Physiology of the BOLD signal and MR Image Acquisition

19.8.2021 Kerttu Seppälä

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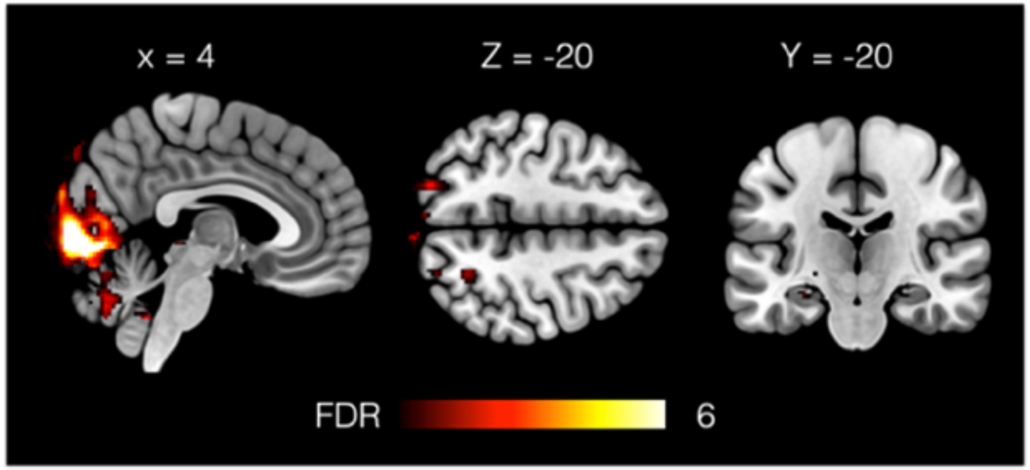
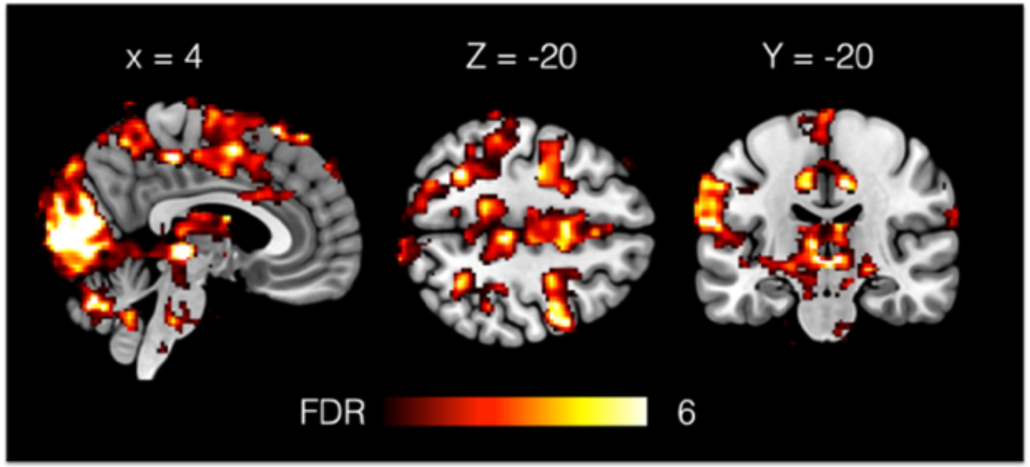
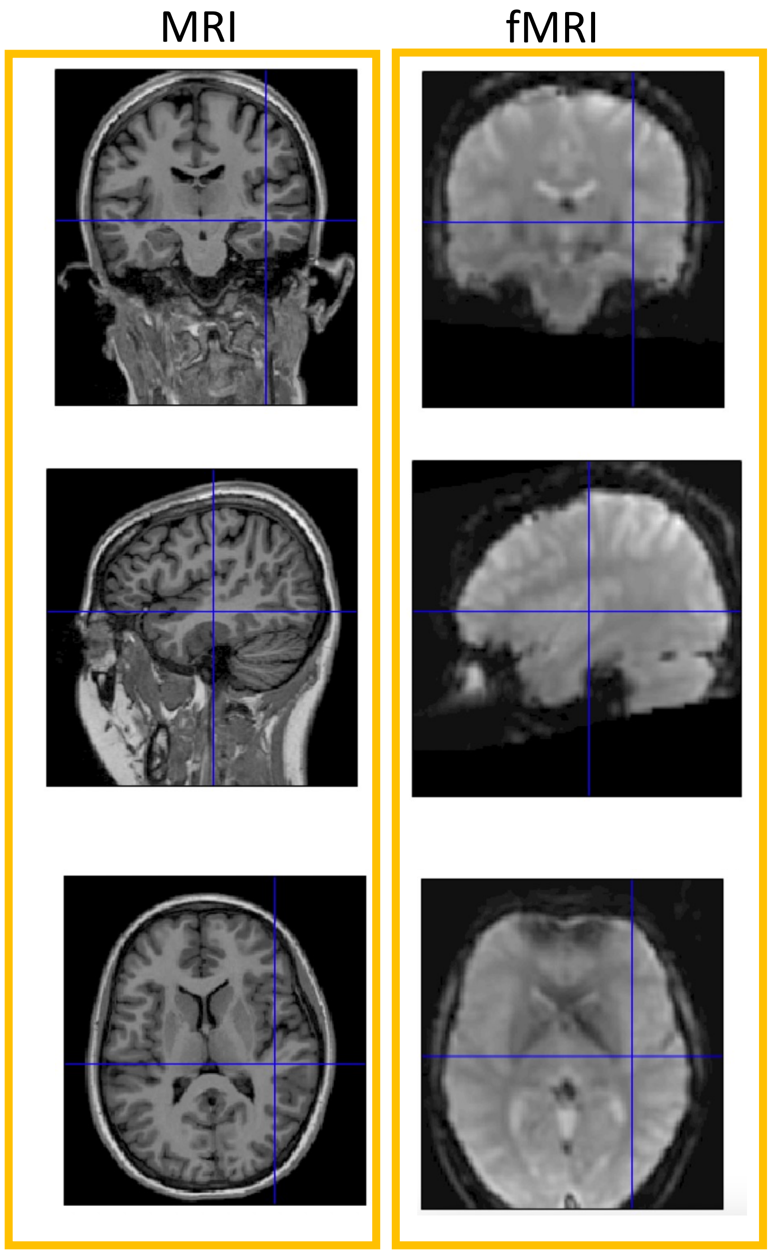
What is MRI?



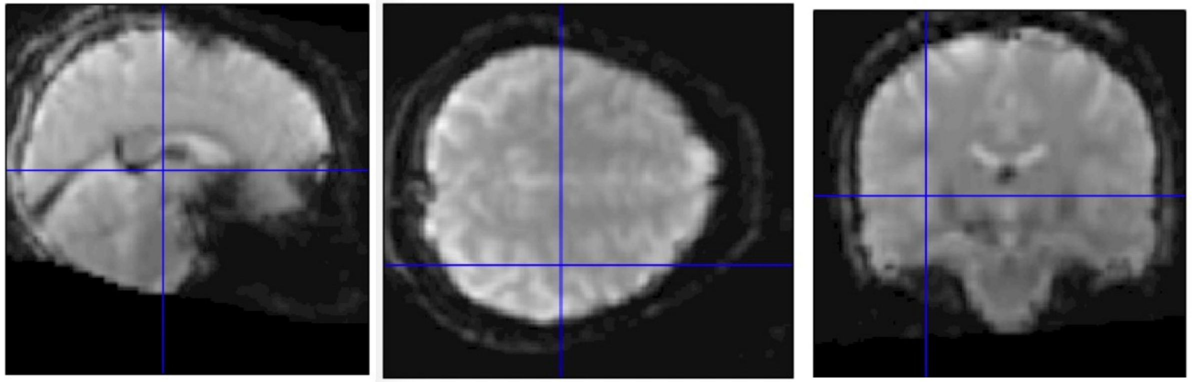


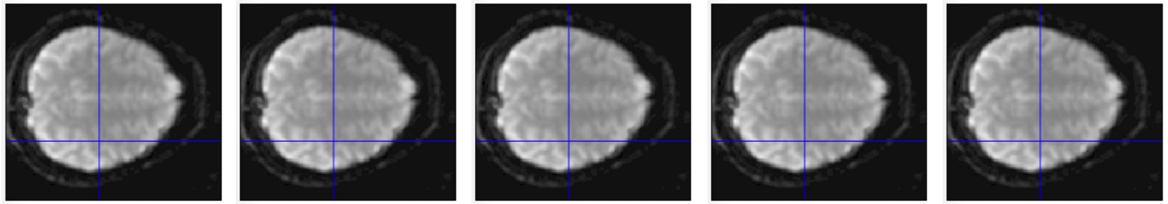
What is MRI and fMRI?

- Images taken with MRI scanner (Magnetic Resonanse Imaging)
- **Anatomical MRI:** anatomical image gives structure (but they cannot reveal short-term physiological changes)
- **fMRI:** functional images
  - measure changes in subjects' brains function while they are focusing on a task in MRI scanner or try not to do anything
  - Purpose
    - 1) fiding specific part of the brain where mental process happens
    - 2) patterns of brain activation associated with mental processe
  - signal based on rapid changes in blood oxygenation over time on specific areas
    - the signal is coming from nuclear level, fMRI measurements are not interfering with neuronal firing or blood flow



