Convergence of superior parietal, orbitofrontal, and lateral prefrontal inputs into the human striatum

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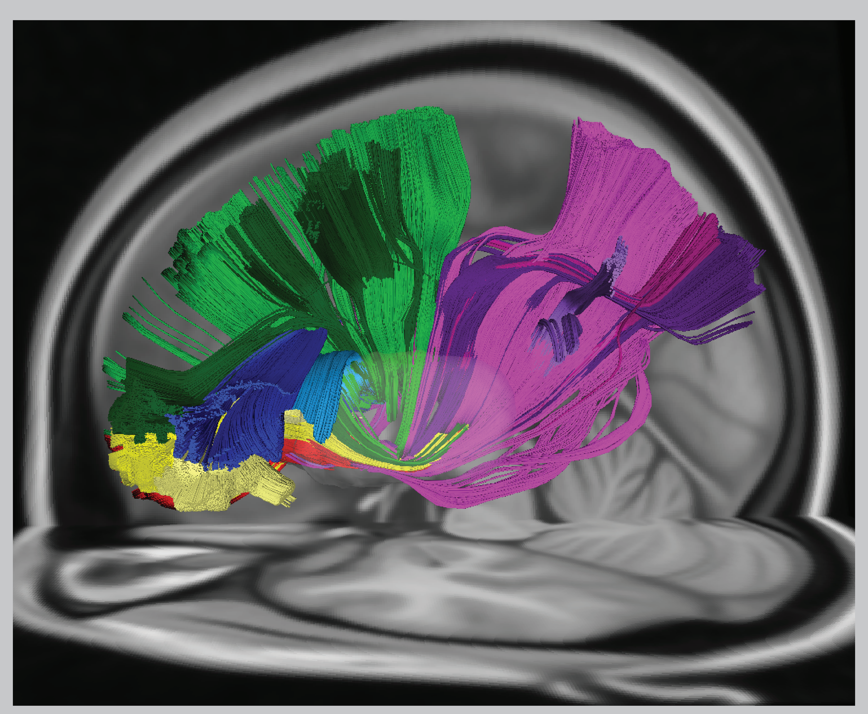
Background

Histological and functional neuroimaging research provides evidence that orbitofrontal, dorsolateral prefrontal (Haber & Knutson, 2010), and parietal areas (Choi et al., 2012) associated with reward, executive control, and spatial attention respectively, project to the striatum. Yet it remains unclear whether these projections converge on common striatal targets. Such convergence could provide a neural substrate that allows reward to influence spatial attention (Lee & Shomstein, 2013).

Hypothesis

Distinct striatal regions should exhibit overlapping structural and functional connectivity with orbitofrontal, dorsolateral prefrontal, and parietal areas.

Methods



Left sagittal view of corticostriatal streamlines from 13 ROIs on CMU-60 averaged template

Participants

Neurologically healthy adults (DSI: N = 60, 32F, mean age = 26.5; rsfMRI: N = 55, 29F, mean age = 26.5) recruited locally from Pittsburgh, PA and the Army Research Laboratory in Aberdeen, MD with IRB-approved consent.

MRI Acquisition

Siemens Verio 3T with 32-channel head coil at the Scientific Imaging and Brain Research (SIBR) Center, CMU.

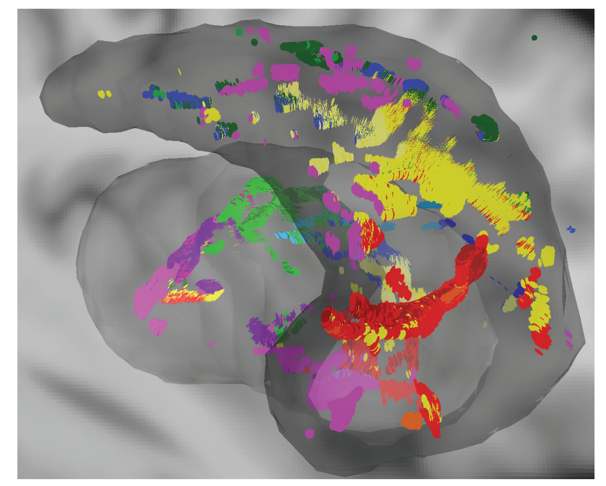
Diffusion Spectrum Imaging (DSI): 257-direction, TR = 9916ms, TE = 157ms, voxel size = 2.4 x 2.4 x 2.4mm, FoV = 231 x 231mm, b-max = 5000/mm^2, 51 slices.

