Multi-Scale Intrinsic Functional Connectivity of the Striatum in Developing Adolescents

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Introduction:

The striatum is a system of deep-brain nuclei topographically organized by sensory-motor modality and cognitive function. Masked Independent Component Analysis (mICA) was applied to probe the intrinsic spatiotemporal organization of the striatum using resting-state functional magnetic resonance images (fMRIs) collected longitudinally in youth participants from ages 11-18.

Methods:

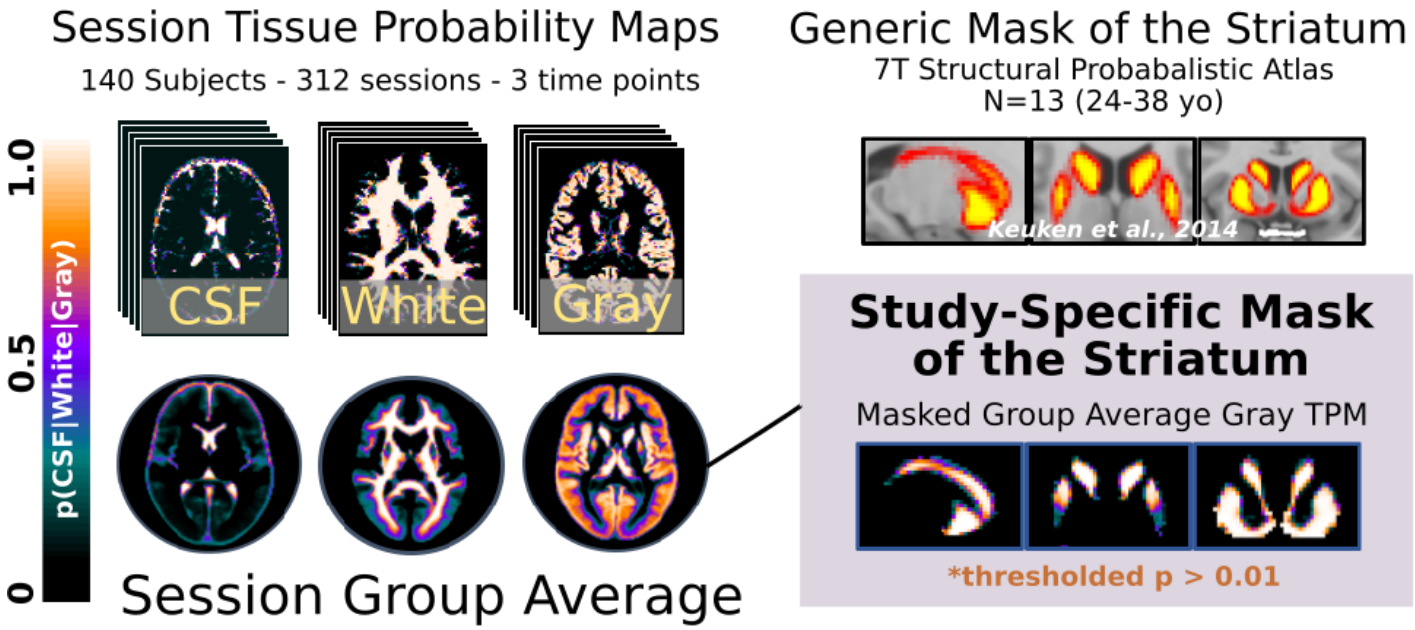
Subjects. 143 right-handed youths aged 11-14 from the Washington, D.C. area participated in a longitudinal brain imaging study investigating the precursors and effects of early substance use. MRI data were collected three times at ~18 month intervals. Youth with structural and resting-state fMRIs in a single session were retained for analysis (N=126/91/95 @ 0/18/36 mos, 312 total, 140 unique subjects). Participants had no history of mental disorders, serious head injury, or substance use at baseline.

Data Acquisition. A 3T Siemens Tim Trio with a 12-channel head coil was used to acquire whole-brain rsfMRIs & structural MRIs (sMRIs) with a T1-weighted MPRAGE sequence (TR/TE/TI/=1920/2.52/900ms, 1mm^3 voxels). Subjects kept their eyes open and allowed their minds to wander during rsfMRIs (TR/TE=2280/30ms, 3mm^3 voxels, 5:49m).

