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An Introduction to Neuroimaging Methods for the Nurse Scientist

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Abstract

Background: Since the inception of magnetic resonance imaging, thousands of studies have appeared in the literature reporting on multiple imaging techniques. However, there is a paucity of neuroimaging research programs developed by nurse scientists.

Objectives: The purpose of this manuscript is to introduce the nurse scientist to complex neuroimaging methods with the ultimate goal of creating impetus for future use of brain imaging in nursing research.

Methods: This manuscript reviews common neuroimaging methods, presents vocabulary frequently used in neuroimaging work, provides information on access to resources in neuroimaging education, and discusses considerations for use of neuroimaging in research.

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Mr. Atalla, Ms. Kalvas, Ms. Humbel, and Dr. Monroe would like to report their affiliation with The Ohio State College of Nursing and therefore their professional relationship with Dr. Rita Pickler, the Editor-in-Chief of *Nursing Research*.

Results: Ten imaging modalities are reviewed, including structural and functional magnetic resonance imaging, computed tomography, positron emission tomography, and encephalography.

Discussion: Choosing an imaging modality for research depends on the nature of the research question, needs of the patient population of interest, and resources available to the novice and seasoned nurse scientist. Neuroimaging has the potential to innovate the study of symptom science and encourage interdisciplinary collaboration in research.

Keywords

neuroimaging; magnetic resonance imaging; computed tomography; MRI functional; nursing research

Neuroimaging constitutes several modalities for imaging of the structure and function of the brain. Each modality has various benefits and barriers to conducting clinical research in human and non-human primates. Since the inception of magnetic resonance imaging (MRI), thousands of studies have appeared in the literature reporting on multiple imaging techniques. There are several published examples of nurse-led deliverables focused on neuroimaging (Monroe et al., 2017, 2018, 2015; Monroe, Gore, Chen, Mion, & Cowan, 2012). However, there are few neuroimaging research programs developed by nurse scientists. Surprisingly, this shortage persists in the face of neuroimaging technology that is becoming increasingly more accessible to nurse scientists through multiple educational opportunities (Table 1).

Methods

This manuscript reviews common brain imaging methods, presents vocabulary frequently used in neuroimaging work (Table 2), and discusses considerations for use of neuroimaging in research. The purpose of this manuscript is to introduce the nurse scientist to these complex methods with the ultimate goal of creating impetus for future use of neuroimaging in nursing research. The literature presented references seminal manuscripts describing each method.

Results

Structural MRI

Structural MRI is a staple of brain imaging, showing neurological structures with clarity and precision, making them well suited for visual examination and determination of abnormal brain anatomy and pathology (Wattjes, 2011). Clinical structural MRI will often be a T1-weighted (T1W) image. This weighting describes the spin-relaxation characteristics, or the rate of decay of applied magnetization, of the excited protons of water molecules in the brain. Images with T1W provide good contrast between the brain's gray matter (dark gray), white matter (light gray), and cerebrospinal fluid (CSF; black); alternatively, these images may also be T2-weighted (T2W), which provides contrast between CSF (bright) and brain matter (dark), and may be extended to show contrast between gray matter (light gray) and white matter (dark gray; "3T How To: Structural MRI Imaging - Center for Functional MRI - UC San Diego," n.d.).

Fluid attenuation inversion recovery.—Fluid attenuation inversion recovery (FLAIR) is a T2W MRI sequence that is highly sensitive to pathological abnormalities, as longer T2 relaxation times, or the time it takes for applied magnetization to decay, are often associated with diseased tissue, making this imaging technique clinically useful for the detection of cerebrovascular disease, metastatic disease, and hemorrhage; however, unlike structural T2W sequences, FLAIR attempts to suppress the signal of CSF, which has the longest T2 relaxation time of any brain tissue class (Kates, Atkinson, & Brant-Zawadzki, 1996). FLAIR images are especially useful for detecting pathological white matter lesions. These lesions manifest in FLAIR images as bright and easily differentiable regions of halos, spots, and confluence (Kim, MacFall, & Payne, 2008). FLAIR MRI is an excellent modality to aid in determining the acuteness of white matter disease, especially in patients with dementias of a vascular etiology (Wattjes, 2011).

