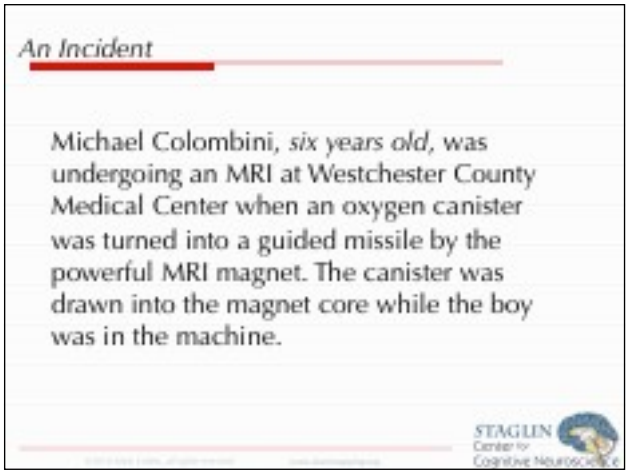
The purpose of this video and slide set is to alert all personnel working at the Staglin Center for Cognitive Neuroscience to the safety hazards associated with the MR scanner and to offer a set of guidelines for the safe use of the equipment.

We have drawn on a variety of sources to create this instructional video, including materials developed by the MRI manufacturers, and by several MRI safety organizations. Most of these contents are common to all MRI devices, though some are quite specific to the Staglin Center environment.



MRI is generally considered a safe modality. However, misuse may cause serious damage to the instrument. More importantly, there have been multiple deaths and injuries at MRI centers. Working in the restricted area without training places you, your subjects and the operation of the center overall at risk.

Staglin Center Safety Certification

- Instructional Material
- Written Exam
- Practical Exam

- Renewed Annually

No one should ever enter the MRI magnet room unaccompanied by a safety trained individual. Becoming safety certified requires several steps. You should first learn about, and understand, the special and often non-intuitive risks of MRI. This video will help to provide that information, and is the first step in the certification process. Second, you must take a written test based on the materials in this video. Finally, you must demonstrate your ability to work safely in the lab during a practical exam.

Certification to use the equipment must be renewed annually.

Video Overview

- Principles of Operation
  - Three Electromagnetic Fields
- Instrument Risks
- External Device Risks
- Patient/Subject Risks
- Consenting
- Minimizing Exposure
- Human Factors
- Reporting
- Resources

The following are covered in this video:

First: Learning a bit about the principles by which the MRI operates will help you to understand the sources of risk.

This video offers instruction in the hazards associated with the MRI itself.

We then consider the dangers created by external devices brought into the environment, that are the cause of the majority of patient safety incidents.

Some people, especially children, ill and elderly patients, offer

Short Term Bioeffects

No scientifically confirmed harmful short-term bioeffects related to exposures to strong static magnetic fields

At 3 Tesla, reported effects include:

- Vertigo
- Headaches
- Metallic Taste
- Nausea

To date, there have been NO controlled studies that have shown any evidence of harmful bioeffects from exposure to the magnetic fields typical of human imaging systems. For this reason, the FDA has labeled exposure to static – non-varying – magnetism a non-significant risk at field strengths below 8 Tesla for adults and below 4 Tesla for children.

Safety

Stored Energy Equivalent to **2 kg** of TNT

High field MRI instruments are based on superconducting magnets. Current is injected into wire that is cooled to a few degrees above absolute zero to create a magnetic field.

A 3 Tesla magnet stores over 10 megajoules of energy in this current, equivalent to 2 kg of TNT, or the energy of a fully loaded semi truck traveling at

Although it is possible to shut down a superconducting magnet, under ordinary circumstance it is always energized, even when the computer console is turned off, and even in the event of a power outage. In fact, the only time that a superconducting magnet is NOT on would be at delivery, at removal, or following a catastrophic quench. The MRI magnet is ALWAYS on

An astonishing variety of objects have been pulled into MR systems. Here are

A few chairs (2X);
Some floor buffers (apparently a common problem) (2X);
A gun that found its way into the instrument (and discharged);
A large rack of equipment;
A walker;

Never attempt to remove objects from the magnet on your own. Doing so is hazardous to yourself, and can cause further damage to the instrument. Pulling out objects like those shown here would very likely require a winch or other mechanical removal equipment.