Resting state fMRI (rsfMRI): 210 volumes, TR = 1500ms, TE = 20ms, flip angle = 90°

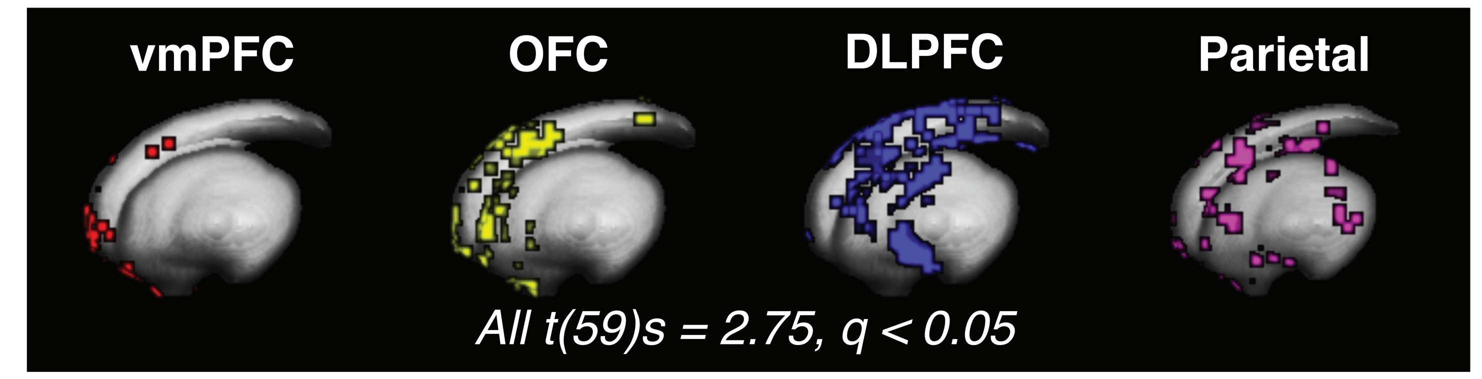
DSI Reconstruction and Fiber Tractography: DSI Studio (dsi-studio.labsolver.org) was used for DSI reconstruction and region-of-interest (ROI)-based deterministic tractography on individual and template (CMU-60) DSI data. Streamlines between 13 cortical areas and ipsilateral striatum masks were grouped by cortical meta-region: OFC, DLFPC, and parietal cortex. T tests with FDR-corrected q-values < 0.05 were conducted to identify voxels with significant structural connectivity, which were combined into convergence zone masks for each striatal nucleus and used as seeds in follow-up tractography.

Functional Connectivity Analysis: Resting state fMRI data were preprocessed and normalized using SPM8 (www.fil.ion.ucl.ac.uk/spm/). Time series activation for convergence zone voxels was extracted, denoised, and t and p values of consistent activation were calculated. Functional connectivity correlations were calculated with 3dTcorr1d (AFNI; afni.nimh.nih.gov/afni/) and converted to Z scores. The probability that voxels had both significant structural and functional connectivity was calculated using T and Z maps from image analyses.