Diffusion tensor imaging.—Diffusion tensor imaging (DTI) is an MRI technique that measures the strength and direction of water molecule diffusion along nerve fibers, allowing direct visualization of white matter bundles (i.e., axons) in the brain (Soares, Marques, Alves, & Sousa, 2013). DTI is a useful imaging modality for disease processes with impaired white matter integrity, such as Alzheimer's disease, multiple sclerosis, or mental health disorders. The basic principle behind DTI is that water molecules will diffuse at different rates along nerve fiber tracts depending on the integrity of the nerve fiber and the presence of barriers. Water molecule diffusion becomes altered in areas of impaired white matter integrity, allowing DTI to detect alterations to white matter not observable in many other forms of MRI (Le Bihan, 2003). Altered diffusion of water molecules in white matter tracts can be measured via fractional anisotropy (FA) and quantified on a scale of zero to one, with values close to one indicating nerve fiber integrity (Mukherjee & Palacios, 2017). Fractional anisotropy values are sensitive to the degree of myelination and axonal density of white matter (Le Bihan, 2003).

One common measure in DTI is the apparent diffusion coefficient (ADC), which measures the amount of diffusion of water molecules within brain tissue (Sener, 2001). The ADC can be used to identify areas of damage to white matter caused by insults such as ischemia (i.e., low ADC values) or edema (i.e., high ADC values). The diffusion-weighted images provided by DTI measure the magnitude of water molecule diffusion in multiple directions (e.g., parallel to nerve fiber tract, perpendicular to nerve fiber tract) at a single point in the brain. These measures can be used to calculate several DTI values. Axial diffusivity (AD) measures the rate of diffusion parallel to the nerve fiber tract, while radial diffusivity (RD) measures diffusion perpendicular to the nerve fiber tract. Mean diffusivity (MD) is a measure of the average diffusion over all directions at a single point, with higher values generally indicating damaged tissues with disorganized diffusion (Soares et al., 2013).

Diffusion tensor imaging provides a sensitive, non-invasive method to study white matter integrity without the use of contrast or chemical tracers. Difficulties in the use of DTI include the inherent complexity of the analysis and interpretation of results, as well as the method's high sensitivity to movement, which may limit the ability to perform DTI in some vulnerable populations (e.g., unable to lie still).

Arterial spin labeling.—Arterial spin labeling (ASL) is an MRI modality that focuses on measuring tissue perfusion. This is typically quantified as cerebral blood flow (CBF), a perfusion flow metric described as the volume of blood per volume of tissue per minute (Alsop et al., 2015). Perfusion is measured by first labeling the arterial blood water, during which the MRI machine may administer a combination of radio frequency (RF) pulses and gradient magnetization to magnetize blood water molecules at a particular slice of tissue (often near the neck; Grade et al., 2015). This change in the molecules' magnetization distinguishes them from unlabeled blood during their transit through the brain's vasculature. After a post-labeling delay period, an image is captured. This may be compared to a control image in which no labeling occurred, and relative CBF may be ascertained as the difference in MRI signal intensity between the label and control image. Labeling must be restricted to arterial blood when designing an ASL study. When labeled water enters the brain tissue, there is an almost instantaneous exchange with the tissue water, making venous blood flow impossible to measure (Grade et al., 2015).

There are three main ASL sequences, of which pseudocontinuous ASL is the most popular (Alsop et al., 2015). Due to its noninvasiveness and use of blood water as an endogenous tracer molecule, ASL poses a viable future alternative to positron emission tomography (PET) in patients whose conditions and health status do not preclude their safety in an MRI machine (e.g., no metal implants or devices). This is especially important since the low signal-to-noise ratio, or resolution, of ASL sequences improves when acquired on equipment with a magnetic field strength of at least 3 Tesla (3T; Alsop et al., 2015; Grade et al., 2015).