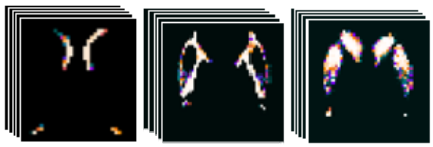
Preprocessing. Standard preprocessing of s/fMRIs was performed in CONN (v17.f) including transformation to MNI152 space with 2mm^3 voxel size. sMRIs were segmented to create tissue probability maps (TPMs) of cerebrospinal fluid (CSF), gray (GM), and white matter (WM). Individual TPMs were averaged to create group maps. fMRIs were labeled as outliers for denoising if scan-to-scan motion exceeded >1mm or global signal change Z>3. A study-specific mask (SSM) of the striatum was obtained by thresholding (p>0.01) the group GM TPM, masking with a 7T-obtained sMRI atlas of the striatum and manual editing to remove non-striatal gray matter. Non-overlapping masks of CSF and WM for removing physiological noise sources were created by masking each subject's TPM with the striatum SSM.

Denoising & mICA. Individual fMRIs were intersected with the striatal SSM, highpass filtered (0.008-0.22Hz) and denoised using: motion parameters, interpolated outlier scans and the top two principal components of the signal within CSF and WM maximum TP striatum mask. Denoised fMRIs were smoothed (4mm FWHM) within a thresholded mask (p>0.1) to minimize signal from adjacent non-GM tissue. Intrinsic striatal connectivity was estimated with mICA using FSL MELODIC (v5.0) with intensity and variance normalization, single-subject singular-value decomposition (dim=56) and group-level principal component analysis followed by fastICA for IC estimation. Split-half sampling (SHS) was implemented to identify clustering solutions for multi-scale parcellations of the striatum and quantitatively assess the stability of these maps with age. SHS was performed 300 times by repeated random splitting of data into two groups, performing mICA for 1-12 IC estimates, then calculating the cross-correlation the cross-correlation ($r \in [-1\ 1]$) between the matched components of the two groups.

Mask Creation for Group Independent Component Analysis



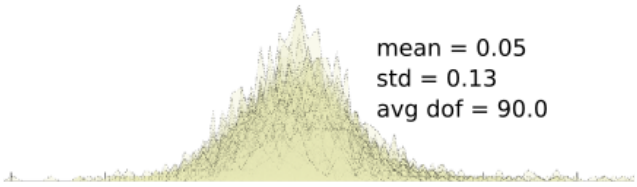
Tissue-Localized Denoising of Physiological Confounds



Session TPMs were masked with the Study-Specific Mask and the tissue with the maximum p value at each voxel was assigned to masks used for denoising

Non-Overlapping CSF & White Masks

max p(white|gray|csf)



BOLD Signal Confounds:

Top 2 PCs of Signal in CSF & White Masks
- 1st and 2nd Derivatives, Quadratic Effects

