MRI GLOSSARY

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HST-583, Fall 2001

90^0 Pulse An RF pulse that rotates the magnetization by 90^0. It is normally a synonym for "Saturation Pulse".

180^0 Pulse An RF pulse that rotates the magnetization by 180^0. Synonym for"Inversion Pulse" when applied on a pure longitudinal magnetization (i.e., no transverse component). Synonym of "Refocusing Pulse" when applied on a pure transverse magnetization (i.e., no longitudinal component).

$\pi/2$ Pulse Synonym for 90^0 Pulse.

π Pulse Synonym for 180^0 Pulse.

Artifacts Features in MR images produced by various complications of the imaging process, and which result in an image that does not portray (in the simple visual sense) an accurate representation of a slice of tissue. Examples of sources of artifact include: subject motion, magnetic field inhomogeneities, blood flow, and partial voluming.

Axial Slice With respect to brain imaging, the plane that chops off the top of the head, with coordinates going left-to-right (from ear-to-ear) and front-to-back (from nose to occiput). Sometimes also called "horizontal".

$\mathbf{B_0}$ The main static magnetic field.

Bloch equations Phenomenological equations that describe the time dependency of the magnetization vector in presence of an externally applied magnetic field and subject to relaxation processes. No flow or diffusion is considered.

BOLD Effect (Blood Oxygen Level Dependent Effect) The change in T_2^* that is caused by changes in the amount of oxygenated hemoglobin in the venous circulation of the brain. Because oxygenated hemoglobin has a much smaller magnetic susceptibility than deoxygenated hemoglobin, and because neural activity causes a change in the amount of oxygenated hemoglobin in the venous blood, the magnetic susceptibility of blood decreases during activation. Thus, its T_2^* increases, and hence there is an increase in intensity in T_2^*-weighted images.

CBF (See Cerebral Blood Flow)

CBV (See Cerebral Blood Volume)

Cerebral Blood Flow (CBF) The flow of capillary blood per unit mass through the cortex (units of ml/minute/100g).

Cerebral Blood Volume (CBV) The volume of blood in a given portion of cerebral cortex.

Chemical Shift Nuclei experience slightly different local magnetic fields because of differences in their immediate chemical environments. If there is a difference in the net magnetic field there will be a difference in the resonance frequency. Chemical shift can produce artifacts in MRI. For example, hydrogen nuclei in

water and hydrogen nuclei in fat experience different magnetic fields and therefore have different Larmor frequencies. Because these frequencies are used to encode position in MRI, the same voxel of tissue containing water and fat will be represented in different places in the image.

Coils See "RF Coils", "Gradient Coils" and "Shim Coils".

Coronal Slice With respect to brain imaging, the plane parallel to the face, with coordinates going left-to-right (from ear-to-ear) and top-to-bottom (from head-to-foot).

Dephasing In the context of MRI, this refers to the loss of net magnetization in the transverse plane due to the fact that the individual nuclei are precessing around the main field $\mathbf{B_0}$ at different rates. Even though the rate that magnetic orientation of the individual nuclei returns to the longitudinal direction is relatively slow (T_1 is typically around 1000ms in the human brain at 3 Tesla), the rate at which the tranverse magnetization disappears is relatively rapid (T_2^* typically <100ms) because the individual nuclei get out-of-phase with each other, and their magnetization vectors cancel.

Diffusion-weighted imaging (DWI) Refers to images designed to detect the random movement of water through tissues by diffusion, that is, outside the vessels. (See also "Perfusion-weighted imaging")

Echo In the context of MRI, "Echo" refers to the regrowth of the transverse component of magnetization after it has disappeared due to dephasing. This "Echo" is, in fact, the NMR signal that is normally recorded and analyzed in MRI. An echo can be formed by the use of magnetic field gradients (see "Gradient-Echo") or by the use of a RF pulse (see "Spin-Echo").

Echo Planar Imaging (EPI) An MRI technique in which a single saturation pulse is used to generate NMR data that is sufficient to define a two-dimensional planar image. The idea is to use rapidly varying gradients in the transverse plane to cause multiple refocusing gradient echoes from the single rf pulse. It requires gradient power supplies of greater strength than are needed for more conventional imaging strategies. Its main advantage is speed.

Eddy Currents An induced spurious electrical current produced by time-varying magnetic fields. Eddy currents can cause artifacts in images and may seriously degrade overall magnet performance.