If a device should come apart in the process of trying to remove it

There are now standards for labeling of devices used in the vicinity of MR systems. The ASTM has created three classes: MR Safe, MR Conditional and MR Unsafe.

MR Safe objects typically are made of plastic, rubber, wood or other non-magnetic and non-metallic materials.

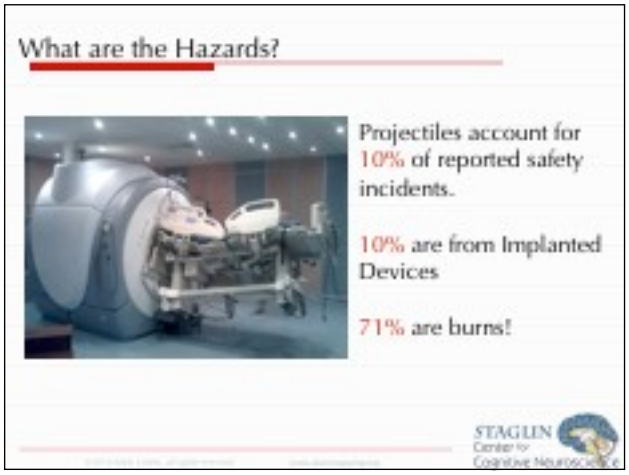
There are certain patient care devices such as wheelchairs and gurneys that may be used safely in the MRI environment.

Under no circumstances should you bring any outside gurneys or wheelchairs into the MRI lab area.

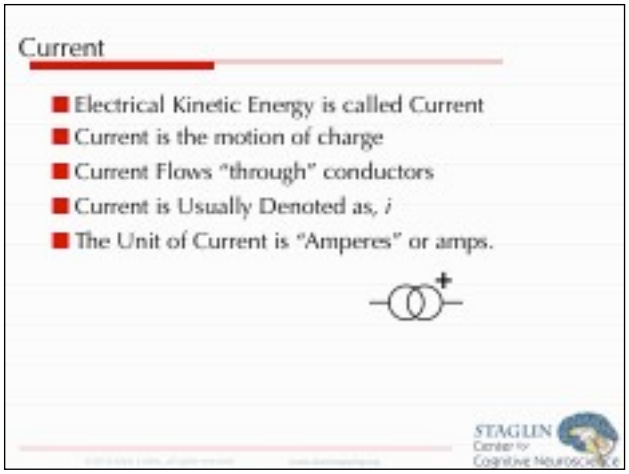
Subjects should be moved to the MR safe

MRI Conditional devices have been tested in the MRI environment under very specific conditions of use, including instrument field strength, location in the room, position on the body, etc... Most MRI fire extinguishers are labeled "Conditional" reflecting the fact that caution is still required in their use. The Staglin center has available an MRI-compatible EEG device that has

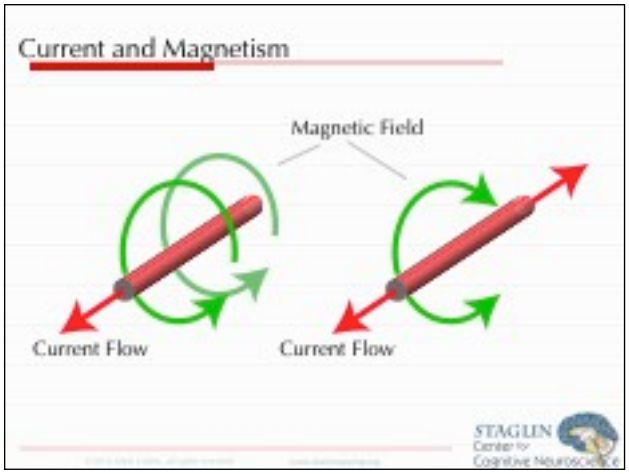
Most devices should be assumed to be **MR Unsafe**, unless specifically labeled otherwise. The MR Unsafe label usually is applied to objects that are intended to be used in an MRI facility but not in the magnet room. **MR Unsafe** labeling is relatively rare, and you should not assume that the lack of such labeling suggests that the devices are safe.