Functional MRI

A functional MRI (fMRI) sequence measures changes in deoxygenated hemoglobin concentration to indirectly reflect brain metabolic demand over time (Glover, 2011; Kwong et al., 1992). Deoxygenated hemoglobin (Hb) exhibits paramagnetic characteristics when an external magnetic field is applied. Due to this characteristic, molecules of deoxygenated Hb align with the applied magnetic field of the MRI machine. This shift in alignment allows for the concentration of deoxygenated Hb to be measured, resulting in an MRI signal known as the blood-oxygen-level dependent (BOLD) signal (Forster et al., 1998). This modality offers researchers a real-time depiction of the brain's activity, whether at rest or attending to a task or stimulus. However, its use of gradient magnets makes it more dangerous in the presence of prostheses or devices that are only conditionally safe at lower MRI magnetic field strengths (Gomes et al., 2007). For example, some pacemakers are safe at 1.5T and conditionally safe at 3T, yet unsafe at 7T, a field strength typically used only in research.

Task-evoked functional MRI.—Functional imaging typically evokes changes in a participant's cerebral blood flow through a series of tasks or stimuli, a paradigm known as task-evoked fMRI. Stimuli may include a series of images, flashing lights, physical sensations (e.g. thermal or mechanical pain), or cognitive tasks (e.g., simple arithmetic). As the research participant engages these stimuli, activated brain regions experience a greater degree of change in deoxygenated Hb concentration, as oxygen is delivered to satisfy increased metabolic demands. This results in greater BOLD signal relative to the surrounding tissue. Determining whether the increased BOLD signal is a consequence of the

task requires post-processing of the images and statistical analysis using one of several available toolboxes (Table 1). The choice of stimulus is an important consideration when performing task-evoked fMRI, as the BOLD signal is the result of a hemodynamic process which reaches its peak a few seconds after stimulus onset and exhibits a slow decline during which the stimulated brain region's BOLD signal returns to baseline (Henson & Friston, 2007). Therefore, an experiment must be designed to allow for some resting state or baseline between stimuli. Otherwise, it may be difficult to accurately determine the statistical significance of a task or stimulus relative to observed changes in BOLD signal.

Resting-state functional MRI.—Similar to task-evoked fMRI, resting-state fMRI (rs-fMRI) measures changes in brain activation over time. However, rs-fMRI is concerned with these changes in the absence of a stimulus or task. A study by Biswal et al. in 1995 found that while the brain is at rest, there exist low frequency temporally-correlated fluctuations in BOLD signal (Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995). Further investigation revealed distinct, latent networks of functionally connected brain regions that are active while the brain is at rest. Results from rs-fMRI analyses are more difficult to interpret than those of task-evoked fMRI, requiring a deeper knowledge of neurophysiology and pathophysiology. However, the sheer volume of data may be the most difficult barrier (Harris, Hirst, & Mossinghoff, 2008; Wang, Zuo, & He, 2010). As such, the study of whole-brain connectivity through voxel-to-voxel analysis is a conceptually and computationally challenging starting point. A simpler approach is *a priori* selection of regions of interest (ROI) in networks described by the literature and ROI-to-ROI connectivity analysis, minimizing the computational workload and allowing clearer interpretation of results.

A distinct advantage of rs-fMRI over task-evoked fMRI is evident when imaging research participants in vulnerable populations, or participants who may otherwise be unable to tolerate or perform a stimulus or task such as frail, elderly subjects, or cognitively impaired individuals.

Computed Tomography

Computed tomography (CT) is an imaging modality that uses X-ray radiation to generate anatomical images. Compared to MRI, the principle behind the acquisition of these images is much simpler. As X-rays pass through the body, the X-rays lose energy relative to the density of the surrounding tissue. The X-rays are detected on the other side of the tissue and the remaining energy of the X-rays is translated into a grayscale image as a pixel of proportional brightness (Webb & Flower, 2012). Modern CT machines utilize a spinning ring, upon which an X-ray emitter is mounted opposite an X-ray detector. The gurney may slowly move in and out of the CT machine during image acquisition. The CT image can be reconstructed to provide a high-quality 3D anatomical scan of the target tissue. Contrast agents may be used when structural characteristics of certain tissues need to be more discernable. These contrast agents typically contain iodine, barium, or gadolinium; however, some patients may experience rare adverse reactions to these agents (Hasebroock & Serkova, 2009; Lusic & Grinstaff, 2013).