Topography of corticostriatal endpoints

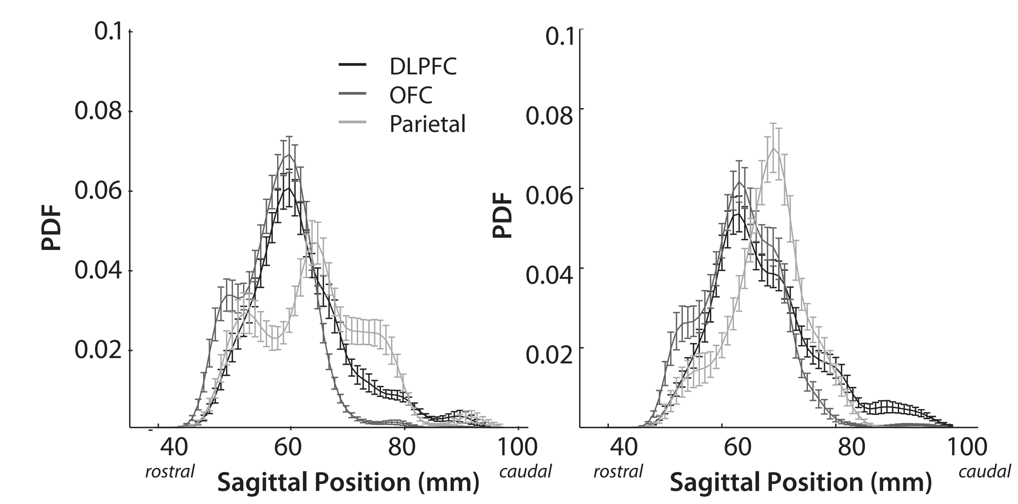


Left medial view of striatal endpoints from 13 cortical surface ROIs on CMU-60



Significant endpoint termination fields to 4 meta-regions of interest

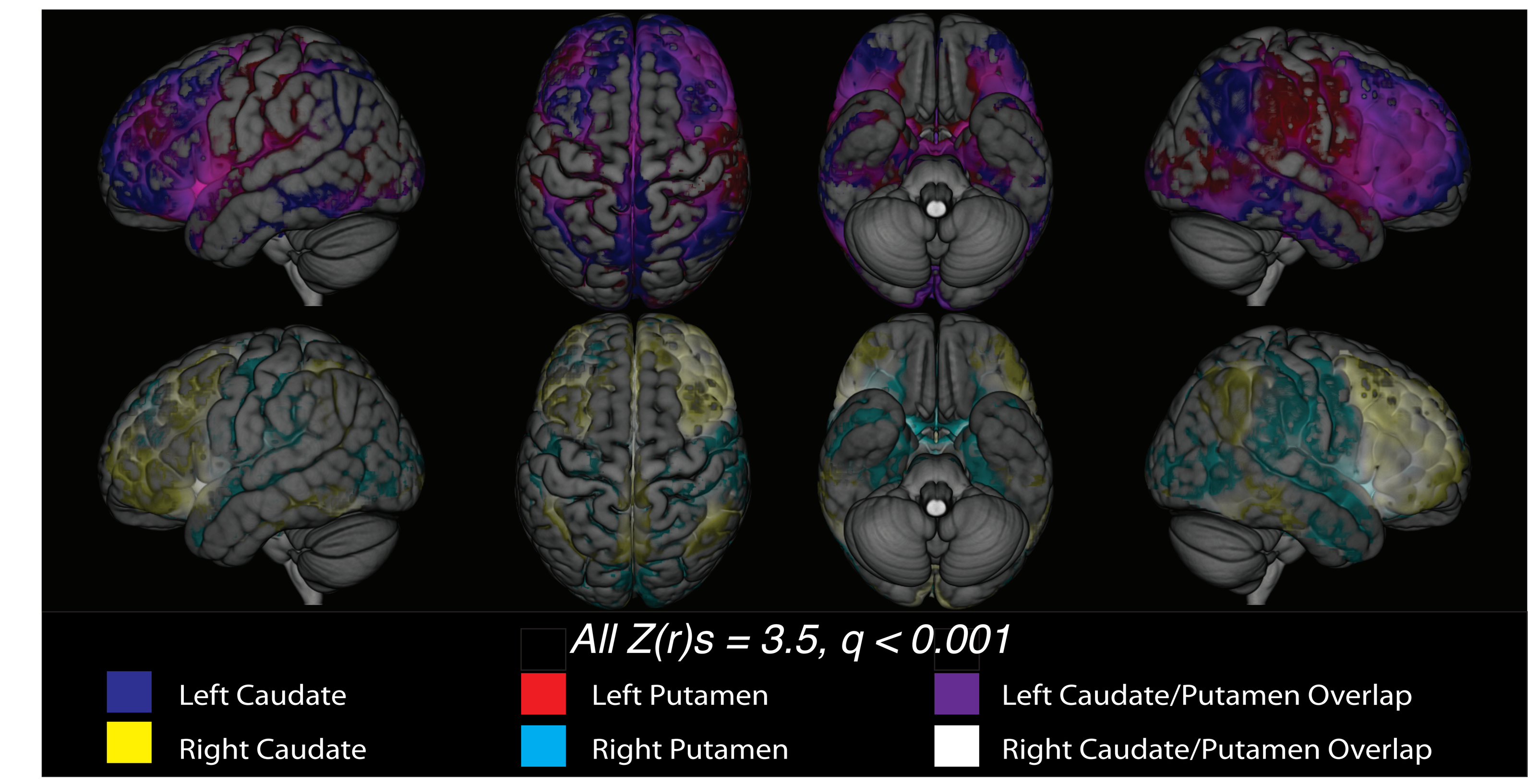
Streamline endpoints from ipsilateral cortical surface regions-of-interest (ROIs) terminate in distributed clusters indicating overlapping projection fields in both striatal nuclei.



Along the sagittal plane, parietal fibers tended to be shifted caudal to DLPFC & OFC fibers, but still showed significant overlap with projections from these two frontal regions.

Functional connectivity to convergence zones

Striatal convergence zones also showed significant functional connectivity with cortical areas that showed structural projections to the striatum.