Endogenous Contrast Agent A chemical that is naturally present in the body, and which has sufficient magnetic susceptibility to influence the MR signal. Deoxyhemoglobin is the relevant example of such a chemical for fMRI.

EPI (See Echo Planar Imaging)

Epoch In the context of fMRI, this term is often used to refer to a portion of a single fMRI run during which the stimulus presentation and/or response task is unchanged. (Note that "unchanged" does not mean that the stimuluation is necessarily static, but that it is treated as a single type of stimulus. For instance, the visual presentation of flickering or moving dots is changing with time, but a 30-second period during which such stimuli were presented continuously would normally be considered a single "epoch". Further complicating the terminology is the fact that what counts as a single epoch of stimulation is somewhat arbitrarily defined by the experimental design. A sequence of visually presented faces might be treated as a single "epoch" in the context of general face processing, but might be separable into several epochs based on grouping by gender, age, familiarity, etc. Thus, a given experimental paradigm might be divided into "epochs" for analysis in several different ways.)

Ernst Angle If a series of rf pulses is applied to a sample, then the Ernst angle is the rf flip angle that yields the most signal for a given TR and T_1 under the assumptions that steady state has been reached and that $T_2^* << TR$. If Ernst Angle $= \alpha$, then $\cos\alpha = \exp\left(-TR/T_1\right)$.

Exogenous Contrast Agent A chemical that is injected into the body to enhance magnetic susceptibility differences between blood, typically, and the surrounding tissue. The contrast agents are paramagnetic so that their presence induces an increase of the local magnetic field inhomogeneities, thus a decrease of the local T_2^* and thereby a decrease in the MRI signal. The most common example is Gd-DTPA (gadolinium diethylene-triamine-penta-acetic acid).

FFT (Fast Fourier Transform) A particularly fast and efficient computational method of performing a Fourier Transform, which is the mathematical process by which raw data is processed into a usable image.

FID (See "Free Induction Decay")

Field of View (FOV) The rectangular region in physical space to which the MRI data collected corresponds. Its dimensions are independenly controlled by the frequency-encode and phase-encode gradients.

Flip Angle The angle through which the longitudinal magnetization is rotated by an rf pulse. The angle can be controlled by the duration of the rf pulse.

fMRI (See "Functional Magnetic Resonance Imaging")

Fourier Analysis The decompostion of an arbitrary mathematical function into a sum (or integral) of weighted sinusoidal (or complex exponential) functions. This is a critically important tool in MRI, because it permits the analysis of a mixture of NMR signals at slightly different frequencies into their component frequencies. The component frequencies are specified by the frequency-encode gradient, and thus permit the correspondence of frequencies (as determined by the Fourier analysis) with position (as determined by the gradient).

FOV (See "Field of View")

Free Induction Decay After the application of a saturation pulse, the NMR signal is created by virtue of the net magnetization rotating at the Larmor frequency in the transverse plane. As time passes, this signal gets exponentially smaller (due to both T_1 and T_2^* decay). A plot of this signal as a function of time is called the "Free Induction Decay". It looks like an exponentially damped sinusoid at the Larmor frequency.

Frequency Encoding This refers to the use of a magnetic field gradient to cause different rates of precession (different Larmor frequencies) along the direction of the gradient during the time that data is acquired. Thus, the frequency composition of the collected data (as determined by Fourier analysis) will correspond to different spatial locations.

Frequency Encode Gradient (See "Gradient Coils")

Functional Magnetic Resonance Imaging (fMRI) This term refers generally to using MRI to study brain function, rather than just brain anatomy. It has become strongly associated with the study of changes in cerebral blood flow and cerebral blood oxygenation, as these are correlated with neuronal activity. However, the term can also used to refer to the study of heart function, and other physiological processes.

Gx, Gy, Gz (See "Gradient Coils")

$\mathbf{G}_{\mathrm{frequency}}$**,** $\mathbf{G}_{\mathrm{phase}}$**,** $\mathbf{G}_{\mathrm{slice}}$**,** $\mathbf{G}_{\mathrm{read}}$ (See "Gradient Coils")

Gradient Coils These are the coils of wire that are used to generate the magnetic field gradients that are used in various ways in MRI. In particular, they are the source of the magnetic fields labeled Gx, Gy, Gz, or, more generally, the source of $G_{\mathrm{frequency}}$, G_{phase}, and G_{slice}. The coils, themselves, are normally labelled "x",

"y", and "z", to indicate the orientation of the magnetic fields that they generate. In the most standard case of an axially oriented image, the "z" gradient coil is used for slice selection, the "x" gradient coil is used for frequency encoding of the image, and the "y" gradient coil is used to generate the magnetic fields that permit phase encoding. In general, however, combinations of these coils are used to generate the slice-select, frequency-encode and phase-encode directions in order to permit imaging in planes other than the axial plane (such as coronal, sagittal, and arbitrary oblique planes). Note that the "$G_{frequency}$" is also often called "G_{read}" because the actual NMR data collection takes place while this gradient is in use.