Raw fMRI data, 1 volume

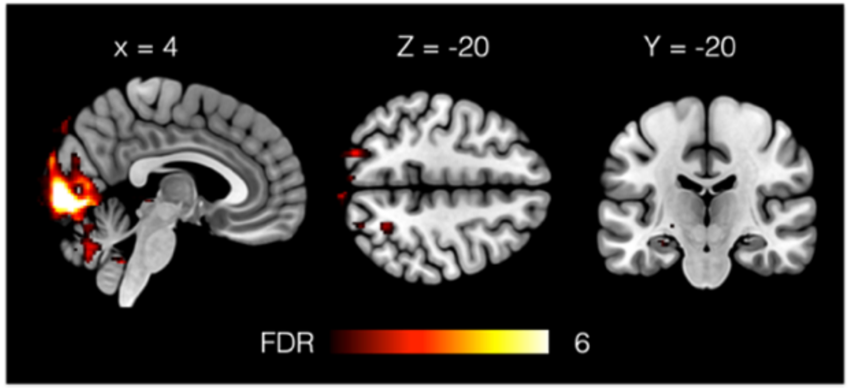


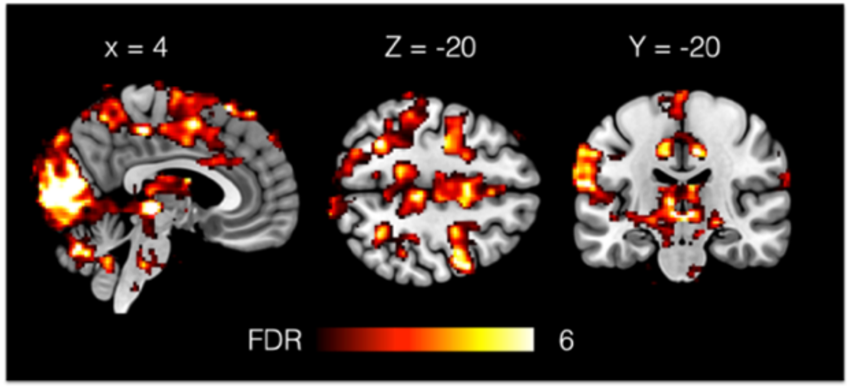


Collect enough volumes over time

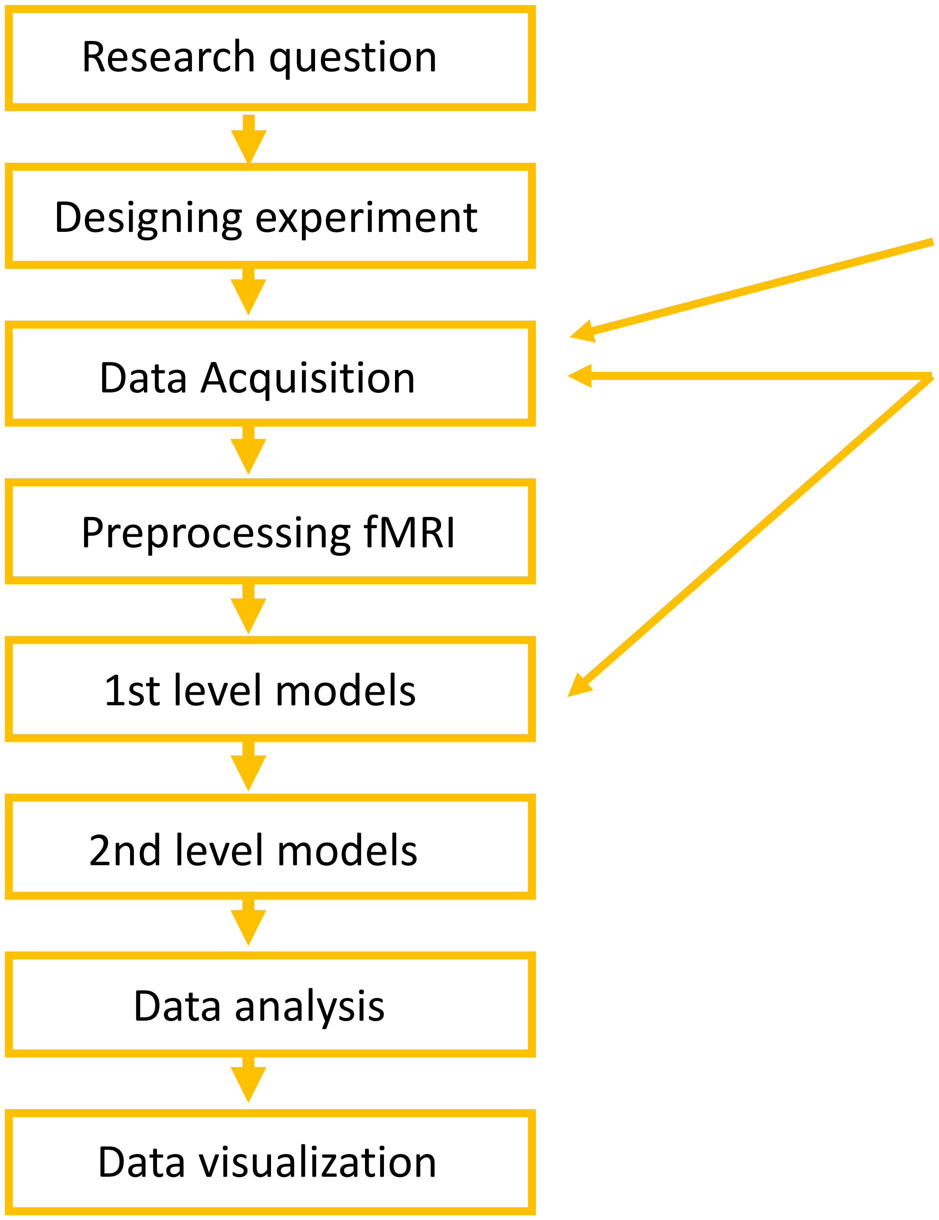
Preprocessing
+ statistics

Beautifull fMRI images



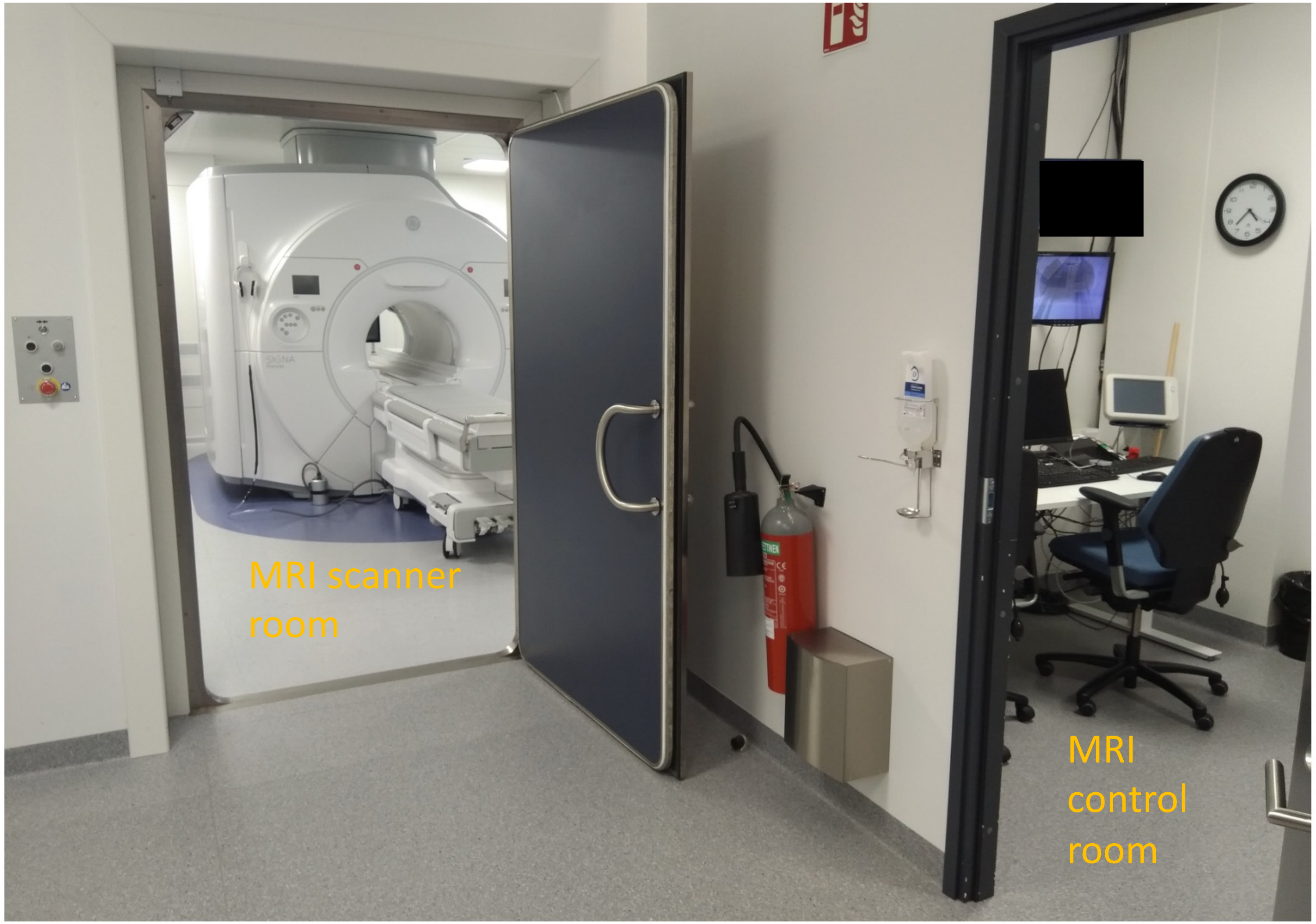


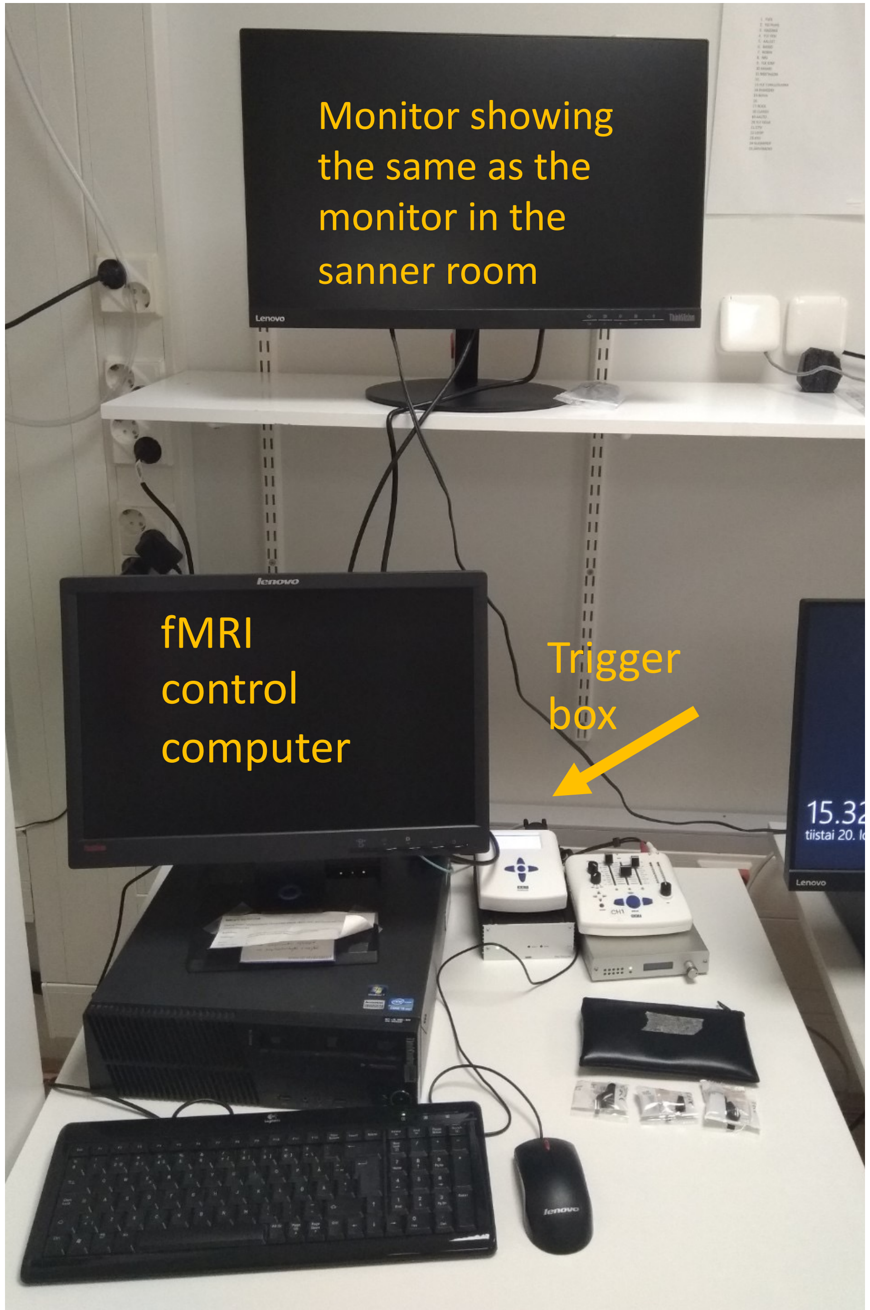
https://fi.wikipedia.org/wiki/Henkil%C3%B6kohtainen_tietokone



