Structural MRI
Class 27 – November 27th 2013
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Objectives
- Be able to list three common misconceptions about structural MRI and explain why these are incorrect
- Be able to label the components of an MRI machine and describe their functions
- Be able to explain how an MRI scanner acquires structural images
- Be able to describe the differences between T1- and T2-weighted images in how they look, how they are acquired, and what they are used for
- Be able to describe what diffusion tensor MRI measures and what these images can be used for

Magnetic Resonance Imaging (MRI) is a technique utilized in both hospitals and research settings to acquire images of tissues inside the body. In neuroscience research, MRI is used to examine changes in brain structure during development, aging, or disease progression and allows investigators to compare neuroanatomical differences between groups. This tool provides doctors and researchers with high-resolution, three-dimensional images of anatomical structures and has thus been influential in medical and scientific advances.

The picture below is one of the very first human MRI images, acquired on July 3rd, 1977. This image is a cross-section of a man’s chest and shows the lungs, heart, and spinal cord. At the time, this image was considered to be a remarkable breakthrough. The field of MRI imaging has obviously come a very long way since this picture was acquired.
Common Misconceptions about MRI

Myth #1: MRI is harmful
Wrong! MRI is very safe. Unlike computerized tomography (CT) scans or X-rays, MRI scanners do not use radiation to acquire images. Instead, MRI machines use very large magnets to take pictures of body tissues. Most hospital MRI machines generate magnetic fields with strengths of 1.5 Tesla, which is 30,000 times stronger than the earth’s magnetic field. The resolution and quality of MRI images increases with the magnetic field strength of the scanner. Most MRI neuroscience research in humans is conducted using a 3 Tesla scanner, and the FDA has recently approved human imaging in scanners with strengths up to 8 Tesla. Since MRI machines produce such strong magnetic fields, it is important to take safety precautions near the scanner, especially with certain types of metal objects.

Myth #2: The MRI machine does not attract metal when it is turned off
Wrong! The magnets in the MRI machine continually generate a magnetic field, even when the machine itself is electrically off. This magnetic field is called the static field, and can be felt upon entering the MRI scanner room. The strength of this field increases exponentially as you get closer to the scanner. To prevent potential injuries, MRI machines are located in secure rooms with signs on the door such as the one below.

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Myth #3: You cannot have an MRI if you have any metal in your body
Wrong! It is only dangerous to have an MRI if you have ferrous metal in your body. Ferrous metals contain iron, which is strongly attracted to a magnet. However, most dental implants and surgical pins and rods are made of non-ferrous metal, so in those cases it would be safe to have an MRI if necessary. If you do have any surgical implants in your body though, it is important to check what type of materials these are made of before having an MRI!
MRI Image Acquisition

The picture below shows the components of an MRI machine. The person is placed in the tunnel of the machine, called the **bore**. The magnets that generate the static magnetic field encircle the bore of the machine and surround the individual inside the scanner. The machine also contains several types of coils, which are loops of conductive wire. The **radiofrequency coils** broadcast a radiofrequency signal and later collect the magnetic resonance signal. The workings of these coils can heat the tissues of the body slightly, but MRI computer software has built-in controls so that any tissue heating will remain at a low, safe level. This is, however, why you cannot wear any jewelry in the MRI scanner even if it is made of non-ferrous metal: the jewelry will heat up and could burn the surface of your skin. Another type of coil in the MRI machine, the **gradient coils**, deliberately change the strength of the static magnetic field in order to obtain spatial information. The gradient coils switch on and off rapidly, producing the loud, banging noises that individuals hear during MRI scans.
MRI relies on basic principles of physics to produce images. The human body is mostly composed of water, which contains hydrogen atoms. Protons in the nuclei of these hydrogen atoms spin around an axis like a spinning top, shown below on the left. In a free state, the axes of these spins are oriented randomly, as shown below on the right.

![Diagram of hydrogen protons in a free state](image)

When a person is placed inside the bore of the MRI scanner, all axes of the hydrogen proton spins align with the direction of the static magnetic field.

![Diagram of aligned hydrogen protons](image)

To acquire an MRI image, the radiofrequency coils in the machine emit **radiofrequency pulses** which excite the protons and change the angles of their spin axes.

![Diagram of radiofrequency pulses](image)

When the radiofrequency pulse is turned off, the proton spins relax and realign with the static magnetic field. In doing so, they send electromagnetic energy back to the radiofrequency coils. This is the MR signal that is used to construct the image.
The proton spins relax at different rates depending on the type of tissue that they’re located in. This is how we are able to differentiate between tissue types - such as gray and white matter - in an MRI image.

MRI machines collect three-dimensional images. This allows us to view the brain in axial, coronal, and sagittal views at the same time.

MRI machines collect images in slices. Each slice of an MRI image shows a slightly different section of the brain than the slice before it, as shown in the picture below. The slice on the upper left is the most posterior, and the slice on the bottom right is the most anterior. The person collecting the MRI images can vary the number and thickness of slices that they wish to collect. The thinner the slices, though, the more slices that you will need to collect in order to obtain an image of the entire brain.
**Types of MRI Images**

MRI machines can collect several different types of structural images. Every modern MRI scanner can collect each of these types of images, because the image type is determined by the pattern of radiofrequency pulses and not by the scanner itself.

**T1- and T2- weighted images**

T1-weighted images are the “typical” MRI structural images. In T1-weighted images of the brain, cerebrospinal fluid is black, gray matter is dark gray, and white matter is light gray. Researchers conducting a structural MRI study typically only collect T1-weighted images, since the contrast in these images allows for accurate differentiation of brain structures. This is also the image type that functional MRI data are overlaid on.

In T2-weighted images of the brain, cerebrospinal fluid is bright, gray matter is light gray, and white matter is dark gray. This type of image is collected mostly for medical purposes, since the contrast allows radiologists to see abnormalities within the ventricles and sulci better than on T1-weighted images. However, radiologists do use both T1- and T2-weighted images in order to determine a medical diagnosis. T2-weighted images are sometimes collected for research purposes, but since the gray and white matter boundaries are not as clearly defined as in T1-weighted images, they are often not as useful for analysis.

The picture below compares an axial T1-weighted image, on the left, to a T2-weighted image at the same slice level on the right.

The timing of the radiofrequency pulses that are applied in the MRI machine will be different depending on which image type is being collected.
Diffusion Tensor images
These images depict the white matter tracts in the brain. Diffusion tensor MRI measures the diffusion of water molecules over white matter, which is faster along axons than perpendicular to them. This results in an image of brightly-colored white matter and dark gray matter and cerebrospinal fluid. The color of an area in diffusion tensor images indicates the direction of water molecule movement, and thus the direction of axonal connections. Green indicates diffusion in an anterior/posterior direction, red in a left/right direction, and blue in a superior/inferior direction. These images are used in research to examine white matter integrity and myelination, and are used by doctors to diagnose white matter disorders and assess fiber tract damage from a stroke. The sequence of radiofrequency pulses applied during diffusion tensor image acquisition is completely different from those used to collect T1- or T2-weighted images.

The picture below shows an axial diffusion tensor color map. Brighter areas indicate greater cohesiveness of water molecule movement and thus stronger axonal connections. Diffusion tensor MRI pictures are considered by many to be the “prettiest” type of structural MRI image.