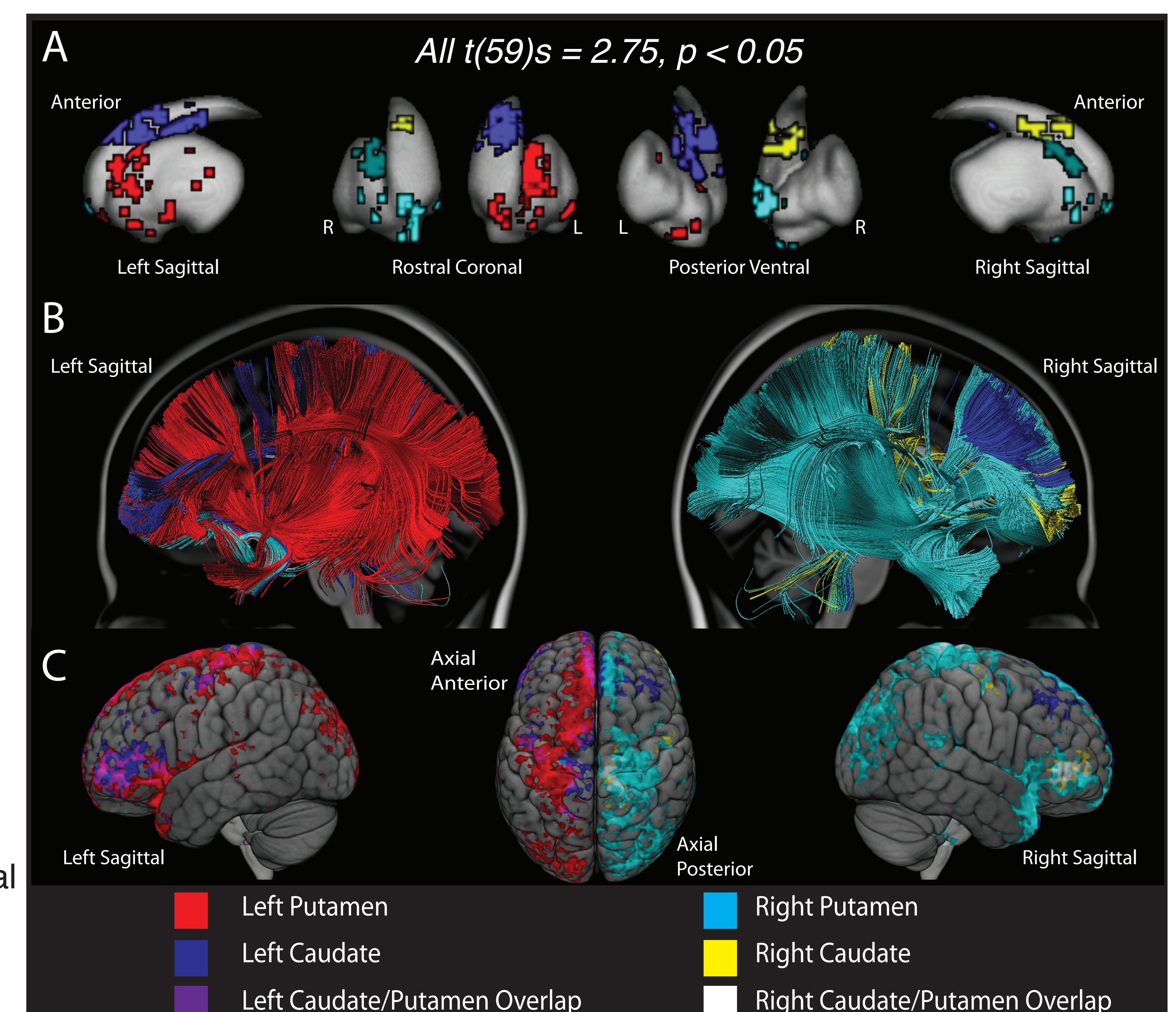


Convergent inputs from distributed cortical locations

A) Distinct clusters of endpoints from OFC, DLPFC, and parietal regions (i.e., convergence zones) were observed in both striatal nuclei bilaterally.

B) Template tractography for all fibers terminating in these convergence zones resulted in symmetric, ipsilateral connectivity from the convergence zones to distributed cortical regions.

C) Across all subjects, fibers from these striatal locations tended to terminate in distributed orbitofrontal, lateral frontal, sensorimotor, and superior parietal lobule locations.



Overlap of structural & functional connectivity

Voxels with significant structural connectivity had high probability (mean = 66%) of also having signifcant functional connectivity.

P(Functional I Structural)	Left	Right
Caudate	73%	60%
Putamen	60%	63%

Summary & Conclusions

White matter projections from orbitofrontal, dorsolateral prefrontal, and parietal regions appear to converge on the same voxels in the caudate and the putamen.

Cortical areas with overlapping projections to the striatum also show strong functional connectivity to the same striatal voxels.

These convergent projections into the striatum may provide a mechanism whereby reward, executive control, and spatial attention information are integrated during reinforcement learning.

References

Choi, E., Yeo, B., Buckner, R. (2012) The organization of the human striatum estimated by intrinsic functional connectivity. *J Neurophysio,* 108(8), 2242-63

Haber, S., Knutson, B. (2010) The reward circuit: Linking primate anatomy and human imaging. *Neuropsychopharmacology,* 35(1), 4-26

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