#### Imaging

The MRI Research Unit (MRU) houses a 3T General Electric (GE) high performance MRI scanner. The site is state-of-the-art for image acquisition and analysis as described below.

***MRI Scanning Suite*** Our 3.0 T General Electric (GE) whole body scanner at NYSPI resides within a 3200 sq ft MRI Suite that includes the scanning room, a console area, a room dedicated for animal preparation, a laboratory for the design and construction of radiofrequency coils, a subject "on-deck" waiting area where scanning related tasks can be practiced and the procedures for the scan can be reviewed, a “prep” room equipped with a medical exam table, physical exam equipment, and a phlebotomy chair for examining participants and performing simple medical procedures, a family waiting room, and a wheelchair-accessible changing room and lavatory. The MRI scanner and other hardware are described below. The unit is staffed with a full-time MRI technologist, administrator, information technology and equipment manager, a physicist, an electrical engineer who builds and maintains equipment and software used for physiological monitoring, and a full-time, dedicated pulse programmer.

***Whole Body 3T MRI Scanner***  The MRI unit houses a GE SIGNA Premier 3T MRI Scanner with a 70cm diameter patient bore. This magnet has a high homogeneity and is actively shielded with wide-open superconducting system, utilizing single cryogen unit technology, which provides zero boil-off rate. The magnet delivers high, uniform homogeneity (2.5ppm on magnet homogeneity for 50cm DSV), which is essential for FatSat and high image quality at the edges of FOV and in demanding techniques such as spectroscopy and ultra-fast echo-planar imaging sequences. The high performance SuperG gradient coil with direct water cooling per axis and powerful gradient amplifiers can be operated at gradient amplitudes up to 80.0 mTesla/Meter with slew rates as high as 200 Tesla/Meter/Sec within a hollow construction for high duty cycle, which enables ultra-high spatial resolution (0.1 mm slice thickness in 3D) and ultra-fast imaging, short TR and TE, within the entire 70cm patient aperture. Furthermore, 18 passive super-conducting shim coils improve the main field homogeneity up to <0.1ppm on the spectral width of an 8cc brain volume by five second-order and three third-order corrections automated resistive shimming. With 146-channel Total Digital Imaging (TDI) RF chain, SIGNA Premier has very high SNR enabling improved parallel imaging and multi-slice excitation (HyperBand, 4X acceleration) schemes (multiband with higher MUX factor). The TDI architecture is combined with the new, innovative AIR Technology coil suite that is designed to enhance parallel imaging (HyperSense, 8X reduction in scan time) while drastically reducing the RF coil weight and improve patient comfort. We will have a TDI 48 channel Head Coil that delivers high performance using fit-adaptable design that accommodates 99.9% of the subject head sizes while preserving high SNR and supports advanced imaging capabilities such as HyperCube Flex, a 3D imaging sequence that significantly reduces scan times and eliminate artifacts such as motion and aliasing by reducing the phase field of view without the presence of aliasing artifacts. Premier also offers HyperBand, HyperSense, MAGiC, that allows up to 8 image contrast in about 5 minutes and advanced diffusion imaging applications. MAGiC allows changing image contrast by adjusting TE, TR, and TI post acquisition. Further, the system runs on Orchestra reconstruction platform that allows our users to compose their own reconstruction algorithms that can be integrated with the data acquisition on the scanner. The 3D volumetric imaging sequence, Cube, allows slicing the 3D images in any arbitrary direction post acquisition, and suppression of CSF and either white or gray matter to increase contrast. It is also equipped with PROPELLER MB which is a multi-shot sequence that reduces motion artifacts without compromising tissue contrast. This technique offers new contrasts such as T1 FSE. A two-channel fast transmit modules, along with an ultra low-noise digital RF subsystem and frequency synthesizer, and a quadrature-drive transmitter/receiver capability for T/R coils, provide high SNR and stability (<0.05 ppm frequency variation, <5% amplitude variation, and <0.5 degree phase variation) to different neuroimaging studies.

After reconstruction, and scan completion, images are transferred to a Dell Equallogic network storage array with 120TB of commercial grade SATA6 drives in a RAID 6 configuration, and then made available to for download to lab computers via XNAT, a secure, HIPAA-compliant, SSL-encryped web interface available to all PIs and collaborators.

***Computing Facilities*** The MRI console is directly connected to the XNAT host server, a Docker-centric VM, which manages sharing of the acquired MRI data throughout the institute in addition to providing daily onsite and offsite backup capabilities. The XNAT server is connected via a gigabit Ethernet backbone to both the MRI unit computing cluster and to workstations throughout the institution. The MRI computing cluster is a scalable multi-node server dedicated to image processing, currently hosting the HCP processing pipeline a 48 CPU server with 40TB of scratch space and an additional 133TB of storage space dedicated to mirroring publically available datasets, such as the recently released HCP dataset and the ABCD releases. All personal computers and workstations are linked to a printer and to the computer network at the New York State Psychiatric Institute (NYSPI) as well as to Columbia University (CU). The libraries of both NYSPI and CU are available, including all their online databases such as Medline, PsychInfo, PubMed, Health and Psychosocial Instruments, and many more.