X,Y,Z Motion Parameters
- 1st and 2nd Derivatives

Outlier Scans
- >1mm motion, Z>3 global signal change

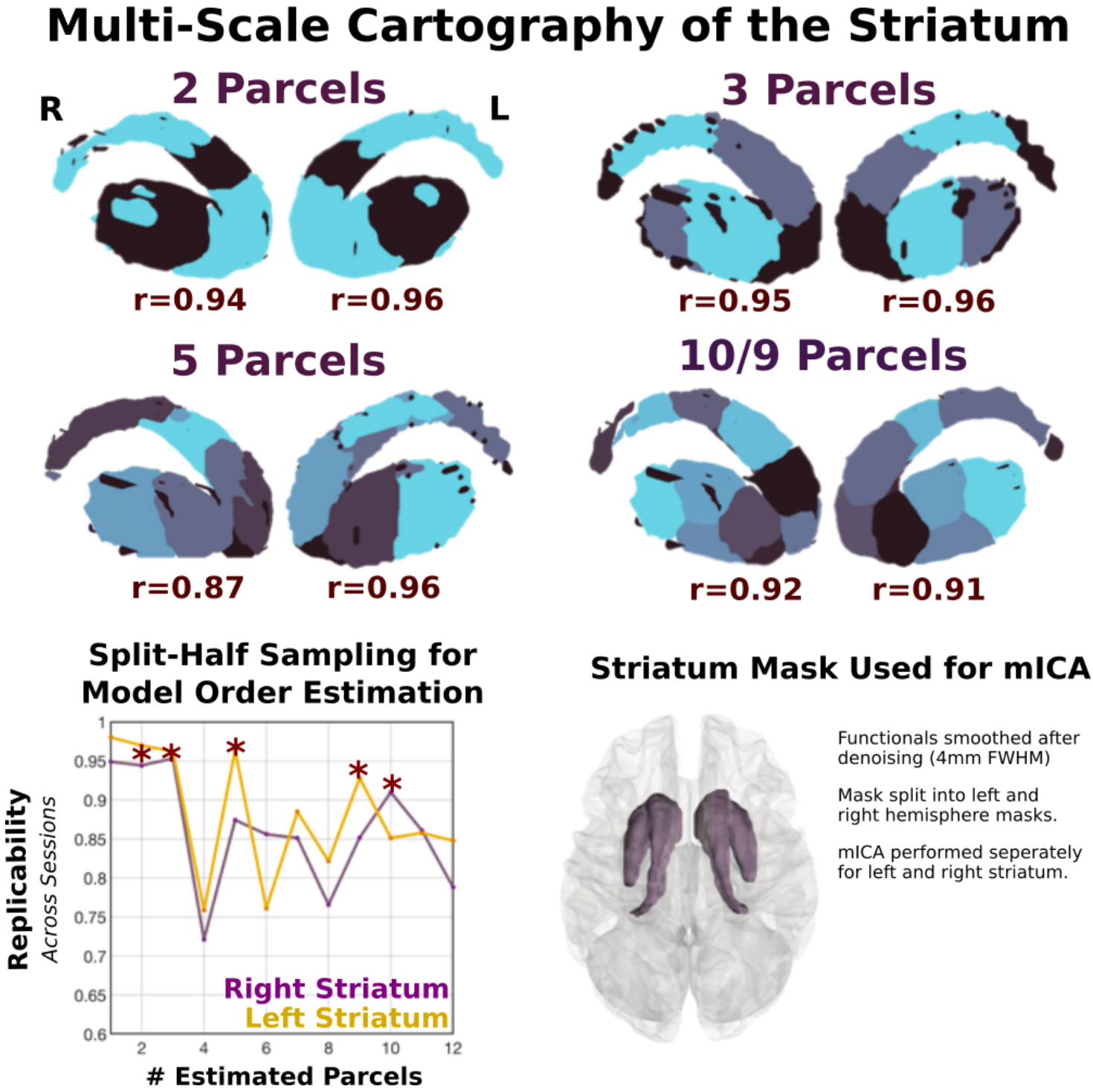
Signal filtered with high band-pass
- [0.008 - 0.22 Hz]

Session-Specific Denoising Covariates

·Mask Creation for Independent Component Analysis. ICA was performed on the striatum using a mask created from the group average gray matter tissue probability map.

Results:

SHS revealed highly reliable solutions for 2 & 3 parcels (r>0.95) in bilateral striatum, 5 (r=0.96) & 9 (r=0.91) for left and 10 (r=0.92) for right only. The fidelity of intrinsic striatal networks across subjects plummets beyond estimates of 10 ICs. Denoising of the striatum with localized noise sources in adjacent tissue outperformed the standard (aCompCorr) method. The reliability of 9/10 ICs with aCompCorr (r=0.70/0.71) was lower than the localized denoising approach (r=0.94). Reproducibility also varied by age group. Youth aged 14-16 showed lower reliability for 2, 3, 5, 9 & 10 parcel estimates (r>0.80) compared to 11-13yos and 16-18yos (r>0.90).



Conclusions:

Maps of intrinsic network activity in the striatum are dynamic at multiple spatial scales throughout adolescence. Age-specific patterns can be found nested within classical striatal subdivisions.

Lifespan Development:

Normal Brain Development: Fetus to Adolescence [2]

Modeling and Analysis Methods:

Methods Development
Segmentation and Parcellation [1]
Task-Independent and Resting-State Analysis

Neuroanatomy:

Subcortical Structures

Keywords:

Basal Ganglia
Development
FUNCTIONAL MRI
Segmentation
STRUCTURAL MRI
Structures
Sub-Cortical
Other - Parcellation

[1|2]Indicates the priority used for review

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Yes

Please indicate which methods were used in your research:

Functional MRI
Structural MRI
Computational modeling

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

AFNI
SPM

FSL
Free Surfer

Provide references using author date format

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