The primary advantage of CT is the short scan time. A brain CT may be collected in just a few minutes. This short scan time is a necessary feature, as a distinct disadvantage of CT is the exposure to ionizing radiation, which can cause damage to tissue and DNA (Brenner & Hall, 2007). For reference, a single CT may expose an adult patient to 20 millisieverts of radiation, which is nearly half of the occupational dose limit for radiation workers in the nuclear industry (Cardis et al., 2007; “NRC: Information for Radiation Workers,” n.d.).

Positron emission tomography

MRI and CT offer structural and anatomical images of unparalleled quality, but are poorly suited for *in vivo* imaging of biochemical and physiological processes. MRI images offer a discontinuous representation of the process being imaged, and acceleration of image acquisition is dependent on T1 and T2 tissue relaxation times. Although CT does offer a continuous image acquisition paradigm, X-rays are not susceptible to changes in energy by the molecules used in metabolic processes.

Instead, positron emission tomography (PET) may be used for *in vivo* imaging of biological, biochemical, and physiological processes. Visualizing these processes requires administration of a radionuclide tracer to the research participant. Radionuclides used in PET emit positrons when they decay through a process known as beta decay. For example, fluorodeoxyglucose (^{18}F-FDG) is a ubiquitous PET radionuclide used for characterizing abnormal glucose metabolism and can help identify malignant tissue engaged in such processes (Jadvar & Parker, 2005; Laking & Price, 2001). Positron emissions are detected by cameras called scintillators. A modern PET machine consists of any number of scintillators, each connected to photomultiplier tubes, which amplify the signal of the emitted positrons. Radionuclides do not require stimulation to emit a positron, and so, unlike MRI, there is a constant source of signal that may be collected. This signal can be visualized as an intensity map, with regions of the body displaying abnormal deposition and metabolism of the radionuclide tracer discernable by a radiologist (Berger, 2003).

Unlike MRI and CT, PET is a poor modality for structural imaging. This is often remedied by registering PET images with anatomical CT images, or simultaneous collection of both modalities using hybrid PET/CT systems. Another weakness is radionuclide acquisition. Tracer molecules do not exist in nature and must have a short half-life, or time in which half of the substance decays, to limit harmful radiation exposure to both the research participant and the researchers. Cyclotrons are small accelerators used for radionuclide production, but due to the short half-life of these molecules, they must be located close to the PET imaging center (Paans, van Waarde, Elsinga, Willemsen, & Vaalburg, 2002). Images must be collected over the course of radionuclide decay, and may result in scan times of 10–40 minutes (Berger, 2003). Similar to CT, the most notable disadvantage of PET imaging is the risk of harmful radiation exposure to the participant, which may cause damage to tissue and DNA.

Electroencephalography and Magnetoencephalography

Electroencephalography (EEG) and magnetoencephalography (MEG) are functional neuroimaging techniques that map brain activity by detecting signals of ionic currents from

biochemical processes occurring at the cellular level during neural activation (Hansen, Kringelbach, & Salmelin, 2010; Lopes Da Silva, 2013). Sensor arrays are used to record these ionic currents, which are electrical fields in EEG and magnetic fields in MEG (Hansen et al., 2010; Lopes Da Silva, 2013). The signals detected by EEG and MEG are a real-time, direct recording of information transmission between neurons (Hansen et al., 2010). The frequency, bandwidth, and amplitude of the electrical or magnetic signals are recorded and called oscillations. Oscillations are not just correlates of brain activation but are considered a representation of underlying neural mechanisms of cognitive processes (Lopes Da Silva, 2013).

The method of signal detection in EEG relies on sensors attached to the scalp resulting in waveforms that can be distorted by CSF, the bones of the skull, and tissues of the scalp. The magnetic fields detected by MEG are less distorted because of the constant magnetism permeating brain tissue (Lopes Da Silva, 2013). Statistical analysis and modeling help to resolve distortions. Despite differences, both EEG and MEG ultimately yield nearly the same neural information and their localization to a specific brain region is similar enough to be considered almost interchangeable (Cohen et al., 1990; Lopes Da Silva, 2013). Both EEG and MEG can be used to examine and investigate cognitive processes such as perception and memory, brain attentional systems, transfer of information, and the organization and consolidation of memories. Both yield information on the dynamic interaction between areas of the brain with the specificity of milliseconds (Lopes Da Silva, 2013). There is evidence that EEG and MEG can be used as biomarkers for epilepsy or neuropsychiatric disorders, such as attention-deficit hyperactivity disorder, autism, and schizophrenia (Lopes Da Silva, 2013).