***Scanner Simulator*** The subject “on deck” area is equipped with a “Scanner Simulator” designed by Psychology Software Tools (PST) which closely replicates the scan environment in terms of the physical dimensions of the bore, an imitation RF head coil, a high volume sound system capable of replicating the sounds of all MRI sequences, a visual presentation system, and MoTrak motion tracking and software, designed to teach participants, particularly children by the use of video games, how to hold still during scans. Use of a simulator has been shown to dramatically improve the quality of images in children by minimizing motion artifact.

***RF Coil Laboratory*** A design laboratory in the MRI unit houses electronic device building and repair. It consists of 400 sq ft area with bench space and tools storages and is equipped with electronics such as voltmeters, oscilloscopes, circuit design and construction, etc. It has the capability to design, construct and test electronic circuits. The laboratory has developed specialized coils, such as surface coils, dual tuned coils, and coils for fetal baboon imaging and GABA spectroscopy, which reduce RF inhomogeneities and susceptibility artifacts.

***Comprehensive Image Acquisition Capabilities*** Multiband EPI sequences provide high-resolution functional applications (matrices up to 512 x 512). The basic spectroscopy package enables proton spectroscopic applications on single voxel and multi-voxel (3D chemical shift imaging, i.e. CSI) basis. A multi-nuclear spectroscopy package and broadband RF amplifier for Phosphorous, Lithium, and Carbon is available. High B-value diffusion-weighted EPI technique with FLAIR preparation capabilities is installed, as is the latest Diffusion Tensor Imaging (DTI) acquisition package, spiral sequences, and perfusion imaging. Advanced vascular imaging includes Time-of-Flight (TOF) angiography and magnetization transfer contrast (MTC) methods. The GE MRI system also includes advanced image processing software, such as READY View and BrainWave. These permit easy visualization of single-voxel and multi-voxel spectra MRS data, 2D and 3D chemical shift imaging, parametric metabolite mapping, diffusion tensor post processing, functional brain mapping (BOLD), as well as fMRI stimulus sequencing and presentation.

***Stimulus/Response and Physiological Monitoring*** The suite is equipped with a Biopac MRI compatible physiological monitoring system which provides real-time recording of galvanic skin response, electrocardiography, respiratory rate, pulse oximetry, and electromyography during scans. All waveforms are sampled, displayed, and recorded via Dell laptop through Acqknowledge software. Several MRI-compatible multi-button response units, joystick and trackball are available via a Current Designs fiber-optic response interface. The system runs multiple packages for visual and auditory stimulation. Visual stimulation is provided via a Hyperion DLP MRI-Compatible projector, reflected via a mirror to a screen behind the participant. An SR-Research Eyelink 1000 MR-Compatible Eye Tracking System is available to monitor saccades, pupil dialation, focal point, and other measures during the scan. This unit utilizes fiber-optic technology, which is robust to interference from MR gradient noise and operable in the strong magnetic field. Audio stimulus presentation and subject communication are accomplished using headphones and microphone supplied by an Avotec Silent Scan. The stimulus delivery and data recording systems are capable of synchronizing with MRI data acquisition.

**Personnel** The MRI Unit has 10 full-time faculty members, including the Director (Dr. Rachel Marsh, Ph.D.), Technical Director (Gaurav Patel, MD., Ph.D.), an engineer for design and support of electronic hardware for MRI and fMRI studies (Yunsuo Duan, Ph.D.) , a pulse programmer (Feng Liu, Ph.D.), and a high-field MRI physicist (Alayar Kangarlu, Ph.D.). The MRI Operations Manager and Administrative Director is Matthew Riddle, B.F.A., who oversees the day-to-day operations of the MRI Suite as well as maintaining computer equipment, peripherals, the MRI cluster, and the XNAT server (along with the XNAT vendor Radiologics (<http://radiologics.com>). He is accompanied by a full-time MR technologist (Jack Gray, B.A.) dedicated to data acquisition, transfer, storage, and patient safety, and an administrative assistant (Joe Figliolia, B.A.) who manages scheduling and billing.

***MRI Offices*** All faculty members have private offices in the New York State Psychiatric Institute. The offices (roughly 200 sq. ft. each) are equipped with a phone, a desktop computer, filing cabinets, and internet connectivity.