Gradient-Echo A form of magnetic resonance signal from the refocusing of transverse magnetization caused by a the application of a specific magnetic field gradient.

Gyromagnetic Ratio The ratio of the resonance frequency to the magnetic field strength for a given nucleus. (See "Larmor Frequency")

Hemodynamic Response The changes in blood flow, blood volume and blood oxygenation in response to local neural activity.

Horizontal Slice (See "Axial Slice")

Images Per Slice (ips) This is the number of images of a specific, single slice, collected during a single fMRI run. (See Figure at beginning of Glossary).

Imaging Session (See "Session")

Inversion Pulse A burst of electromagnetic energy at the Larmor frequency that lasts just long enough to cause the net longitudinal magnetization to rotate 180^0. It takes the longitudinal magnetization and transforms it into longitudinal magnetization that points in the opposite direction. (See also "Saturation Pulse").

Inversion Recovery Sequence This is the basic T_1-weighted image sequence. This MRI sequence generates signals which represent the longitudinal magnetization present after the application of a 180^0 inversion RF pulse. The sequence can be abbreviated by the notation 180-TI-90. This means: apply a 180^0 inversion pulse, wait an interval TI (inversion time) and then apply a 90^0 pulse, after which the NMR signal is measured. The TI interval is used to let the longitudinal magnetization recover through spin-latice or T_1 relaxation. After TI the 90^0 pulse is used to rotate the available longitudinal magnetization on to the transverse plane to generate a signal. Tissues with fast T_1 recovery will have a larger longitudinal magnetization at the end of TI, thus will produce a stronger signal after the the 90^0 pulse. Therefore, in T_1-weighted images bright tissue represents short T_1 and dark tissue long T_1.

ips (See "Images Per Slice")

Isotropic Voxel A volume element with equal dimenstions in x, y, and z.

K-Space The Fourier transform domain of ordinary space. The relationship between the two is the same as that between (angular) frequency and time. k-space has three dimensions, as ordinary space. A point in k-space is thus defined by a vector $\mathbf{k}$ with components k_x, k_y and k_z. In real space, such a vector corresponds to a sinewave pattern of wavelength $\lambda = 2\pi/|\mathbf{k}|$, with the direction of the normal to the wavefronts being the direction of $\mathbf{k}$.

Larmor Equation $\omega = \gamma B$, where omega (ω) is the rotational frequency in radians per second, gamma (γ) is the gyromagnetic ratio, and B is the magnetic field strength. This is the most fundamental equation from which spatial encoding can be understood.

Larmor Frequency The rate at which a given nucleus precesses in a magnetic field of a given strength. The frequency which will cause a transition between the two spin energy levels of a nucleus. This rate is proportional to the field strength. The constant of proportionality is given by the "gyromagnetic ratio" for each kind of nucleus. For hydrogen nuclei, this constant of proportionality is 42.58 in units of MHz/Tesla. (See "Larmor Equation")

Longitudinal Magnetization Magnetization in the direction parallel to that defined by the magnetic field of the main magnet (i.e., parallel to $\mathbf{B_0}$).

Longitudinal Relaxation (a synonym for spin-lattice relaxation). Refers to the gradual recovery of the net magnetization ($\mathbf{M_0}$) due to the main magnetic field ($\mathbf{B_0}$) after an rf excitation pulse has flipped the longitudinal magnetization by some angle.

$\mathbf{M_0}$ The net macroscopic magnetization in the sample at thermal equilibrium. $\mathbf{M_0}$ is defined by the spin population excess in the lower energy state.

MRA (See "Magnetic Resonance Angiography")

MRI (See "Magnetic Resonance Imaging")

MRS (See "Magnetic Resonance Spectroscopy")

Magnetic Resonance Imaging (MRI) The proceess of creating an image based on the differences in NMR signal from different places in the sample.

