Imaging

The MRI Research Unit (MRU) houses a 3T General Electric (GE) high-performance MRI scanner. Paired with this MRI scanner, the MRU makes state-of-the-art for image acquisition and analysis techniques available to its users. Combined, the MRI Unit-supported acquisition and processing pipelines incorporate several techniques that improve the speed of acquisition and the signal-to-noise ratio, improving spatial and temporal 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). Second, the facility supports the use of 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 processing pipelines that use 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. Below we detail the implementation of these techniques.

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 sequence programmer (Feng Liu, Ph.D.), and a Medical Director (Lawrence Kegeles, MD., Ph.D.). The MRI Operations Manager and Administrative Director (Matthew Riddle, B.F.A.) oversees the day-to-day operations of the MRI Suite and maintains the computer equipment, peripherals, the MRI cluster, and the XNAT server (along with the XNAT vendor XNATWorks (http://xnatworks.io). He is accompanied by two full-time MR operators (Jenna Anderson, M.S. and Julissa Osorno, M.S.) dedicated to data acquisition, transfer, storage, and patient safety, and an administrative assistant (Shiva Kalaiselvan, B.A.) who manages scheduling and billing. Additional support is provided by Jack Grinband Ph.D. for creating and testing new processing pipelines, Juan Sanchez-Peña and David Semanek for implementation and maintenance of processing pipelines, and by NYSPI Information Technology for the maintenance of the MRI Computing Facility. All faculty members have private offices in the New York State Psychiatric Institute.

MRI Scanning Suite Our 3T 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, an "on-deck" participant 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.

Whole Body 3T MRI Scanner The MRI unit houses a GE SIGNA Premier 3T MRI Scanner with a 70cm diameter patient bore and a 48-channel phased array head coil. This magnet has high field 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, up to 8X 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 participant 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. 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 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.

Scanner Simulator The participant waiting 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.

Stimulus/Response and Physiological Monitoring The suite is equipped with an MRI-compatible BIOPAC 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, a Celeritas Fiber-optic interface, and Natatech fiber-optic response system. 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 dilation, 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 and an Optoacoustics MRI Noise Cancellation system. The stimulus delivery and data recording systems are capable of synchronizing with MRI data acquisition.

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 The MRI Unit has the capacity to implement state-of-the-art imaging sequences developed by GE as well as to fine-tune protocols specific to individual study needs under the guidance of our dedicated pulse sequence programmer. This includes field-standard protocols for both task and resting state acquisition along with high-resolution structural scans harmonized to large multi-site studies, e.g., ABCD and HCP, [1,2] and optimized to our scanner. 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.

Available sequence options:

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=60ms, 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=60ms, 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=60ms, 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).

Single-band: The anatomical images consist of T1-weighted images (BRAVO, 3D sagittal, 1.0mm isotropic, matrix size=256x256, slices=180, flip angle=12°, TI=450ms, TR=7ms, TE=3ms) and T2-weighted images (CUBE, 3D sagittal, 1.0mm isotropic, matrix size=256x256, slices=208, TR=3200ms, TE=60ms, ETL=140). The functional images will be acquired with a single-band GE-EPI sequence (3.0 mm isotopic, slice plane=transverse, TR=2000ms, TE=25ms, ASSET=2, matrix size=64x64, flip angle = 77°, slices=45, phase encode direction=P->A).

Diffusion MRI: Diffusion MRI could be acquired with either single-band or multiband SE-EPI sequence. For example, dMRI in ABCD protocol: 1.7mm isotropic, slice plane=transverse, MUX=3, ARC=1, matrix size=140x140, slices=81, b-values=500/1000/2000/3000, 96 diffusion directions.

MRS:MR spectroscopy could be acquired with standard single-voxel PRESS sequence (PROBE-P) or STEAM sequence (PROBE-S) and advanced MRS sequences such as J-editing PRESS (MEGA-PRESS) and TE-averaged PRESS (TEA-PRESS). PROBE 2D/3D CSI sequences are also available.

MRI Computing Facility The MRI Unit also hosts the MRI Computing Facility, a core computing resource available to all MRI investigators at NYSPI. After scans are completed and images are reconstructed, they're sent to XNAT storage, which is part of a local cluster of secured redundant storage at NYSPI, as well as backed off offsite on Amazon S3 storage.

The MRI unit maintains a hybrid cloud service that allows users access to secure storage and extensible processing resources that are fully compliant with HIPAA and backed by the security and integrity controls of Amazon Web Services (with whom we maintain a BAA) and the NYS ITS. Collected and derived data are fully backed up by AWS storage and processed through pipelines deployed in Docker containers and AWS instances and managed by the MRI Research Program. The data are stored in an AWS S3 bucket, accessible by local and cloud-based computing facilities. Containerized processing pipelines (see below) are launched via an in-house web interface. Raw and processed data can then be transferred to the lab's workstations. The storage array also contains local copies of publicly available datasets, such as the Human Connectome Project Young Adult, Healthy Brain Network, and Rockland Sample datasets, facilitating comparisons of locally collected data with these large datasets. All data are stored and analyzed in compliance with BIDS standards.

Image Processing and Analysis: The MRI Computing Facility provides access to standardized functional and diffusion MRI processing pipelines via AWS, including fMRIPrep[11]/xcp[12], ABCD-BIDS[13], and QSIPrep pipelines. The fMRI pipelines output data to the Human Connectome Project fs_LR surface atlas space and post-process data according to the recommendations in Power *et al.* 2014.[15] Commonly used analysis tools are also installed and maintained on the local computing cluster for additional analysis, e.g., using AFNI, FSL, SPM, FreeSurfer, MATLAB, etc.

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