8:00–9:00	Physiology of the BOLD signal and image acquisition
9:00–9:45	GLM for fMRI analysis
9:45–10:00	Coffee break
10:00–11:00	Experimental designs for fMRI
11:00–12:00	Preprocessing with fMRIprep
12:00–13:00	Lunch break
13:00–14:00	First level models
14:00–15:00	Second level models
14:45–15:00	Coffee break
15:00–16:00	Data visualization

How to collect data?


MRI scanner room
MRI control room


Monitor showing the same as the monitor in the sanner room
fMRI control computer
Trigger box

Siemens MAGNETOM Sola 1.5 T

https://www.siemens-healthineers.com

Siemens MAGNETOM Vida 3T

Philips Ingenia 1.5 T

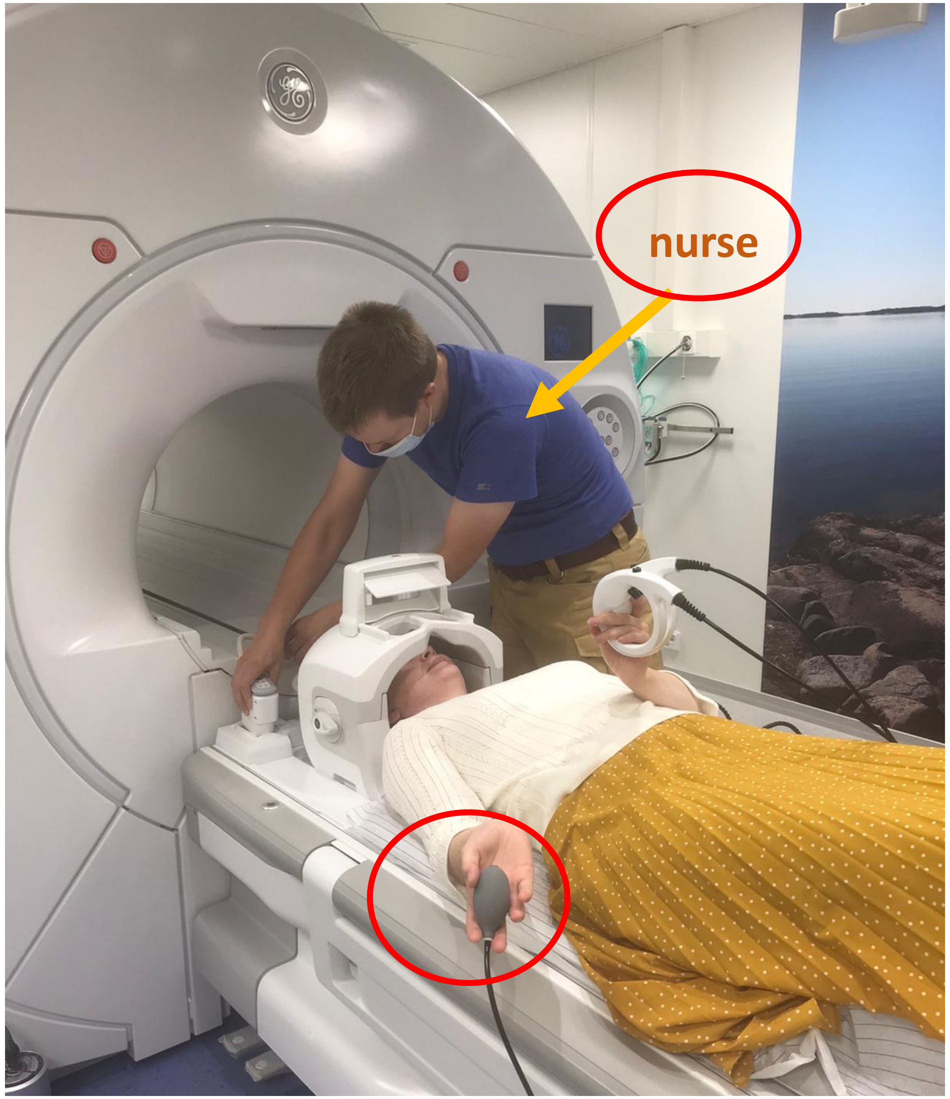
https://www.philips.fi/

Philips Ingenia 3T

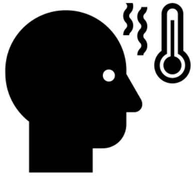
GE SIGNA 1.5 T

www.gehealthcare.com/products/magnetic-resonance-imaging/

GE SIGNA 3T



While scanning:



- Noise → double ear protection
- Claustrophobia → communicate
- SAR (specific absorption rate) → no patients with fever
- Careful screening: no tattoos, implants, ear rings, etc. In the scanner.

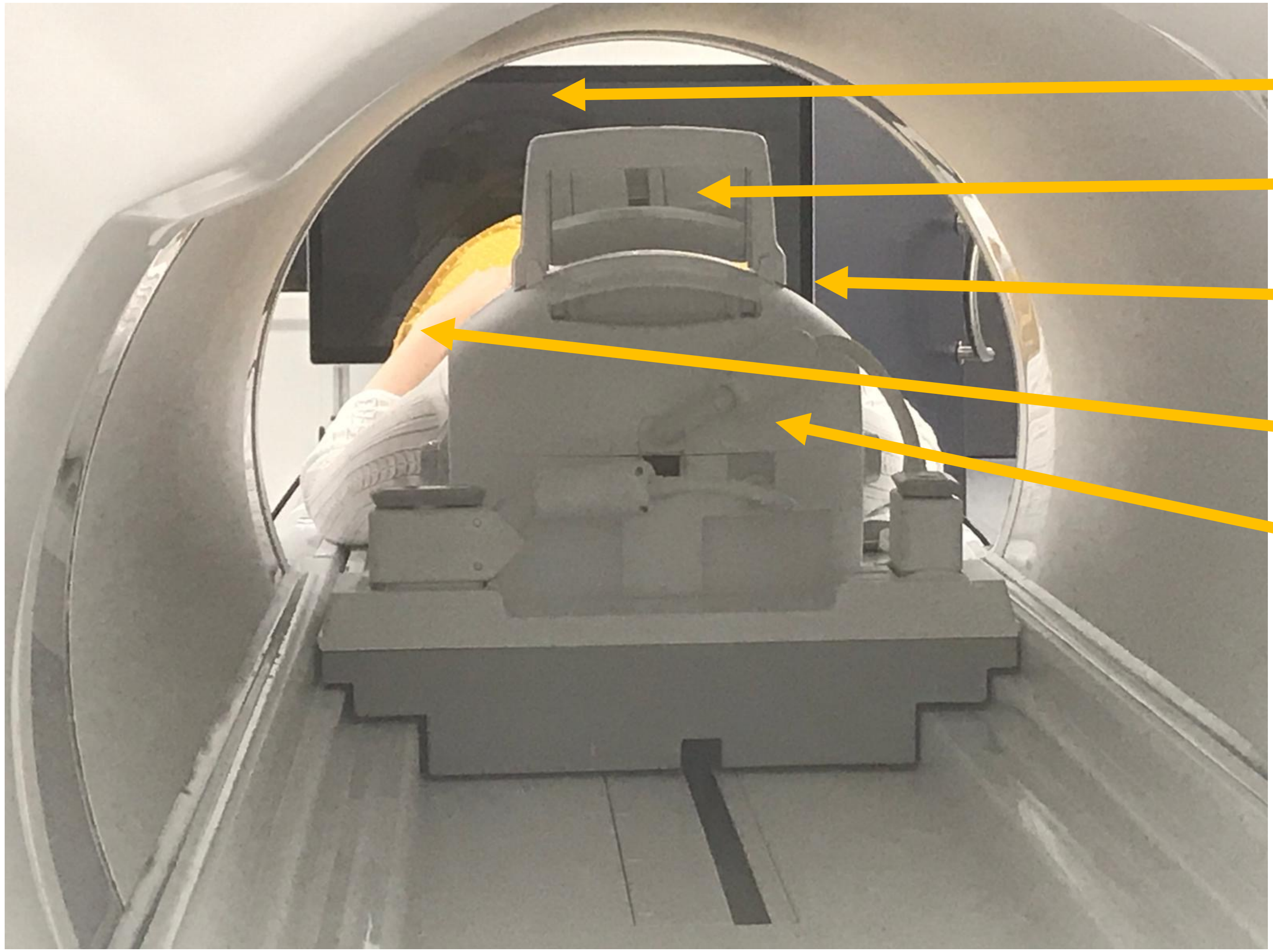
Prepare the subject on the table
Some sites ask the subjects to change clothes, some not, please follow the rules on your own laboratory

Place the subject into the scanner

Important: make the subject feel comfortable

Double hearing protection must be

Extra super important: the subject cannot move! There are selection of different pillows to gently prevent subjects' head from moving



Nice and comfortable positioning, the subject is ready to start the task

The magnet is always on

https://www.harveynorman.com.au/amable-office-chair-red.html

Safety first! The magnet is always on

https://www.harveynorman.com.au/amable-office-chair-red.html

- 1.5 T is 30 000 times stronger than earth magnetic field

⚠ IMPORTANT INSTRUCTIONS

Before entering the MR environment or MR system room, you must remove all metallic objects including hearing aids, dentures, partial plates, keys, beeper, cell phone, eyeglasses, hair pins, barrettes, jewelry, body piercing jewelry, watch, safety pins, paperclips, money clip, credit cards, bank cards, magnetic strip cards, coins, pens, pocket knife, nail clipper, tools, clothing with metal fasteners, & clothing with metallic threads.