Magnetic Resonance Spectroscopy (MRS) The process of creating a spectrum of energy based on variations in the NMR signal frequencies in a given portion of a sample caused by differences in the chemical composition of that sample. See "Quemical Shift".

NMR (See "Nuclear Magnetic Resonance")

Nuclear Magnetic Resonance (NMR) The absorption and emission of electromagnetic energy tuned to the Larmor frequency of a nucleus precessing in a magnetic field.

Partial Volume Within any given voxel, there may be multiple kinds of tissue. If only some of that tissue is responsible for generating changes in MR signal strength, it will be harder to detect. That is, only "part of the volume" will be contributing to the signal.

Perfusion-weighted imaging Refers to images designed to detect the movement of fluids through vessels (arteries, veins, and capillaries). (See also "Diffusion-weighted imaging")

Phase Encoding This refers to the use of a magnetic field gradient to cause different rates of precession for a brief period of time, resulting in phase differences across space in the direction of the gradient.

Phase Encode Gradient (See "Gradient Coils")

Pixel (Picture Element) A single number in a two-dimensional array of numbers that is used to create an image. In MRI, a pixel in the image of a single slice through the body corresponds to a voxel in that body.

Precession A rotational motion about an axis of a vector whose origin is fixed at the origin.

Proton Density (PD) The density of water protons in a given volume of tissue. Images based on Proton Density are generated using a long TR and a short TE.

Pulse Sequence Sequence of pulse signals sent to the rf transmit/receive coil, to the slice-selection gradient coil, to the frequency-encoding coil, and to the phase-encoding coil during an MRI experiment. The pulse sequence ultimately defines how the data is going to be collected in k-space, and thus the characteristics of the reconstructed image (contrast, signal-to-noise, artifacts, etc.).

Quench An event which can only occur in superconducting magnets, it is caused by a loss of superconductivity; a rapid increase in the resistivity of the magnet, which generates heat that results in the rapid evaporation of the magnet coolant (liquid helium). This evaporated coolant is a hazard that requires emergency venting systems to protect patients and operators. A quench can cause total magnet failure.

Readout Gradient (See "Gradient Coils")

Refocusing Pulse An RF pulse that rotates the transverse magnetization by 180^0. Refocusing pulses are normally used to generate a spin echo (i.e., a rephasing of transverse magnetization).

Region of Interest (ROI) A subset of pixels in an image. Because the term has been in use for a long time, "Region of Interest" is sometimes used informally to indicate a subset of voxels in a three dimensional data set. However, the correct term in that situation is "Volume of Interest".

Relaxation As used by physicists, this refers to the process whereby an excited system returns to its equilibrium state.

RF Coils These are the coils used to transmit the radio frequency (RF) electromagnetic energy used to flip the magnetization, and to receive the NMR signal generated by the the precession of the resulting transverse magnetization. A single coil can be used for both transmitting and receiving; or alternatively, separate coils can be used for transmission and reception. The reason to use separate coils is that the requirements are different. A transmit coil needs to be able to send its rf energy uniformly anywhere in the body. The receive coil may only need to pick up signal from a small portion of the body, in some cases. For example, a "surface coil" is sometimes used to receive the signal. It has better signal-to-noise near its center than a receiver coil designed to detect signals uniformly throughout a larger portion of the body.

ROI (See Region of Interest)

Sagittal Slice With respect to brain imaging, the vertical plane perpendicular to the face, with coordinates going front-to-back (from nose-to-occiput) and top-to-bottom (from head-to-foot).

Saturation Pulse A burst of electromagnetic energy at the Larmor frequency that lasts just long enough to cause the net magnetization to rotate 90. It takes the longitudinal magnetization and transforms it into transverse magnetization. (See also "Inversion Pulse").

Scan In the context of fMRI, this refers to a single, continous collection of images.

Session The time that a single subject is in the MR scanner. This is typically about 2 hours for fMRI.

Shim Coils Coils positioned near the main magnetic field that carry a relatively small current that is used to provide localized auxiliary magnetic fields in order to improve field homogeneity. See also "Shimming".

Shimming The process of improving the magnetic field homogeneity by compensating for imbalances in the main magnetic field of an MRI system. This can be accomplished through a combination of passive (mechanical) shimming (e.g., adding or removing steel from the magnets poles) and active shimming (the use of shim coils) to fine-tune the magnetic field.

