**RESOURCES**

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| FACILITIES: Specify the facilities to be used for the conduct of the proposed research. Indicate the performance sites and describe capacities, pertinent capabilities, relative proximity, and extent of availability to the project. If research involving Select Agent(s) will occur at any performance site(s), the biocontainment resources available at each site should be described. Under “Other,” identify support services such as machine shop, electronics shop, and specify the extent to which they will be available to the project. Use continuation pages if necessary. |

**Center for Brain Science Neuroimaging Facilities**

**Waiting and Consenting Rooms**

The entrance to the Neuroimaging Facility is comprised of a spacious and comfortable main waiting room with a reception desk, couches, and chairs. Adjacent to the main waiting room is a separate decorated child-friendly waiting/play room with toys and an activity table. Another adjacent room is used exclusively for screening and consenting to ensure the privacy of our participants.

**Behavioral Testing Rooms**

Three rooms for behavioral testing are located immediately adjacent to the scanner suite allowing seamless participant testing before and after scanning. One of the rooms is equipped with an infrared eye tracking system and pupil measurement apparatus (EyeLink 1000 Plus, SR Research Ltd., Ottawa, Ontario, Canada) and a system for physiological monitoring (MP150, Biopac Systems, Goleta, CA) allowing for time-locking of stimuli, responses, and eye movement/pupillary data.

Six additional behavioral testing rooms are located at the entrance to the 2nd floor office space and provide quiet and controlled environments for piloting and developing behavioral paradigms.

**3.0T Siemens Prisma MRI Scanner Suite**

*Scanner.* The 3.0 Tesla Siemens MAGNETOM Prisma whole-body MRI system has significant hardware advances. The Siemens Prisma system is capable of EPI, second order shimming, CINE, MR angiography, diffusion and perfusion studies, and spectroscopy. This scanner has a short-bore (2m) magnet, a fast gradient system that provides high-speed structural and functional imaging, and a 64-receiver channel data acquisition system for parallel imaging with acceleration factors up to four-fold, permitting increased temporal resolution and reduced geometric distortions in functional MRI scans. The gradient rise time (200 T/m/s on all three gradient axes simultaneously) and peak gradient strength (80 mT/m per axis), and duty cycle are the most powerful specifications in the industry for whole-body systems (double the current standard gradient strength for advanced human MRI systems). Other advanced features include a parallel transmit array to allow B1 shimming, zoomed image field-of-view selection, and selective excitation, all of which improve image uniformity and help to reduce image acquisition time; an all-digital RF chain between the control room and the magnet, which significantly improves RF stability and image SNR; and enhanced parallel-receive array hardware; modern image reconstruction hardware optimized for rapid reconstruction of images requiring computationally intensive steps, allowing novel image acquisitions to display results in real-time rather than minutes/hours later or require manual offline reconstruction.

*Coils.* The Siemens 64-channel head/neck receive-array coil further enhances image SNR especially for functional MRI, with its significantly improved peripheral image SNR, generally corresponding to the cortex of the human brain. The 64-channel coil for the Prisma system has been designed to permit greater subject comfort with an increased visual field of view for the subjects, and greater accessibility for peripheral equipment including not only eye-tracking cameras, but for equipment that goes inside the coil, such as simultaneous EEG, transcranial direct current stimulation or transcranial magnetic stimulation. An improved 32-channel head receive-array coil and a 20-channel coil are also available.

*Sequences.* The sequences available include those of the MGH/HST Athinoula A. Martinos Center for Biomedical Imaging through a Master Research Agreement with Siemens, and through the Human Connectome Project (HCP), and include the latest variants of accelerated and multi-band / simultaneous multi-slice for functional, diffusion, and structural acquisitions. (1) *Functional*. Traditional and Simultaneous Multi-Slice (SMS) sequences are fully supported. Sequences obtain whole-brain functional MRI with spatial resolutions of 1.5-2.5mm and temporal resolution of 650-2000ms. Use of the University of Minnesota SMS BOLD sequence allows saves the single-band reference image for a high-contrast intermediate between functional and anatomical scans, and also provides multi-echo BOLD capability. (2) *Structural*. Multi-echo T1-weighted MPRAGE sequences with reduced susceptibility-induced distortion and high bandwidth are supported that can match T2-weighted T2SPACE scans for accurate co-registration. Variants are available with embedded volumetric navigators to track real-time motion and/or update the scan field of view to compensate for such motion or reacquire. Extremely rapid T1-weighted sequences employ wave-CAIPI readout (providing usable structural images in one min). (3) *Diffusion*. SMS-capability enhanced diffusion acquisitions are available that provide spatial resolutions below 2mm with 100 or more b-vectors in a 6-8 min scan. (4) *Arterial Spin Labeling (ASL).* Advanced ASL sequences are available that apply SMS in a development sequence from University of Minnesota provided for the HCP. SMS-ASL also allows finer spatial resolution than usual (2.5mm) and a multi-delay feature post-labeling permits the calculation of Cerebral Blood Flow (CBF) and Arterial Transit Time (ATT) maps from a single 5 min scan.