### Image acquisition and analysis

***Human connectomes project (HCP).*** The MRI Unit supports HCP compatible multiband BOLD fMRI sequence for both task and resting state acquisition along with high-resolution structural scans 1,2. In addition, the MRI Unit image acquisition and processing pipeline incorporates several innovations that improve the speed of acquisition and the signal to noise ratio, improving resolution. First, the facility supports acquisition of high-resolution structural and functional images, which minimize partial volume averaging of signals from white matter or CSF with those from gray matter. The high-resolution functional image acquisition parameters take advantage of multiband echo planar imaging (MB-EPI), which has recently been implemented on the GE MRI scanner at CU/NYSPI by Robert Dougherty and colleagues the Center for Cognitive and Neurobiological Imaging at Stanford University (<http://cni.stanford.edu/wiki/MUX_EPI>)3,4. Second, the facility supports use field maps to perform distortion correction. Both gradient-echo and spin-echo field maps are used to “undistort” the functional images acquired with MB-EPI sequences, allowing for more precise alignment of the functional and structural images. Third, the facility supports use of estimates of the inner and outer boundaries of the cortical gray matter and the locations of the subcortical structures generated by FreeSurfer to create an abstract representation of gray matter, encapsulated in the “cifti” file format 1. Smoothing and analyses are then performed with the cifti files, which can be done efficiently and without concern about partial volume effects. Fourth, the facility supports automatic alignment of data from multiple imaging modalities within each individual, such as myelin maps, cortical thickness, resting state fMRI, and task fMRI data, allowing for the validation of mapping data from one modality with that of another. Fifth, the facility automatically aligns each individual’s surfaces and volumes to the HCP-generated atlas, facilitating comparisons with the HCP’s 1200 healthy controls. This allows for easy comparisons of our patients scanned at CU/NYSPI to healthy controls with high fidelity.

Structural and functional MRI scanning session: The facility will support high-resolution functional imaging scans using the GE SIGNA Premier 3.0 Tesla full body MR system equipped with a 48-channel phased array head coil. For these scans, the subject is placed in the scanner with cushioning placed around their head to restrict head movement. Following localizer scans (5 minutes), distortion correction scans (B0 fieldmap and a pair of spin echo EPI scans with opposite phase-encode directions), a pair of T1-weighted images, and a pair of T2-weighted images is acquired over 25 minutes. These are followed by at least four 5-minute resting state fMRI scan, and then the task fMRI runs follow.

Scan parameters:

HCP compatible:  The anatomical images consist of T1-weighted images (MPRAGE, 3D sagittal, 0.8mm isotropic, matrix size=300x300, slices=220, flip angle=8°, TI=1060ms, TR=2500ms, TE=3.4ms) and T2-weighted images (CUBE, 3D sagittal, 0.8mm isotropic, matrix size=300x300, slices=220, TR=3200ms, TE=60, ETL=140).  The functional images will be acquired with a multi-band GE-EPI sequence (2 mm isotopic, slice plane=transverse, TR=900ms, TE=28ms, MUX=6, ARC=1, matrix size=108x108, flip angle = 52, slices=66, phase encode direction=P->A).

ABCD:  The anatomical images consist of T1-weighted images (MPRAGE, 3D sagittal, 1.0mm isotropic, matrix size=256x256, slices=208, flip angle=8°, TI=1060ms, TR=2500ms, TE=3ms) and T2-weighted images (CUBE, 3D sagittal, 1.0mm isotropic, matrix size=256x256, slices=208, TR=3200ms, TE=60, ETL=140).  The functional images will be acquired with a multi-band GE-EPI sequence (2.4 mm isotopic, slice plane=transverse, TR=800ms, TE=30ms, MUX=6, ARC=1, matrix size=90x90, flip angle = 52, slices=60, phase encode direction=P->A).

ABCD with lower MB factor:  The anatomical images consist of T1-weighted images (MPRAGE, 3D sagittal, 1.0mm isotropic, matrix size=256x256, slices=208, flip angle=8°, TI=1060ms, TR=2500ms, TE=3ms) and T2-weighted images (CUBE, 3D sagittal, 1.0mm isotropic, matrix size=256x256, slices=208, TR=3200ms, TE=60, ETL=140).  The functional images will be acquired with a multi-band GE-EPI sequence (2.4 mm isotopic, slice plane=transverse, TR=900ms, TE=30ms, MUX=4, ARC=2, matrix size=90x90, flip angle = 52, slices=60, phase encode direction=P->A).

Image Processing: Images are transferred to a workstation with the Human Connectome Project processing pipeline installed. In addition to performing the standard automated structural and functional MRI processing procedures (movement correction, atlas realignment, creation of cortical surface model etc.) as implemented by FSL 5 and FreeSurfer 6 this pipeline implements two additional procedures that improve upon standard imaging preprocessing procedures: required use of field-mapping sequences to “undistort” the GE-EPI images 7 and the creation of a “gray-ordinate” cifti file that only contains data from cortical and subcortical gray matter 1 The resulting structural and functional data are aligned in volume space to the MNI152 atlas 8 and in surface space to the HCP-generated Conte69 surface atlas 9.

fMRI data analysis: For statistical purposes, fMRI data are analyzed with a combination of FSL 5, HCP Workbench 1, MATLAB (Natick, MA), and custom software. Task-related effects will be estimated according to the general linear model at each voxel. Group effects will be estimated using a random effects analysis to highlight brain regions activated in common in all subjects along with group-related differences, and the statistical maps will be corrected for false discovery rate (FDR).

**References for MRI Facilities**

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