Choosing one method over another may depend upon which is more easily accessible to the researcher, but comprehensive and nuanced data may be collected by using both EEG and MEG on the same research participant (Hansen et al., 2010; Lopes Da Silva, 2013). New ways to integrate EEG and MEG with fMRI are underway, which should lead to improved methods for exploring cognitive processes.

Discussion

When considering the multiple options for neuroimaging techniques, it is important to first consider the nature of the research question. If the research question concerns the structure of specific brain regions, or damage to brain structures from particular disease processes, structural MRI, including FLAIR and DTI techniques, or CT are likely the best options. If the specific disease process of interest is related to tissue perfusion, ASL should be considered. Alternatively, if the research question is more concerned with connectivity and communication between brain regions, fMRI, PET, or EEG and MEG are good candidates. Task-evoked fMRI should be considered if the researcher is interested in brain activity in response to a particular stimulus, while resting-state fMRI should be used if the research focuses on latent brain networks. If research concerning connectivity and communication between brain regions is best explored by the examination of real-time, continuous images of brain activity, PET scans or EEG and MEG should be used.

Once the general neuroimaging method is chosen (i.e., structural or functional, discontinuous or continuous), the specific needs of the patient population of interest should be considered. Will the research subjects be able to tolerate longer, more invasive scans, such as MRI and PET, or are shorter, moderately invasive scans such as CT needed? Less invasive scans, such as EEG and MEG, may be the best approach for vulnerable populations (e.g., pediatric, critically ill, cognitively impaired). Functional MRI and PET scans will require the participant to lie still for a long period of time, as scans may take 40 minutes or longer than an hour to complete. This may not be feasible for vulnerable populations, including patients with chronic back pain or cognitively impaired individuals who cannot remain still. Additionally, many patients with metal implants (e.g., prosthetics) or devices (e.g., medication pumps) cannot undergo MRI. Computed tomography may be a better option in these participants for structural imaging, as those scans tend to take less time. If a degree of functional imaging is needed, EEG and MEG should be considered, which are the least invasive.

Patient safety must be ensured when using CT or PET, as radiation exposure can cause damage to tissue and DNA. Female research participants of childbearing age should confirm that they are not pregnant prior to undergoing imaging. When using CT, the researcher must also be sure to ask research participants about previous experience with CT contrast, as some patients may experience rare adverse reactions to contrast agents. Full discussion of the benefits and risks to research participation should be included in the informed consent document, and researchers should work closely with their institutional review board to ensure ethical research practice.

In addition to considering the needs of the research subjects, the nurse researcher must also weigh the limitations of neuroimaging research, primarily funding. In addition to the cost of obtaining imaging in research subjects, which requires paid access to a radiological suite with staff, nurse researchers will need to consult with neuroscientists and radiologists who are able to analyze and interpret the images. This may involve an interdisciplinary research collaboration, or it may require hiring a neuroscientist and/or radiologist who will need financial compensation. Therefore, adequate research funding is of upmost importance for the completion of neuroimaging research. For example, the National Institutes of Health has numerous Institutes that support all types of neuroimaging research focusing on the neurobiology of various disease states and examining the mechanistic underpinnings of brain structure and function. Neuroimaging can also be used to measure the effect of numerous interventions on brain neurophysiology. Fortunately, numerous educational opportunities and tools are available to nurse researchers to facilitate the conduct of neuroimaging research (Table 1).

Neuroimaging is an innovative method for accomplishing the goals of nursing research. With the utilization of multiple neuroimaging modalities, nurses can use technology to improve symptom science through the identification of biomarkers of disease processes and symptoms states, as well as demonstrate efficacy of interventions designed to improve or maintain health (National Institute of Nursing Research, 2016). Despite the wealth of knowledge to be gained from neuroimaging, few nurse scientists include these methods in their program of research. Nurses perceive many barriers to engagement in the research

setting, including time constraints, lack of knowledge of the current literature, inadequate research skills, and lack of research support and collaboration (Hutchinson & Johnston, 2004; Moreno-Casbas, Fuentelsaz-Gallego, de Miguel, González-María, & Clarke, 2011). These barriers become even more important when considering the time and resources needed for developing a program of neuroimaging research.