Please consult the MRI Technologist or Radiologist if you have any question or concern BEFORE you enter the MR system room.

True for everyone and everything entering the scanner room

⚠ **WARNING:** Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure (i.e., MRI, MR angiography, functional MRI, MR spectroscopy). Do not enter the MR system room or MR environment if you have any question or concern regarding an implant, device, or object. Consult the MRI Technologist or Radiologist BEFORE entering the MR system room. The MR system magnet is ALWAYS on.

http://www.mrisafety.com/images/PreScrnF.pdf

http://www.mrisafety.com/

Please indicate if you have any of the following:

❐ Yes ❐ No Aneurysm clip(s)
❐ Yes ❐ No Cardiac pacemaker
❐ Yes ❐ No Implanted cardioverter defibrillator (ICD)
❐ Yes ❐ No Electronic implant or device
❐ Yes ❐ No Magnetically-activated implant or device
❐ Yes ❐ No Neurostimulation system
❐ Yes ❐ No Spinal cord stimulator
❐ Yes ❐ No Internal electrodes or wires
❐ Yes ❐ No Bone growth/bone fusion stimulator
❐ Yes ❐ No Cochlear, otologic, or other ear implant
❐ Yes ❐ No Insulin or other infusion pump
❐ Yes ❐ No Implanted drug infusion device
❐ Yes ❐ No Any type of prosthesis (eye, penile, etc.)
❐ Yes ❐ No Heart valve prosthesis
❐ Yes ❐ No Eyelid spring or wire
❐ Yes ❐ No Artificial or prosthetic limb
❐ Yes ❐ No Metallic stent, filter, or coil
❐ Yes ❐ No Shunt (spinal or intraventricular)
❐ Yes ❐ No Vascular access port and/or catheter
❐ Yes ❐ No Radiation seeds or implants
❐ Yes ❐ No Swan-Ganz or thermodilution catheter
❐ Yes ❐ No Medication patch (Nicotine, Nitroglycerine)
❐ Yes ❐ No Any metallic fragment or foreign body
❐ Yes ❐ No Wire mesh implant
❐ Yes ❐ No Tissue expander (e.g., breast)
❐ Yes ❐ No Surgical staples, clips, or metallic sutures
❐ Yes ❐ No Joint replacement (hip, knee, etc.)
❐ Yes ❐ No Bone/joint pin, screw, nail, wire, plate, etc.
❐ Yes ❐ No IUD, diaphragm, or pessary
❐ Yes ❐ No Are you here for an MRI examination?
❐ Yes ❐ No Dentures or partial plates
❐ Yes ❐ No Tattoo or permanent makeup
❐ Yes ❐ No Body piercing jewelry
❐ Yes ❐ No Hearing aid
(Remove before entering MR system room)
❐ Yes ❐ No Other implant ________________________
❐ Yes ❐ No Breathing problem or motion disorder

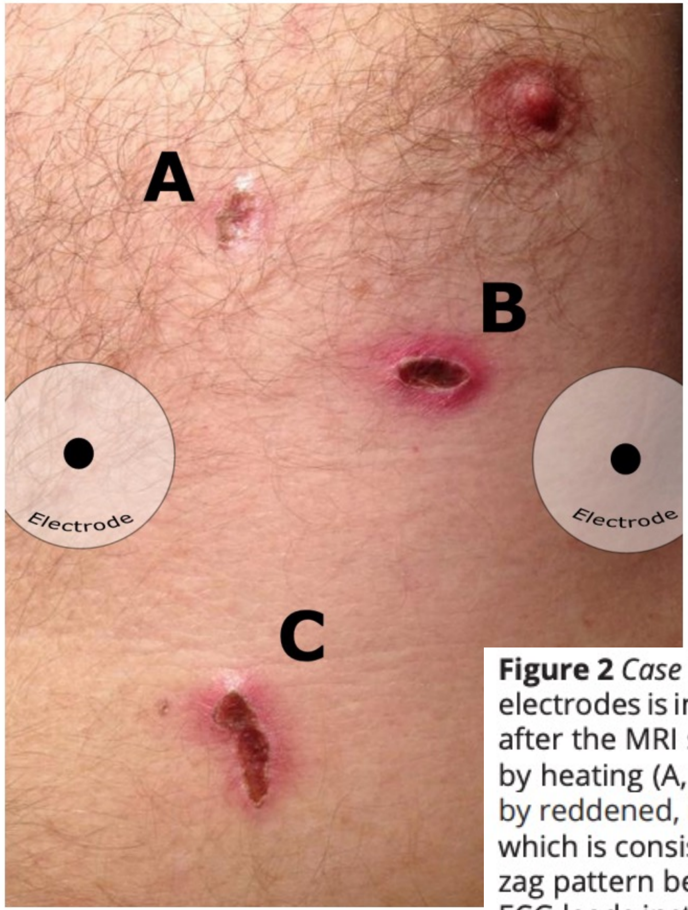


Figure 2 *Case 1:* Image of skin burns caused by ECG leads. Placement of the electrodes is indicated by the graphical overlay. The image is dated one week after the MRI scan and demonstrates three elongated burn lesions caused by heating (A, B & C). The lesions are covered with crusts and surrounded by reddened, inflamed skin and are therefore no longer in the acute phase which is consistent with the time of injury. The wounds are oriented in a zig zag pattern between the electrodes, which indicates trauma caused by the ECG leads instead of the ECG electrodes.

Brix et all., J Radiol Imaging, 2016, 1(4):29-32

I attest that the above information is correct to the best of my knowledge. I read and understand the contents of this form and had the opportunity to ask questions regarding the information on this form and regarding the MR procedure that I am about to undergo.

Signature of Person Completing Form: ____ Date _____/_____/_____
Signature

www.mrisafety.com/images/PreScrnF.pdf

When you know what to do, image acquisition is fun!

Where is the MRI signal coming from?

MR imaging is easy

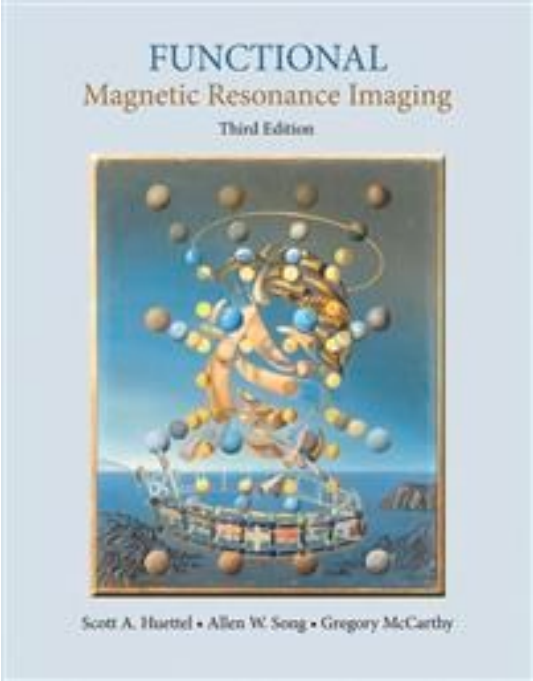
1) **Place the subject** into the MRI scanner in strong magnetic field