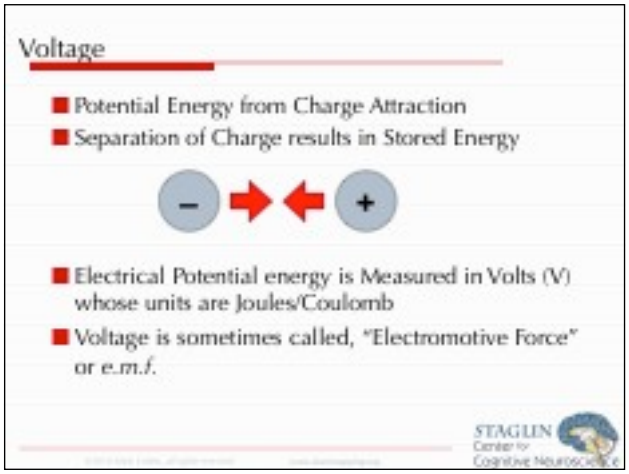
Despite the drama of MRI projectiles and implanted medical devices, these make up together just 20% of the reported incidents.
The overwhelming majority of the real subject and patient harm is in the form of burns. The next section of this video explains why and how such burns occur. We will first introduce some simple electrical concepts.



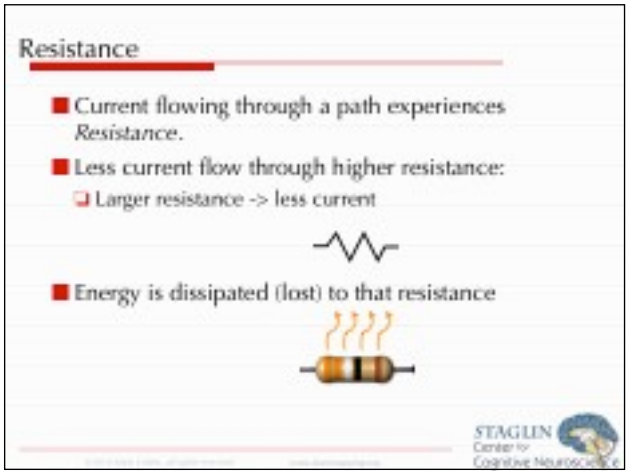
Current refers to the flow of charged particles - usually electrons - through a conductor. Current is a form of kinetic energy. In electrical circuits, current is usually given the symbol, *i*. It is measured in units of Amperes or amps. One amp is a rather large amount of current: enough to light a 100 watt lightbulb or to drive a large pump.



Current and magnetism are related intimately and, through relativistic analysis are reflections of the same phenomenon. In particular, the flow of current through a electrical conductor creates a magnetic field that wraps around the conductor and is proportional to the amount of flowing current. Equivalently, placing a conductor in a time-varying magnetic field creates an

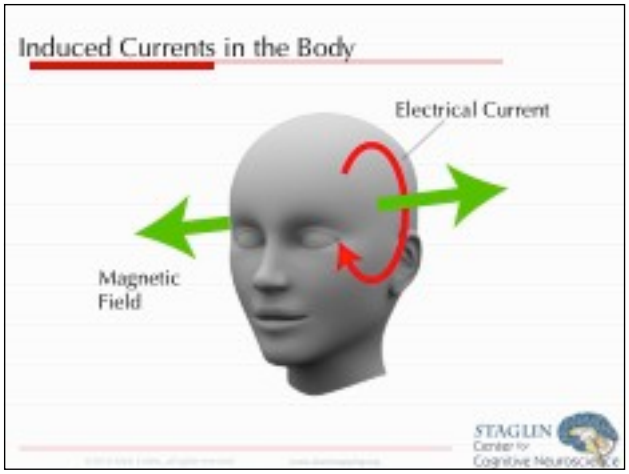


Voltage is a measurement of Potential Energy. Oppositely charged particles are attracted to each other, so that separating electrically charged particles represents stored energy and thus a voltage difference.