Facilitators of nurse engagement in research include adequate time for the conduct of research, research education, and availability of research support. In order to increase the use of neuroimaging in nursing science, many of these barriers must be overcome. Nurse scientists will need additional education and training in neuroscience and computer programming. This additional training may include longer post-doctoral and career development awards that allow for the development of expertise in neuroimaging methodologies. Interdisciplinary collaborations with neuroscientists and radiologists will be imperative for developing the skills necessary to conduct quality neuroimaging research. Nurses have a wealth of patient-centered expertise in symptom science, which complements their knowledge of health and disease across the human life span. In addition, nurses can use imaging methods to develop programs of research on non-human primates that are not possible in humans. Thus, nurses are well positioned to bring critical knowledge to interdisciplinary teams using imaging science.

Conclusion

Given the tremendous potential for patient benefit and innovation in disease and symptom science, nurse scientists must begin to consider the use of neuroimaging in their programs of research. We recommend that nurses interested in imaging science do not allow fear of complex technology to prevent them from considering these methods. Instead, those interested should seek out other scientists currently using these methods. Given the paucity of nurses currently using these methods, nurses could consider mentors in other disciplines including psychiatry, psychology, radiology, anesthesiology, neuroscience, and pharmacology to name a few. In our experience, multidisciplinary teams welcome nurses as part of the research group. The nurse’s responsibility is to develop the requisite skills and training to not only be a part of a multidisciplinary team but to lead the research team using neuroimaging to inevitably advance science and health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Helpful neuroimaging short courses and resources

Course	Link	Description
Andy's Brain Blog	http://www.andrewjahn.com	Andrew Jahn offers many useful video tutorials on neuroimaging methods and analysis.
Massachusetts General Hospital (MGH)	https://www.nmr.mgh.harvard.edu/training/courses	MGH offers many courses on structural and functional connectivity, multiple imaging modalities, and methods and analysis.
Multimodal Neuroimaging Training Program (MNTP)	http://www.mntp.pitt.edu/	MNTP at the University of Pittsburgh offers a yearly summer workshop on different imaging modalities.
Neurometrika	http://www.neurometrika.org/Courses	Offers basic, intermediate, and advanced courses in research design and analysis using fMRI methods in research and practice.
Statistical Parametirc Mapping Parent Site	http://www.fil.ion.ucl.ac.uk/spm/	Offers introductory online courses and documents, links to yearly training courses, and software and documentation.
Stanford Talks	https://talks.stanford.edu/tutorials/neuroimaging-tutorials/	Offers many neuroimaging tutorials and discussions in video format.
Resources	**Link**	**Description**
FMRIB Software Library	https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/Atlases	FSL offers a toolbox for neuroimaging analysis with multiple brain templates and atlases.
Neuroimaging Tools & Resources Collaboratory	https://www.nitrc.org/	Offers neuroimaging tools for analysis of structural and functional imaging from multiple modalities.
Neurosynth	http://www.neurosynth.org/locations/	A tool for examining coordinates of regions of functional activation and their associated structural regions.
The Human Brain	http://www.thehumanbrain.info/brain/locator.php	A tool for inputting brain coordinates and outputting associated brain locations using multiple coordinate systems.

Table 2.