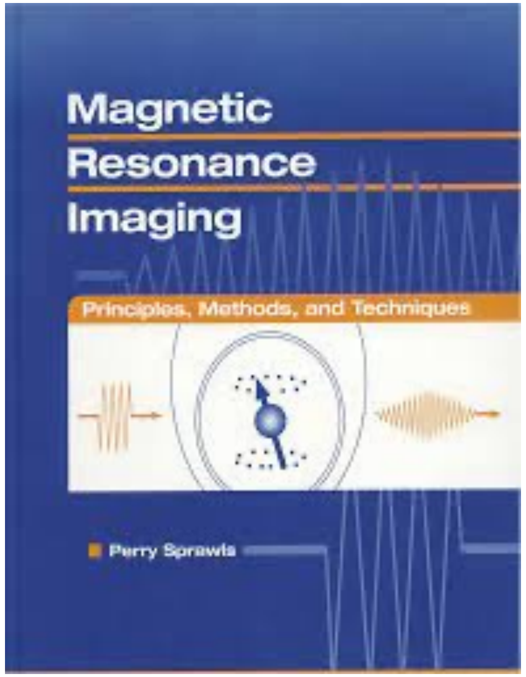
2) Sent a **radio wave in**

3) Turn the **radio wave off**

4) The **subject emits a signal** for head coil to catch

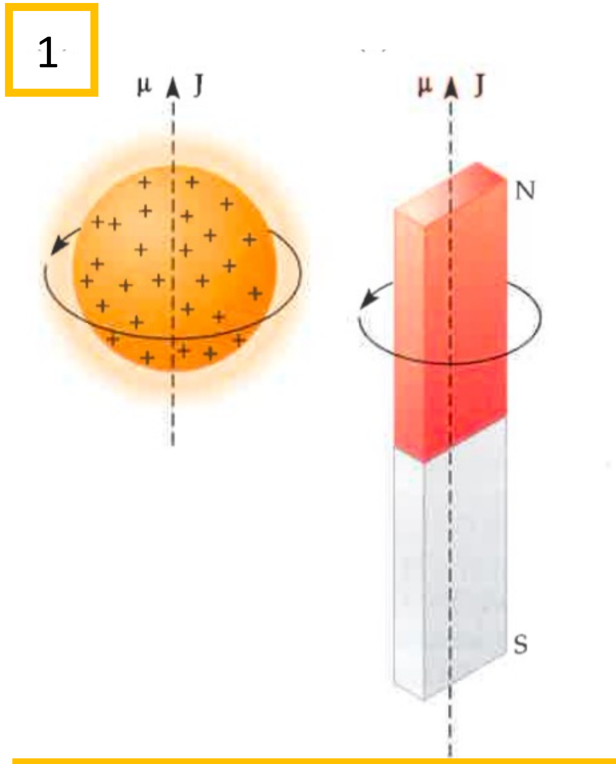
5) **Reconstruct** the image

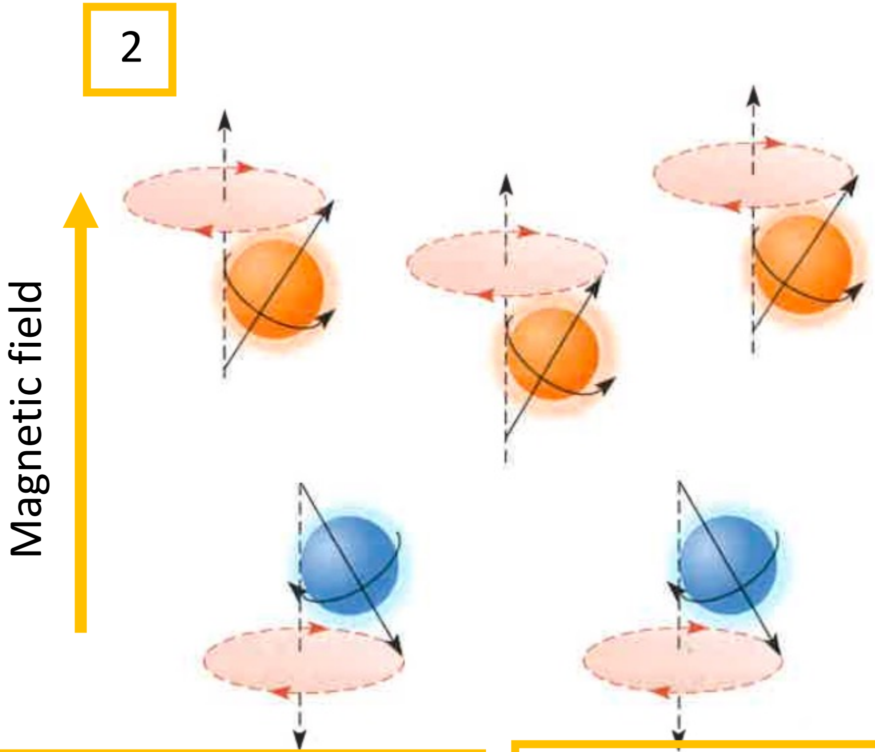


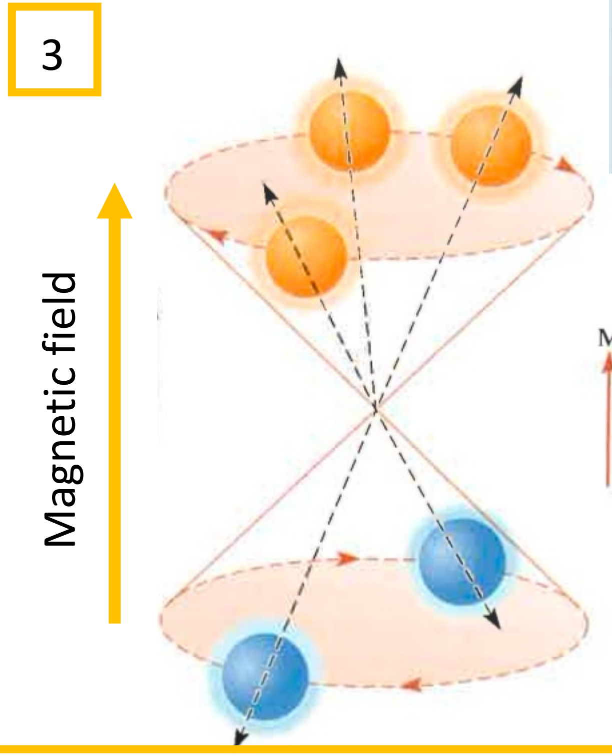


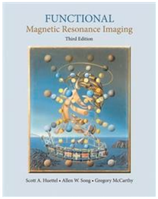
Huettel Scott A., Song Allen W., McCarthy Gregory: Functional Magnetic Resonance Imaging, 2014, Oxford University Press Inc

Sprawls, Magnetic Resonance Imaging, Online Edition, provided by Sprawls Educational Foundation http://www.sprawls.org









1. Spin:

- Intrinsic property
- Proton spinning on their axis

→ 1) because proton has positive charge, spin generates electrical current on it's surface

→ Magnetic moment in external magnetic field (μ)

→ 2) because proton has odd-numbered atomic mass and when spinning → moving mass results in angular momentum (J)

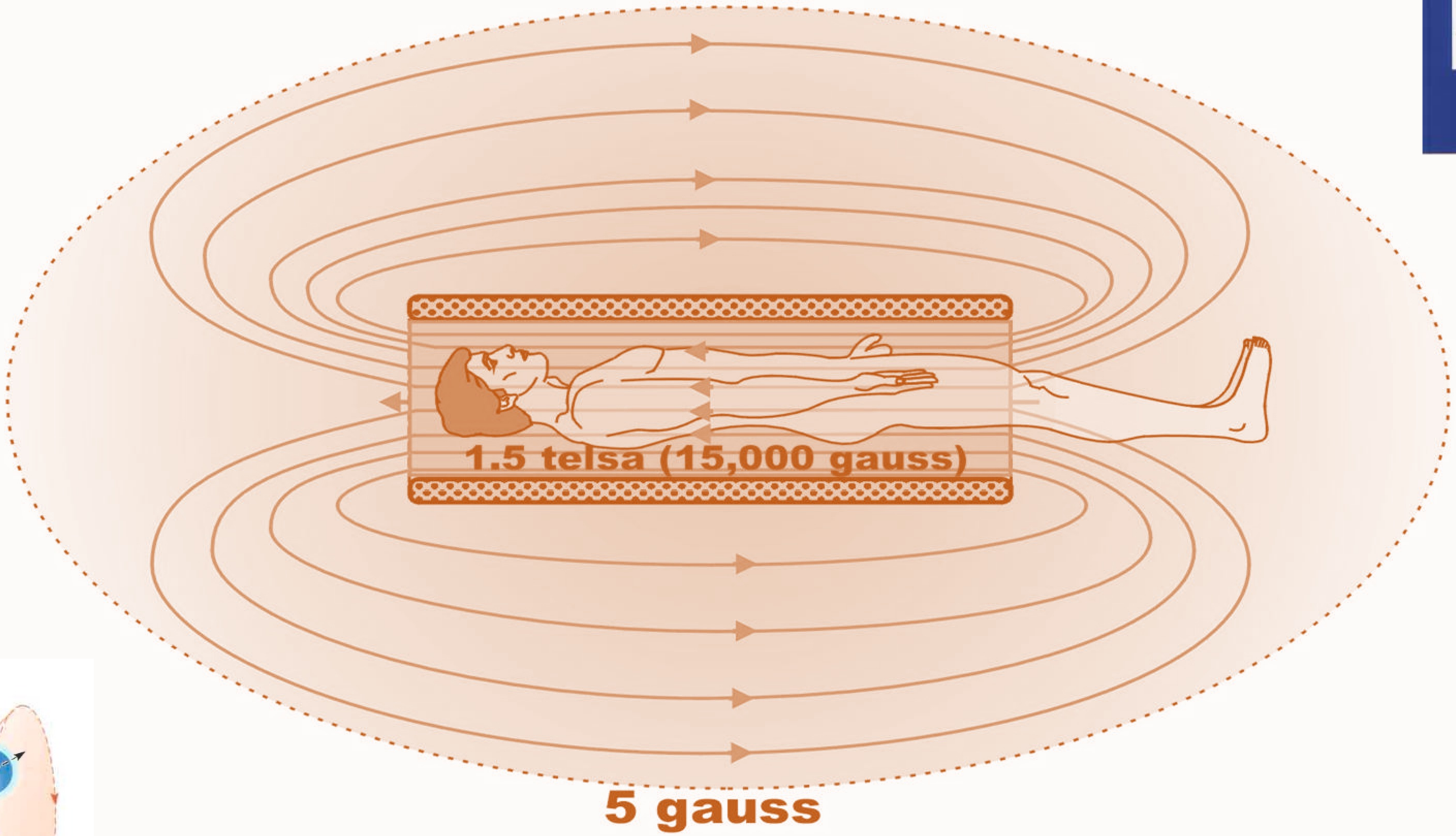
2. Precession

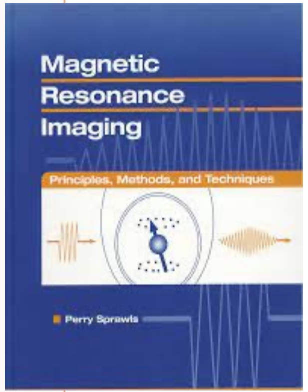
- Spins align within <u>external magnetic field</u>
- Orange spins on lower energy state = parallel state (the amount always more!)
- Blue spins on higher energy state = antiparallel state

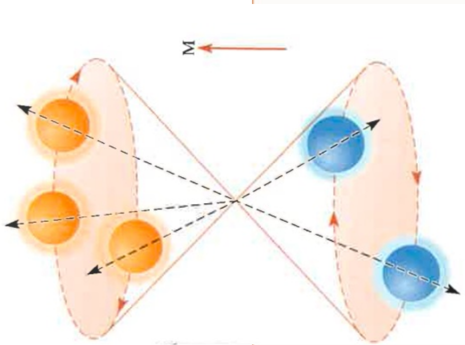
3. Net Magnetization (M):

- Difference between the number of spins in the parallel state and the antiparallel state
- The more spins the the parallel state, the larger the M