Slice Selection By applying a gradient in the longitudinal direction while the initial saturation rf pulse is presented, the region that will be flipped can be limited.

Spin-Echo The NMR signal resulting from the refocusing of magnetization after the application of a 90^0 and 180^0 rf pulses.

Spin-Lattice Relaxation (See "Longitudinal Relaxation")

Spin-Spin Relaxation (See "Transverse Relaxation")

Statistical Map An image based on a statistical parameter computed for each voxel throughout a collection of functional neuroimages. The statistical parameter is ordinarily computed using a grouping of the data based upon the epochs in which they were collected. The value of the statistical parameter can be indicated by its intensity (in a gray-scale map), but is more commonly indicated by a pseudo-color scale overlayed on the MRI.

Susceptibility Artifact This refers to the loss of NMR signal (due to faster T_2^* decay) or to image distortion (due to macroscopic magnetic field inhomogeneities) that arise when two substances of differing magnetic susceptibility are adjacent to one another. The most notable examples in the brain occur when air is near brain tissue (such as near the sphenoid sinus). The differences in magnetic susceptibility cause local inhomogeneities in the magnetic field, which drive faster T_2^* decay.

T_1 relaxation Refers to the gradual recovery of the longitudinal magnetization to its equilibrium value. This relaxation process is typically modelled by an exponential growth with a characteristic time given by T_1.

T_2^* relaxation Refers to the gradual disappearance of transverse magnetization as the system relaxes to its equilibrium state. The processes that induce T_2^* relaxation are signal dephasing (signal loss) arising from both macroscopic magnetic field inhomogeneities and microscopic spin-spin interactions. This relaxation process is typically described by an exponential decay with a characteristic time given by T_2^*.

T_2 relaxation Refers to the gradual disappearance of transverse magnetization as the system relaxes to its equilibrium state. T_2 relaxation refers only to the signal dephasing (signal loss) arising from microscopic spin-spin interactions. The distinction between T_2^* and T_2 relaxation is important because it is possible to choose between pulse sequences that emphasize contrast from one or the other relaxation mechanism (gradient-echo for T_2^*, spin-echo for T_2).

T_1-Weighted MRI An MR image that was generated using imaging parameters that cause contrast to be primarily based on differences in T_1 times for different tissues. (Short TR and short TE are used for T_1-weighting.) Tissues with short T_1 are bright in T_1-weighted images.

T_2-Weighted MRI An MR image that was generated using imaging parameters that cause contrast to be primarily based on differences in T_2 times for different tissues. (Long TR and Long TE are used for T_2-weighting.) Tissues with long T_2 are bright in T_2-weighted images.

Talairach Coordinates A system for specifying locations in individual brains relative to the brain coordinates of an old french lady... It yields three coordinates (x,y,z) based on a rigid rotation of the brain to an orientation specified by anatomical landmarks within the brain, and followed by a piecewise linear transformation of the brain in six sections that preserve continuity (but not continuity of derivatives). Although the use of Talairach coordinates is debatable, it is still the most widely used system for comparing brains between individuals. (It was first developed and presented by J. Talairach in 1967.)

Tesla A unit of magnetic field strength (=10,000 Gauss)

TE or "Time to Echo". The time (normally reported in milliseconds), between the presentation of the saturating rf pulse that flips the longitudinal magnetization by 90^0 and the time that an NMR echo signal is detected.

TI or "Time to Inversion". The time (normally reported in milliseconds), between the center of the first inversion pulse and the middle of the saturating (90^0) pulse in an Inversion Recovery pulse sequence.

TR or "Time to Repetition". The time (normally reported in milliseconds), between consecutive presentations of the rf pulses that flips the longitudinal magnetization to generate an NMR signal.

Transverse Magnetization Magnetization in the plane perpendicualar to that defined by the magnetic field of the main magnet (i.e., perpendicular to $\mathbf{B_0}$).

Transverse Relaxation (a synonym for spin-spin relaxation). Refers to the gradual loss of the measured magnetization in the plane perpendicular to $\mathbf{B_0}$ due to dephasing of the magnetic moments of the individual protons.

VOI (See Volume of Interest)

Volume of Interest A subset of voxels in a three dimensional data set. (Compare to "Region of Interest")

Voxel (Volume Element) A single number in a three-dimensional array of numbers. In MRI, a pixel in the image of a single slice through the body corresponds to a voxel in that body.