*Support equipment and rooms.* The MRI Suite also contains (1) a rear projection system, as well as a goggle system with eye-tracking camera (NordicNeuroLab Inc., Milwaukee, WI), for visual presentation; (2) an S14 fMRI Compatible Insert Earphones system (Sensimetrics Corporation, Malden, MA) and a NordicNeuroLab AudioSystem for auditory stimulation; (3) a Biopac MP150 for somatosensory stimulation and physiological monitoring; (4) ergonomic subject response devices; and (5) an EyeLink 1000 fiber-optic eye-tracking system (SR Research, Ottawa, Ontario, Canada). A changing room, keyed storage lockers, and two restrooms are available to participants immediately adjacent to the scanner suite. A dedicated double-locked storage room down the hall from the scanner maintains copies of consent and MRI screening documentation.

**Mock Scanner**

An MRI simulator or “mock scanner” simulates the real MRI scanner and introduces research subjects, including normal and clinical populations, children and adults, to the scanning environment. The simulator can also be used to develop and test experimental paradigms, and to quickly train new researchers, minimizing the use of costly scanner time for set-up and training. Adjacent to our 3T scanner, the mock scanner (NordicNeuroLab) has a bore diameter of 22” (56cm) (the height from the table to the top of bore is 16.5” (42 cm), and utilizes a simulated head coil assembly with mounted mirror system.  The simulator is equipped with a sliding patient table, realistic in-bore fans and lighting, and a sound system that mimics the vibrations and pulse sequence noises of an MR imager. The experimental setup includes headphones and rear-mounted monitor for auditory and visual stimulus presentation. Two five-key button box response units are identical to those in the MRI scanner. There is also a system to detect head movement (a small chip containing an accelerometer) and provide biofeedback in the form of interruption of the video presentation. This is useful for training subjects, particularly children, to remain still in the scanner. A comfortable observation area allows family members or caregivers to view the procedure from inside the mock scanner room and cheerful decorations make the space welcoming for children.

**Transcranial Magnetic Stimulation**

A state-of-the-art system for transcranial magnetic stimulation (TMS) is sited in a room immediately adjacent to the MRI scanner. This location allows subjects to be scanned, TMS applied, and rescanned in rapid succession. The system includes (1) a MagPro X100 with MagOption Magnetic Stimulator; (2) a Cool-B65 A/P (active/placebo for double-blinded studies) dynamic cooled butterfly coil, which is optimized for high repetition rates and long pulse trains, as well as (3) a C-B60 Butterfly Coil; (4) Coil cooler; and (5) an MEP (Motor Evoked Potentials) Monitor, 1 channel EMG amplifier for determination of Motor Threshold (MagVenture, Atlanta GA). A Brainsight 2 Neuronavigation System (Rogue Research, Montreal, Canada) is used to position the TMS coil to target specific brain areas. This technology uses procedures developed for pre-surgical planning. Markers on the coil are imaged with cameras and positioned based on the subject’s own anatomy. An LCD monitor is available for stimulus presentation and software is available for precise time locking of the task paradigm to stimulus presentation.

**Transcranial Direct Current Stimulation (tDCS)**

For tDCS, two MR-compatible devices are available. (1) NeuroConn DC-Stimulator MR system allows for 1-channel, bi-polar (tDCS, tACS, tRNS, CES, GVS) stimulation, with current selectable up to 4500μA (4.5mA), stimulation duration up to 1,800s (30min) and sinusoidal stimulation up to 250Hz. (2) In addition, the CBS Neuroimaging facility has recently acquired an MR-compatible Starstim 8 wireless hybrid tCS/EEG neurostimulator system. The Starstim system allow for high-definition, multi-focal stimulation with EEG recording from the same electrodes. High definition focal stimulation is achieved through the flexible placement of each 8 small (1 cm radius) Ag/electrodes according to the 10-10 system. Additional flexibility and higher resolution stimulation regimes (compared to bipolar stimulation) are made possible through independent current control of each electrode. Current-controlled tDCS, tACS, tRNS, sham or user-defined waveforms have all been validated with this system. EEG functionality: Number of channels: (up to) 8; Sampling rate: 500 SPS; Bandwidth: 0 to 125 Hz (DC coupled); Resolution: 24 bits - 0.05 μV; Measurement noise: < 1 μV RMS; Common mode rejection ratio: -115 dB; Input impedance: 1 GΩ. Stimulation functionality: Number of channels: (up to) 8; Sampling rate: 1000 SPS; Frequency range: 0 to 250 Hz (tACS) and 0 to 500 Hz (tRNS); Stimulation types: linear combination of tDCS, tACS and tRNS; and Sham; Maximum current per channel: ± 2 mA; Current resolution: 1 μA; Current accuracy: 1%; Maximum voltage: ± 15Vper electrode (allows 30 V of stimulation potential difference). Safety features: Maximum input current per channel: 2 mA; Maximum total inject current: 4 mA (by all electrodes, at any time); Maximum duration per session: 1 hour.