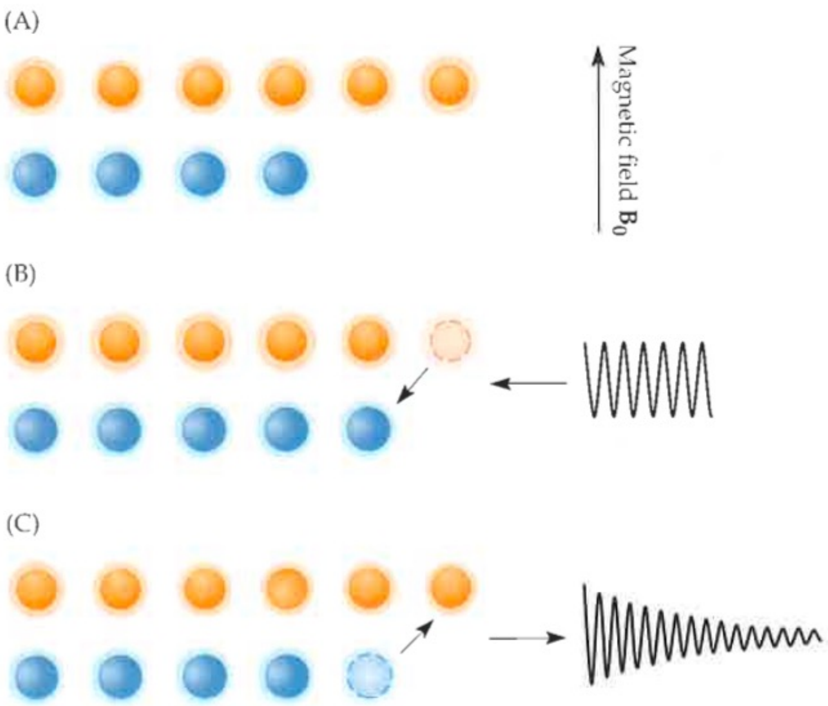
THE MAGNETIC FIELD







Sprawls



A) A neutral situation:

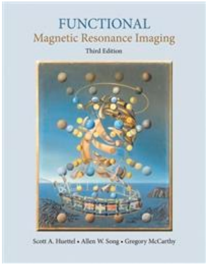
Spins are in external magnetic field, orange lower energy state, blue higher energy state

B) A radio wave comes in:

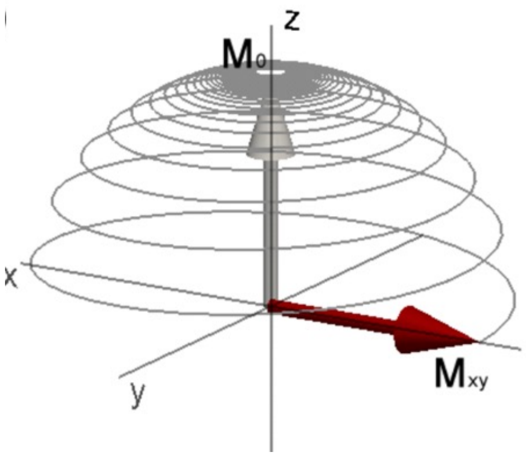
Some of the lower energy state spins jumps to higher energy state (orange spin into blue)

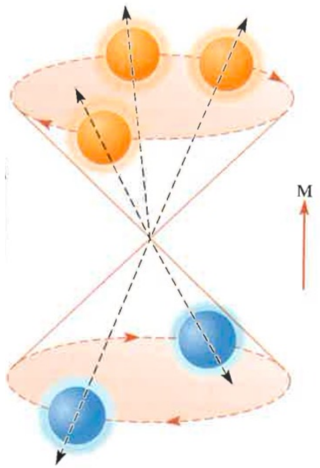
C) Incoming radio wave stops, outcoming starts:

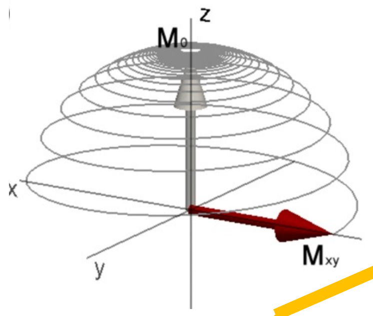
Some of the high-energy state spins return to the lower energy state and release the absorbed energy as a radiofrequency wave with the same frequency as the excitation pulse

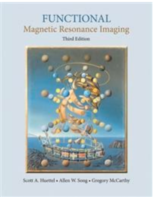


In quantitative way of thinking: 90° excitation pulse tilts the Net magnetization









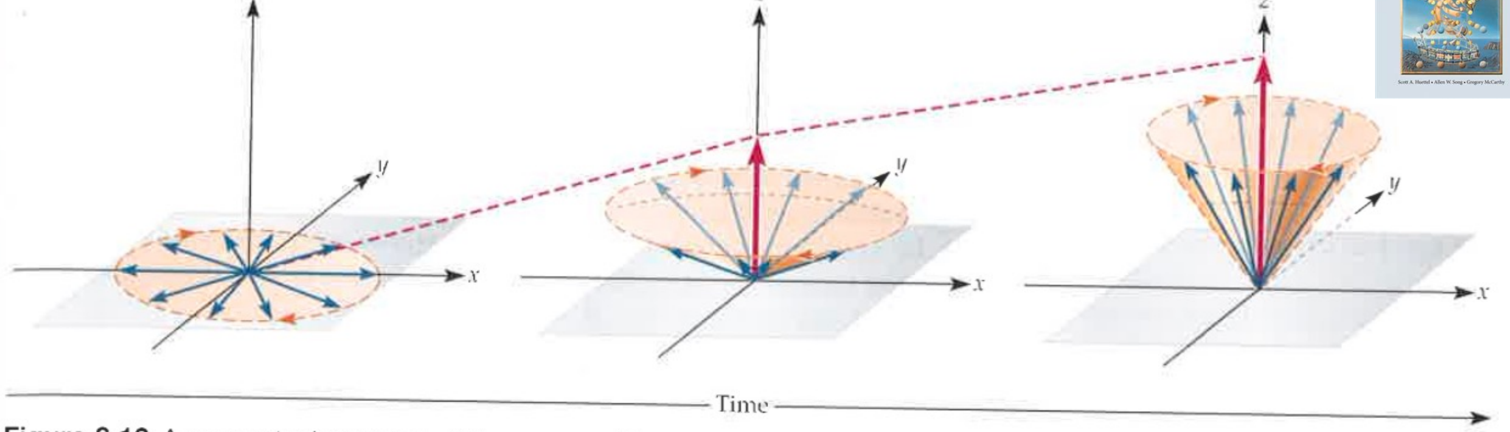


Figure 3.12 A conceptual overview of T_1 recovery. The net magnetization tips into the transverse plane as a result of the absorption of energy by some spins (i.e., those that have changed from low- to high-energy states). Once the excitation pulse ceases, spins begin to release energy back into the surrounding environment. This causes the net magnetization to recover along the longitudinal axis, often returning to near its original amplitude within a few seconds (red dashed line).

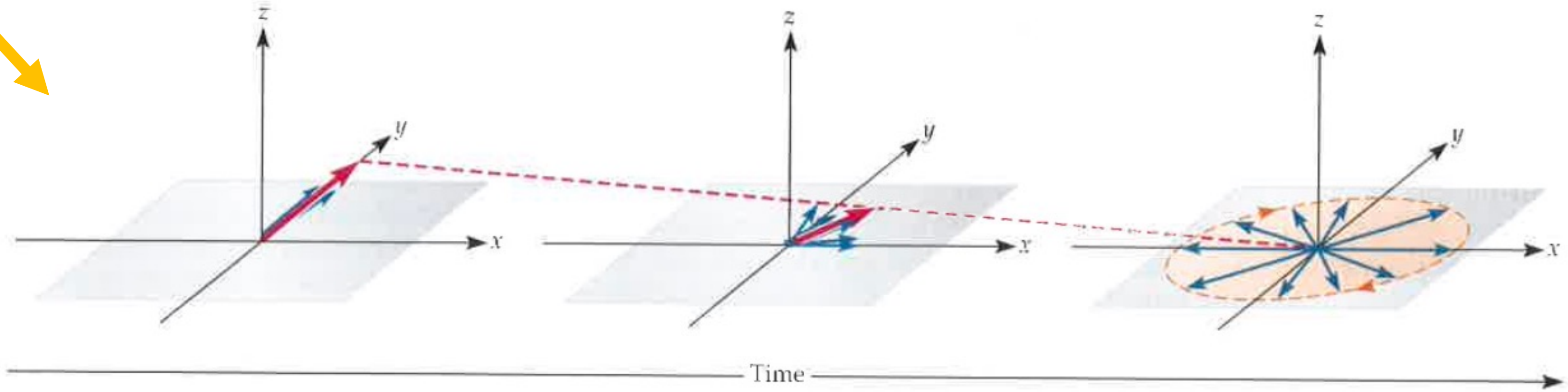
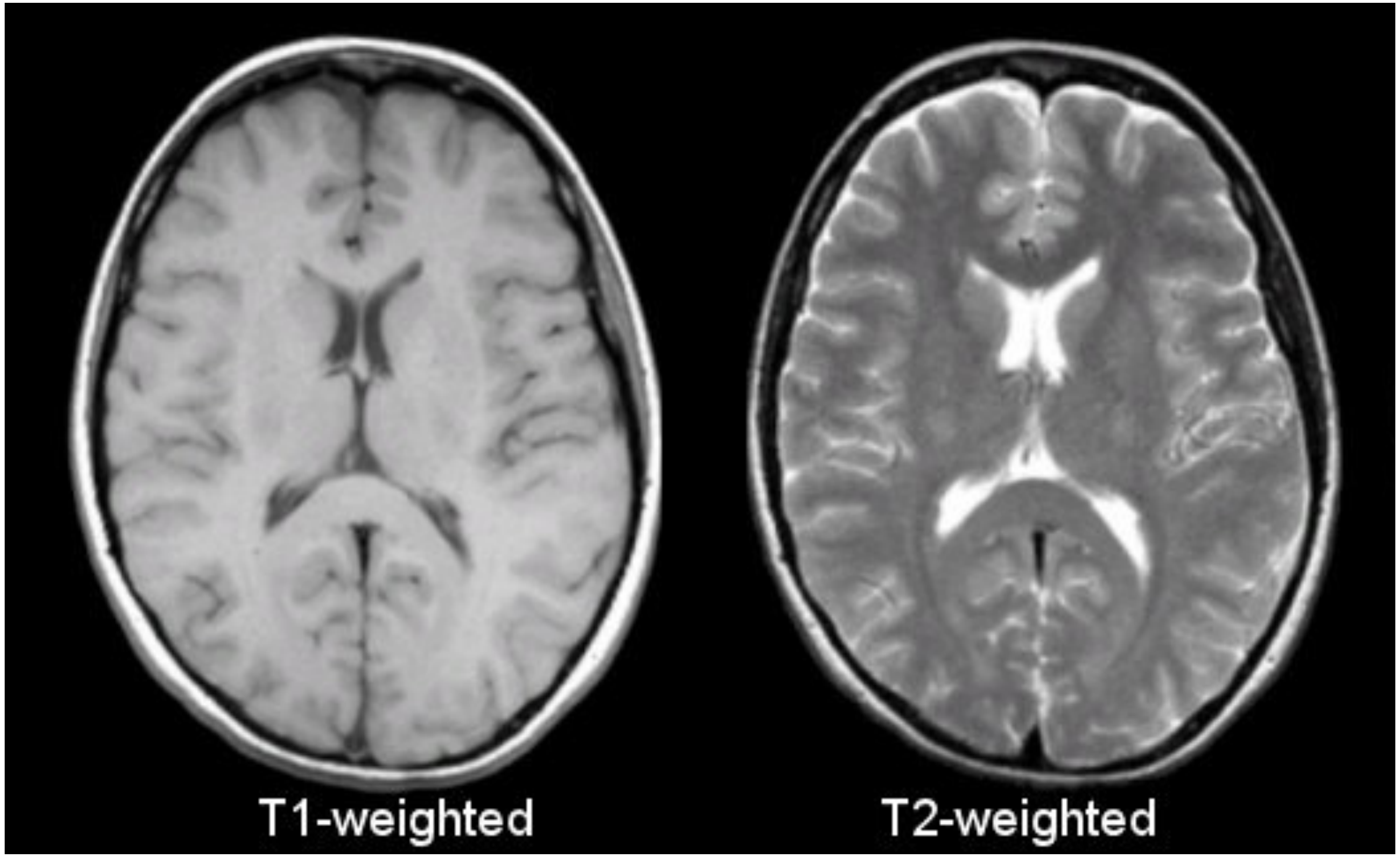


