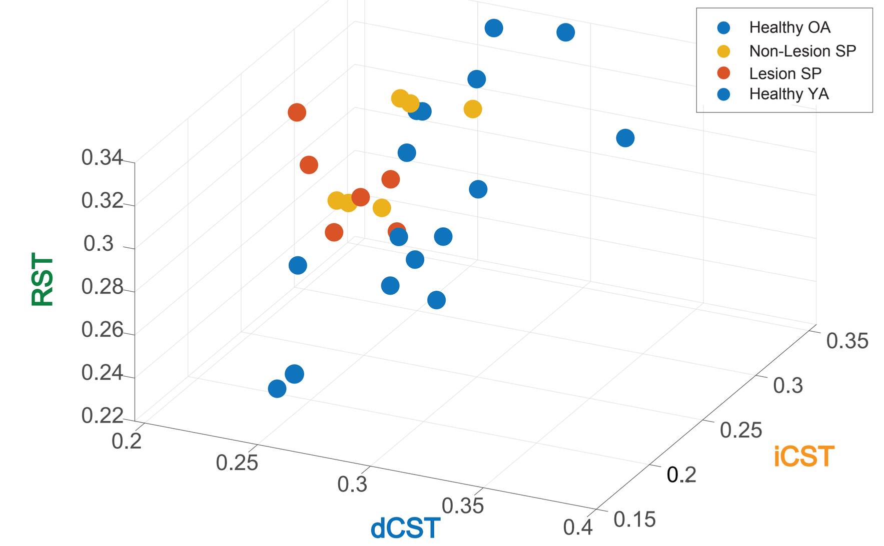


In a healthy older adult (OA) ICBM template, CST tracts (dCST and iCST) are restricted using ROI masks starting at internal capsule (IC) and cerebral peduncle(CP).

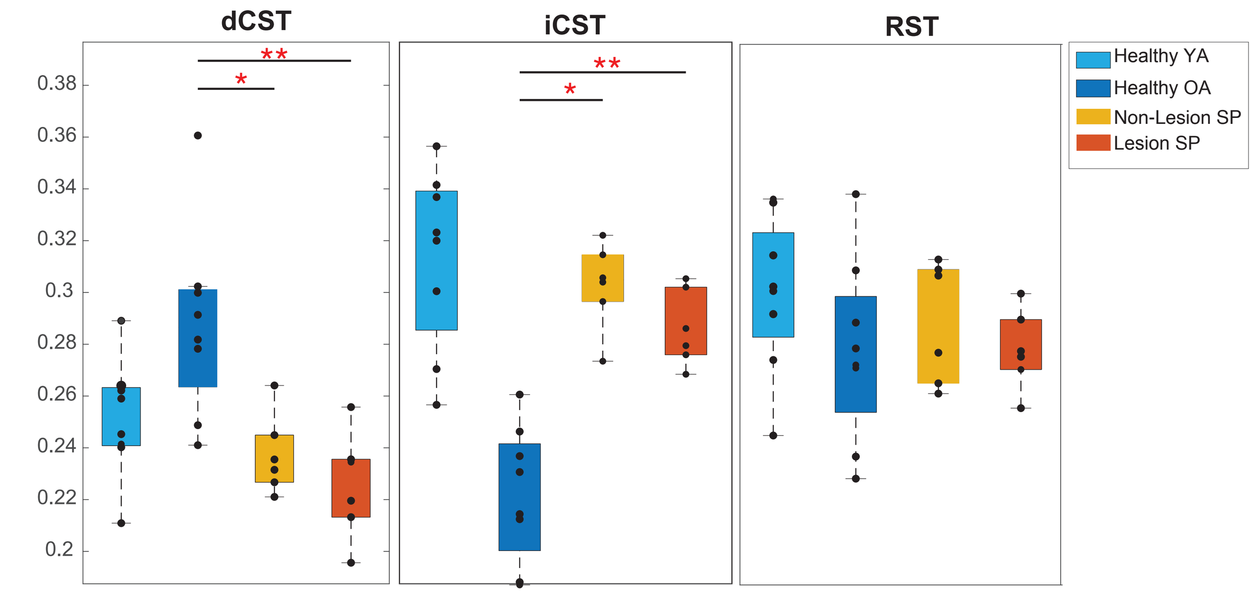
All tracts (dCST, ICST, and RST) are restricted using same ROI masks starting at IC and CP (dCST; iCST).

RST as shown in both single subject's template space and single stroke patient's lesioned and non-lesioned hemisphere.

Voxel QA results



Scatter plots of the QA values for decending tracts, dCST, iCST and RST for three groups: younger adults (YA), older adults (OA) and stroke patient (SP). Stroke survisors show lower values in all tracts.



QA values of healthy younger adults, healthy older adults and non-lesion and lesion side of the stroke survivors are plotted in the boxplot in descending pathways (dCST, iCST, RST).

Discussions

White matter integrity indicated by QA values was higher in healthy young adult and older adults in the direct CST (dCST), and was significantly reduced in stroke survivors, especially in lesioned areas.

In the indirect CST (iCST), the healthy older adults's QA values were significantly lower than all the other groups. More data are needed to allow proper interpretation of this result.

Our method is shown to be effective delineating three essential descending pathways for hand dexterity: the direct and indirect CST, RST, and effectively access the fiber integrity in these pathways.

References

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Awknowledgement

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