Neuroimaging vocabulary

Term	Acronym	Explanation
Amplitude	*A*	Distance from a wave's equilibrium point to the crest of either a crest or trough.
Apparent Diffusion Coefficient	ADC	DTI measure of water molecule diffusion within brain tissue.
Arterial Spin Labeling/ Pseudocontinuous ASL	ASL/ pCASL	Structrual MRI technique that traces blood flow and tissue perfusion. Refinements such as pCASL allow for higher quality images.
Axial Diffusivity	AD	DTI measure of water molecule diffusion parallel to nerve tract.
Bandwidth	*B*	Band of frequencies between the upper and lower cut-off frequencies of a wave.
Beta Decay	ß-decay	Radioactive decay characterized by emission of an electron.
Blood-Oxygen-Level Dependent	BOLD	The change in fMRI signal between oxygenated and deoxygenated hemoglobin.
Computed Tomography	CT	Imaging technique that uses x-rays to generate anatomical images.
Cyclotron	–	Accelerator used for radionuclide production.
Cerebral Blood Flow	CBF	The amount of blood supplied to the brain at any given moment.
Cerebrospinal Fluid	CSF	Clear, colorless fluid that surrounds brain and spinal cord.
Deoxygenated Hemoglobin	Hb	Hemoglobin molecules in which there is no bound oxygen.
Diffusion Tensor Imaging	DTI	Structural MRI technique that measures water molecule diffusion along nerve fibers for direct visualization of white matter bundles.
Electroencephalography	EEG	Functional neuroimaging technique that maps brain activity using sensors placed on the scalp.
Fluid Attenuation Inversion Recovery	FLAIR	Structural MRI technique which suppresses CSF signal to provide image and is highly sensitive to pathological abnormalities.
Fractional Anisotropy	FA	DTI measurement of nerve fiber integrity.
Functional Magnetic Resonance Imaging	fMRI	MRI technique that measures blood oxygenation in the brain, so that assumptions may be made about both broad and specific brain functions.
Functional Neuroimaging	–	Neuroimaging technqiues that examines connectivity between brain regions.
Half-Life	$t_{1/2}$	Time in which a radioactive atom undergoes radiactive decay.
Magnetic Resonance Imaging	MRI	Imaging technique that uses radiofrequency waves and a magnetic field to produce anatomical images.
Magnetoencephalography	MEG	Functional neuroimaging technique that maps brain activity using sensors placed around the scalp.
Mean Diffusivity	MD	DTI measure of water molecule diffusion overall all directions at a single point on a nerve tract.
Oscillation	–	Rhythmic frequency patterns in the CNS that occur during activation of either single neurons or neuronal clusters.
Photomultiplier Tubes	–	Part of PET machine that amplifys the signal of emitted positrons.
Positrons	e^+, $ß^+$	Subatomic particle with the same mass as an electron, but with a positive charged.
Positron Emission Tomography	PET	Functional neuroimaging technique that uses positron-emitting radionuclide tracers for *in vivo* imaging of biological, biochemical, and physiological processes.
Radial Diffusivity	RD	DTI measure of water molecule diffusion perpendicular to nerve tract.
Radio Frequency Pulse	RF	A magnetic field whose direction is oscilating at the Larmor frequency.
Radionuclide Tracer	–	A compound in which atoms have been replaced by their radioactive isotopes. In the context of imaging, these compounds are often biochemical analogues.
Region of Interest	ROI	A shape, coordinate, or anatomical region of the brain in which a researcher looks for activation or inactivation
Resting-State fMRI	rs-fMRI	fMRI technique that measure brain activity while at rest.
Scintillators	–	Photon detectors within a PET machine.

Term	Acronym	Explanation
Signal to Noise Ratio	SNR	The ratio of fMRI signal to noise (background interference causing signal distortion). Higher SNR ratios indicate higher quality images. Noise control and reduction is especially important in fMRI research.
Structural Neuroimaing	–	Neuroimaging techniques that examine the structures of the brain.
Task-Evoked fMRI	–	fMRI technique that measures brain activity in response to a stimulus.
T1 or T2 Relaxation Time	–	T1 relaxation time describes the amount of time needed for the longitudinal magnetization vector to recover to 63% of its original strength after being flipped 90° into the transverse plane by an RF pulse. T2 relaxation time describes the amount of time it takes for the MR signal to decay to 37% of its original strength after tipping the longitudinal magnetization vector towards the transverse plane.
T1- or T2-Weighted	T1W/T2W	Body tissues have associated T1, T2, and Proton Density values, which depend on the tissue's anatomy and chemical composition. For example, T1 image acquisition time is the time it takes for protons in a specific area to realign to the magnetic field after a RF pulse.
Voxel	–	A single volumetric unit of measurement within the brain. The dimensions of a voxel can differ between images based on the imaging technique used.
X-Ray	–	High-energy radiation capable of penetrating most tissue.
Tesla	T	A Tesla is a unit of measurement for magnetic flux density. MRI magnetic fields range commercially from 0.2 T to to 7T. Higher T values effectively indicate higher magnet strength.