Figure 3.11 A conceptual overview of T_2 decay. After the net magnetization has been tipped into the transverse plane, it rapidly decays because of a loss of coherence among the spins. For most types of tissue, the net magnetization available to generate the MR signal decays to near zero within a few hundred milliseconds (red dashed line).

Contrast

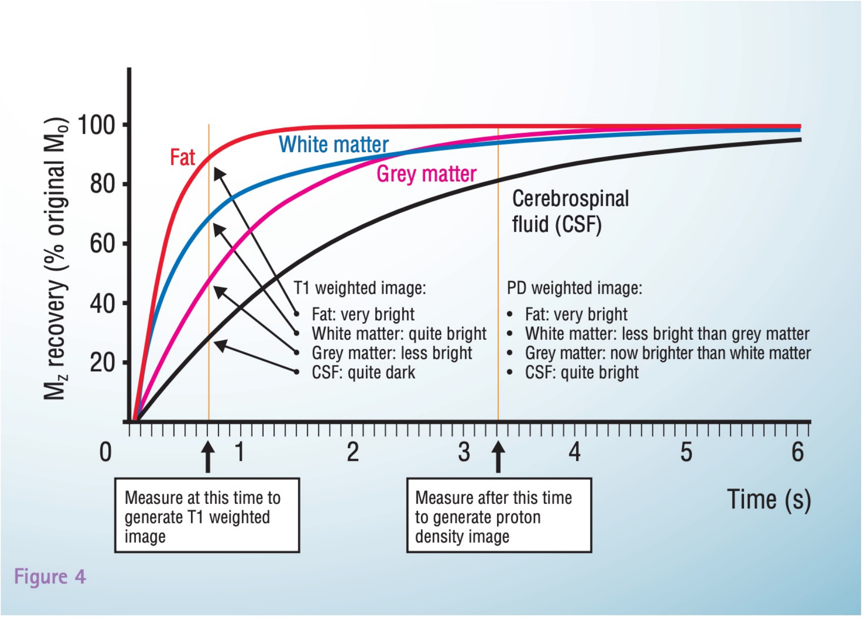
Contrast in medical imaging:

The intensity difference between different quantities (tissues)

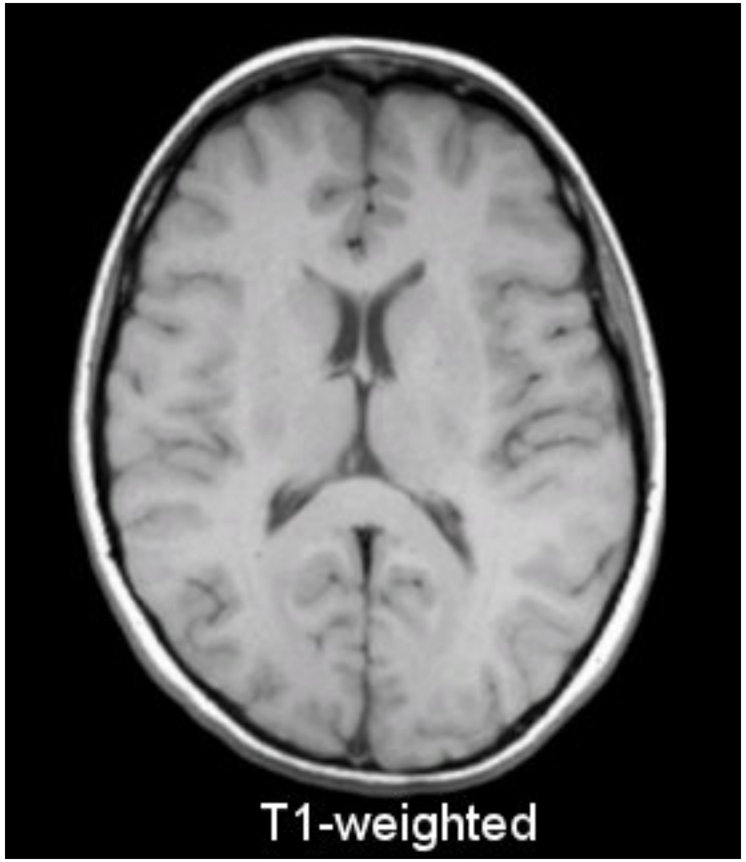


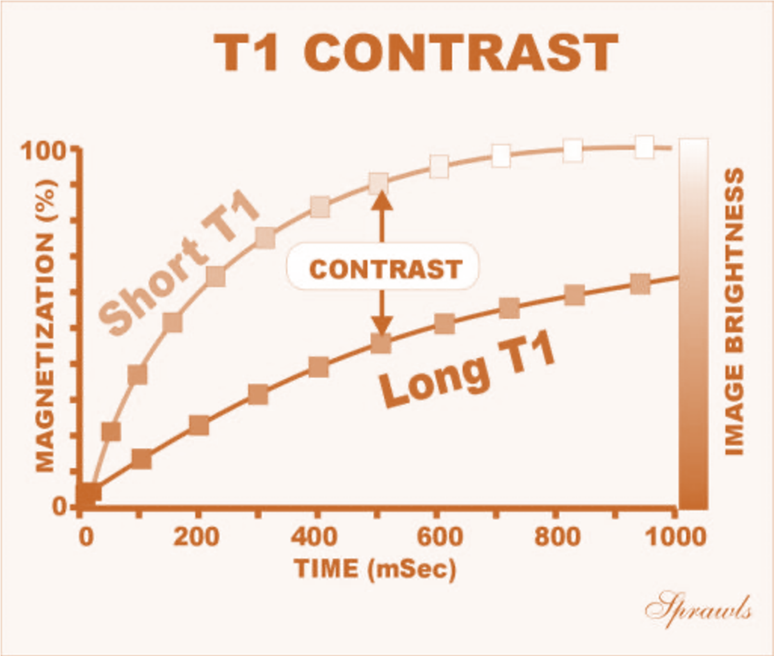
Case Western Reserve University
Magnetic Resonance Imaging (MRI) of the Brain and Spine: Basics
https://case.edu/med/neurology/NR/MRI%20Basics.htm

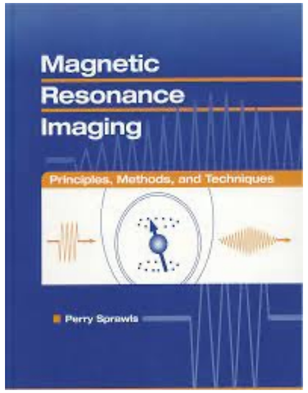
T1 relaxation and contrast



Farrall, Magnetic Resonance Imaging, Practical Neurology 2006; 6: 318-325







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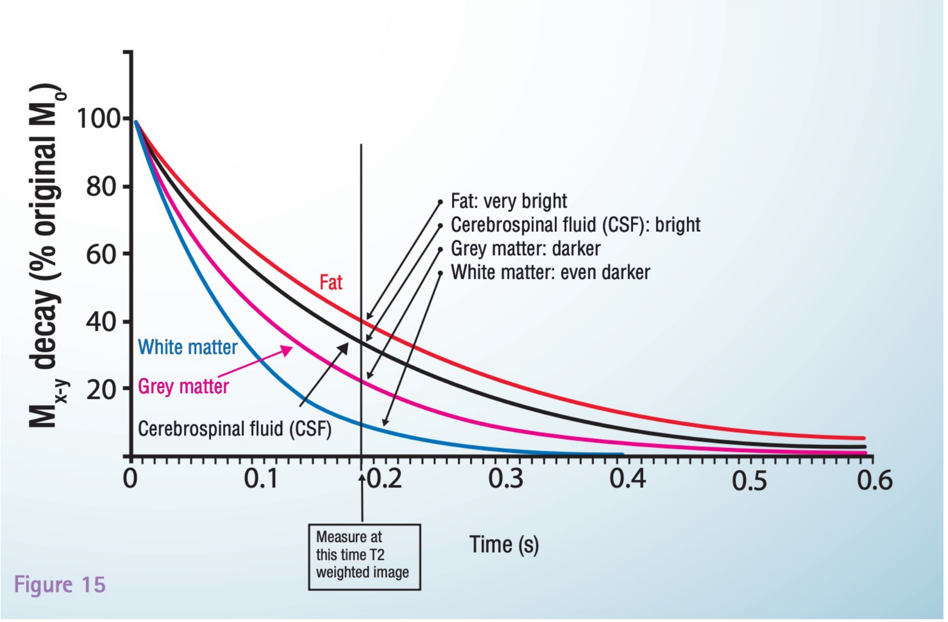
https://case.edu/med/neurology/NR/MRI%20Basics.htm