**Computational Facilities**

The Neuroimaging Compute Facility is available to all Harvard investigators collecting MRI data in the Neuroimaging Facility and is managed by FAS Research Computing, a team of 15+ full-time technical professionals ([http://rc.fas.harvard.edu](http://rc.fas.harvard.edu/)). This dedicated resource allows dedicated high performance computing within a secure framework. The facility comprises four components: processing clusters, storage and backup, network, and software.

*Processing clusters.* The data processing clusters dedicated to neuroimaging data analysis consist of three pools of nodes. Across pools there is a total of 1768 cores with a combined 10TB of RAM and 28 TB of local, scratch (temporary) storage. The first pool consists of 10 nodes for a total of 640 cores (7 Dell PowerEdge M915 blades with 64 core AMD Opteron™ Processor 6274 with 256 GBs of RAM per node, 3 C6145 blades with 64 core AMD Opteron™ Processor 6274 with 256 GBs of RAM per node). The second pool consists of 17 nodes for a total of 1088 cores (17 Dell PowerEdge M915 blades with 64 core AMD Opteron™ Processor 6274 with 256 GBs of RAM per node). The third pool consists of a single ‘high memory’ node that has 3TB of RAM and 40 cores (Dell PowerEdge R930, Intel® Xeon® CPU E7-8891 v4 with 2.8GHz). The separation of the computational resources into three pools allows redundancy and specialization. Specifically, the dedicated high memory node (3TB RAM) allows processing of large datasets within or across individuals at high resolution.

The cluster is maintained with an infrastructure-as-code approach, and primarily relies on puppet for configuration management. Graphite and Grafana allow visualization of arbitrary metrics, from standard tuning metrics like research group cluster usage and backup frequency to site-specific applications like the MRI stability console.

*Storage and backup.* All nodes in the cluster share a pool of network-attached storage that has a current capacity of 600TB and a potential storage growth of 1PB. All systems are tied together via a 4Gbps TCP. In addition, data is continuously backed up, 100 miles away, at the Massachusetts Green High Performance Computing Center in Holyoke Massachusetts. The configuration has been optimized to facilitate the high volume of reads and writes typical of neuroimaging data analysis.

*Network*. The Neuroimaging Compute Facility IT infrastructure is a separate, secure private RFC1918 compliant network isolated from the rest of the university through layers of access controls consistent with Harvard University’s security policies. Only vetted users are given accounts. User passwords are always encrypted when traversing the network and host authentication is performed via Kerberos. The only external entry points to the network are via an SSH gateway and Virtual Private Network (VPN) connection requiring two-factor authentication. Connectivity to the cluster and storage is provided via 10G links on an enterprise class Cisco switch.

*Software*. Available software includes MATLAB (The MathWorks, Natick, MA), Freesurfer, SPM, AFNI, and FSL Tools. Significant internal software development for image and data analysis as well as informatics (e.g., XNAT for managing neuroimaging data, DPdash for managing deep / digital phenotyping data) are ongoing by the Harvard Neuroinformatics Research Group (NRG; http://neuroinformatics.harvard.edu/). The NRG uses Airflow for pipeline management of automated integrity tests, and Singularity for MRI QC pipeline containerization. The most important pipelines are maintained with a Continuous Integration approach, which uses version control and automated tests to ensure pipeline development does not affect the consistency of the metrics.

**Neuroengineering Core**

The Center for Brain Science supports a Neuroengineering Core that is available to the Neuroimaging staff and investigators. The Neuroengineering Core consists of two full-time engineers and a Fabrication Laboratory with extensive machine and electronics equipment. Services provided by the Neuroengineering Core include (1) designing and fabricating novel scientific equipment, (2) encouraging the development of technical skills among researchers, (3) facilitating the transfer of existing technologies between laboratories, (4) consulting on equipment purchasing decisions, and (5) assisting with equipment setup. Recent examples of custom fabrication for the Neuroimaging Facility include the development of a motion detection system for the mock scanner to provide feedback to children and training participants about head motion, fabrication of magnet-compatible ergonomic button boxes for behavioral response acquisition within the MRI scanner, and a trigger/response input device to allow precise time locking for task-based fMRI paradigms.

**Conference Room and Common Space**

Additional resources include (1) a small conference room for 10 to 15 people outside the scanner suite equipped for video presentation (e.g., for MRI training video viewing), (2) a computer work room adjacent to the scanner equipped with Linux workstations for image viewing and data processing, (3) copiers and other general office equipment, and (4) a kitchen/break room for coffee etc.