T2 relaxation and contrast



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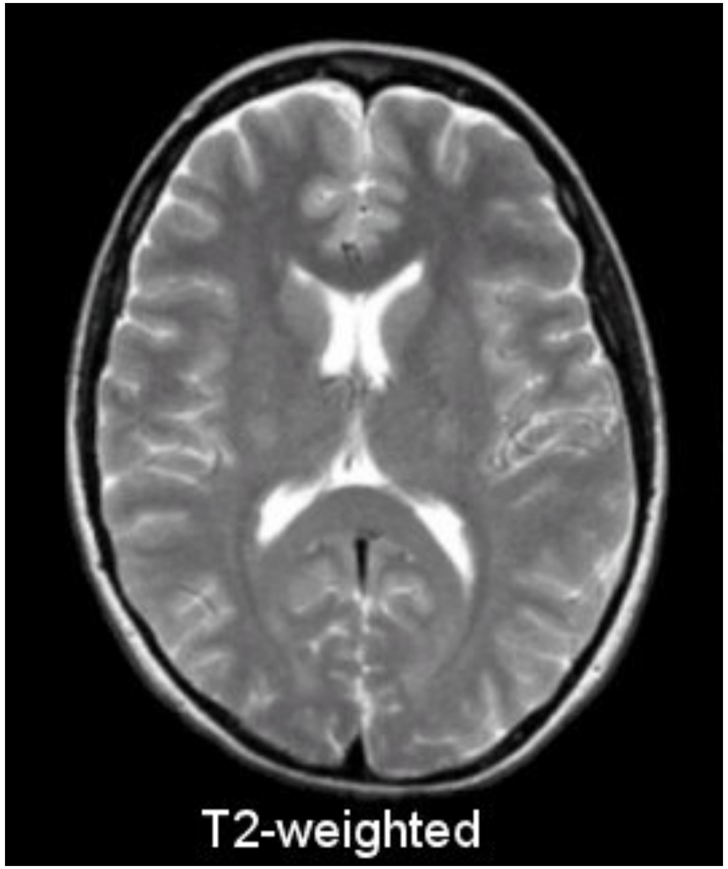

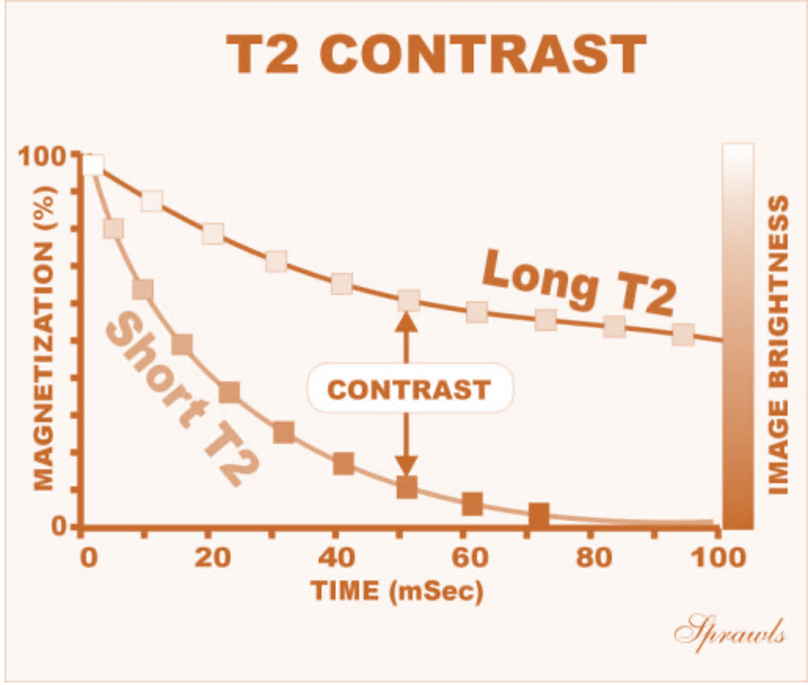

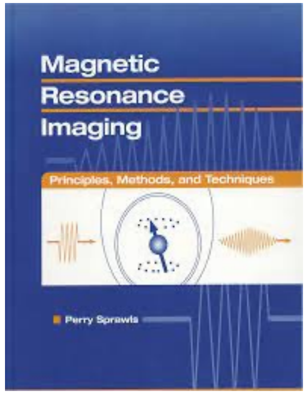

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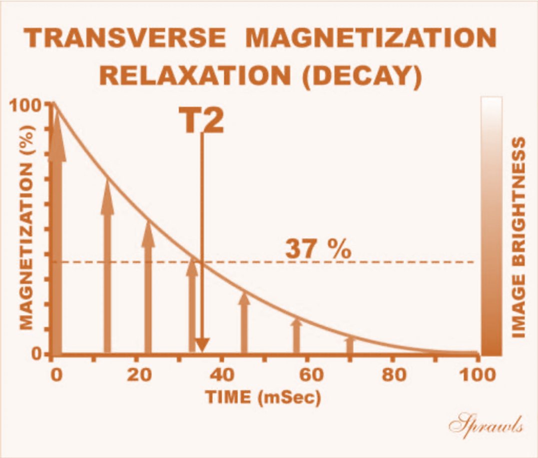
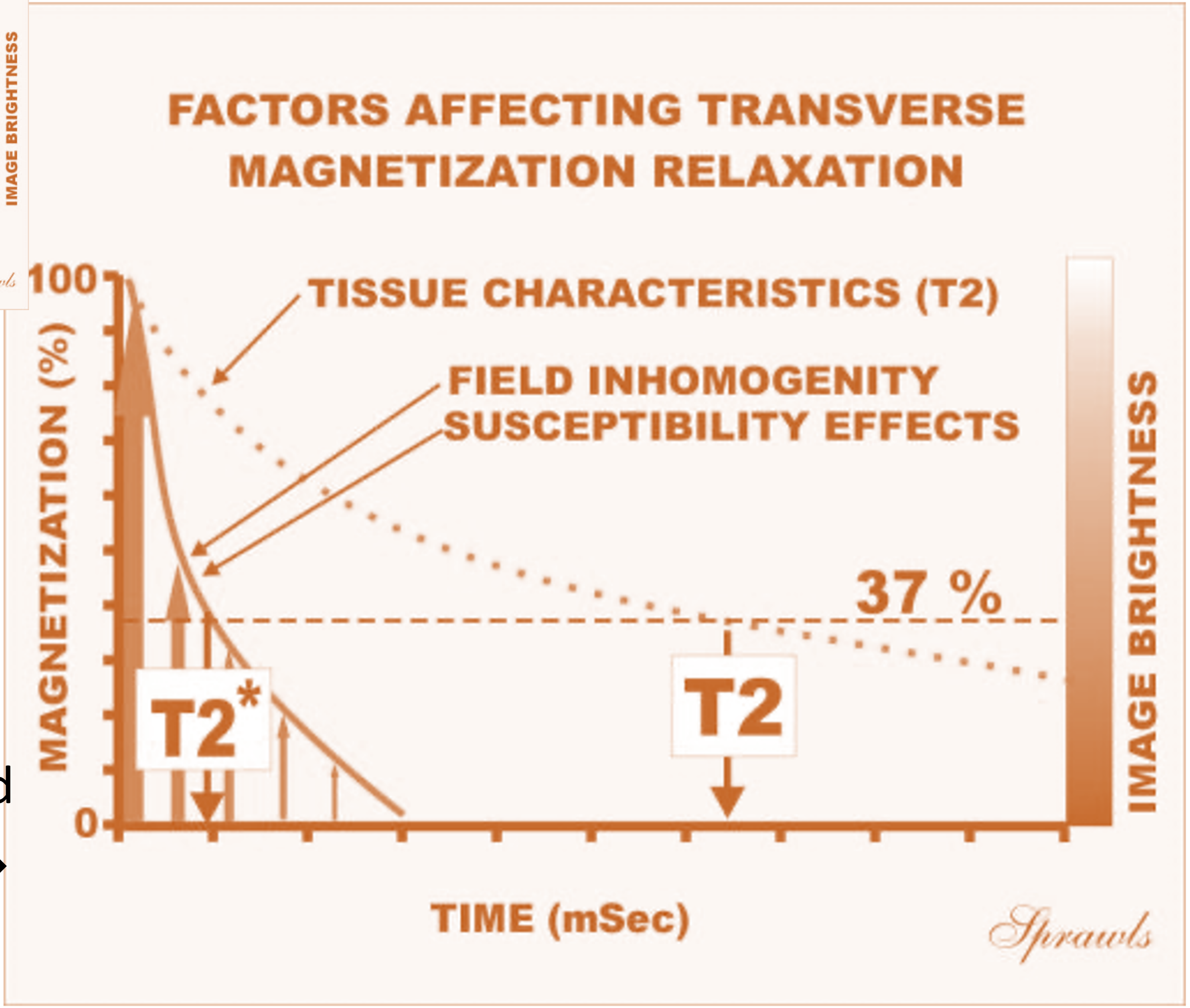
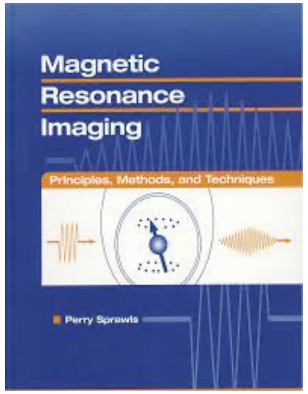
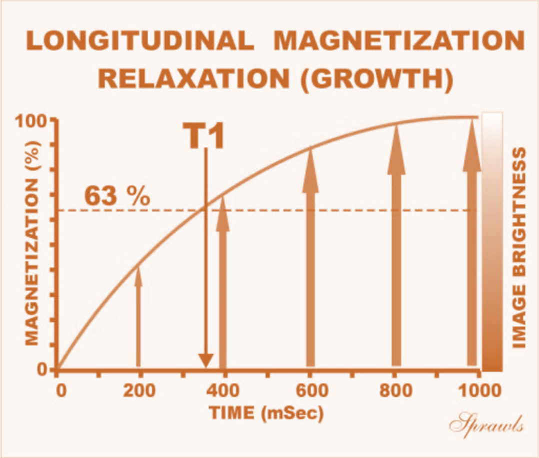
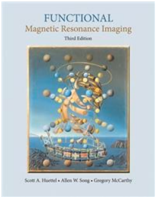








Local magnetic field inhomogeneities → **T2* contrast** (even faster decay)



Quantitative path

$$\mu = \gamma J$$

$$\frac{d\mu}{dt} = \gamma(\mu \times B_0)$$

$$M = \frac{\Delta E}{2k_B T} n\mu_z z$$

$$\omega_{rot} = \gamma B_{1eff} = \gamma B_1 \qquad emf = -i\omega_0 \int_v \overline{B_1} \cdot M(t)dv$$

$$\frac{dM}{dt} = \gamma M \times B + \frac{1}{T_1}(M_0 - M_z) - \frac{1}{T_2}(M_x + M_y)$$