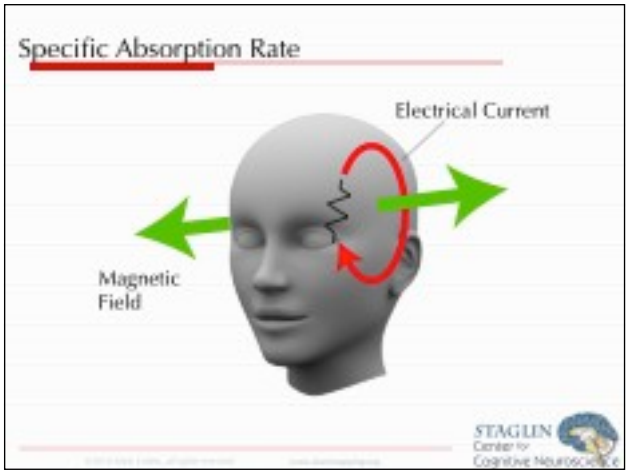
Resistance describes the property, common to most materials, that they impede the flow of electrical current, almost as a small diameter pipe impedes the flow of water within it. As resistance is increased higher voltages are needed to push current through a material.

In circuit diagrams resistors are drawn as a series of jagged lines.

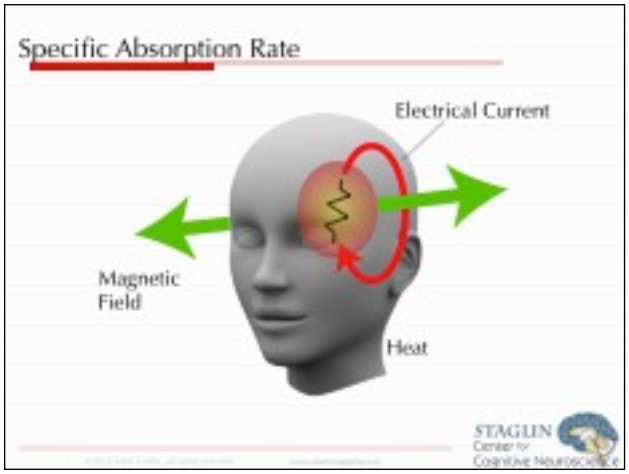


This discussion of current, voltage and resistance is important in understanding the heating that can take place in an MRI instrument.

In order to form images, time varying fields in the form of radio pulses (and gradient pulses) are needed. As these fields pass through the conductive tissues of the body they generate electrical



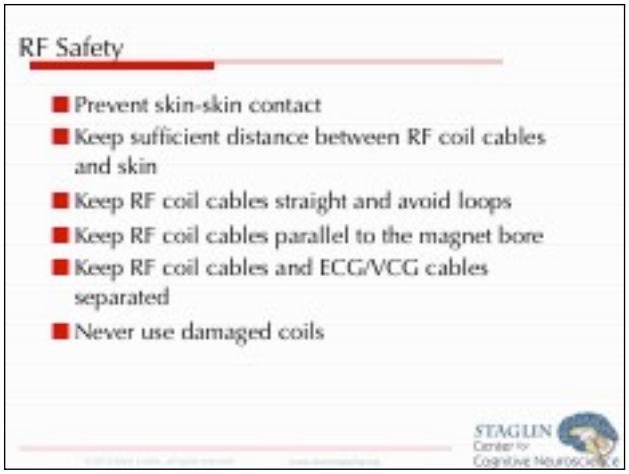
The body tissues are resistive however, so that the circulating current loses energy to the body in the form of heat ...



The rate at which the body absorbs heat energy during scanning is known as the "Specific Absorption Rate" or S.A.R.

S.A.R. is carefully monitored during MR scanning, but for these measurements to be accurate several assumptions must be met. First, the body weight of the subject must be entered correctly, as the allowed dose varies by body weight. Second, the

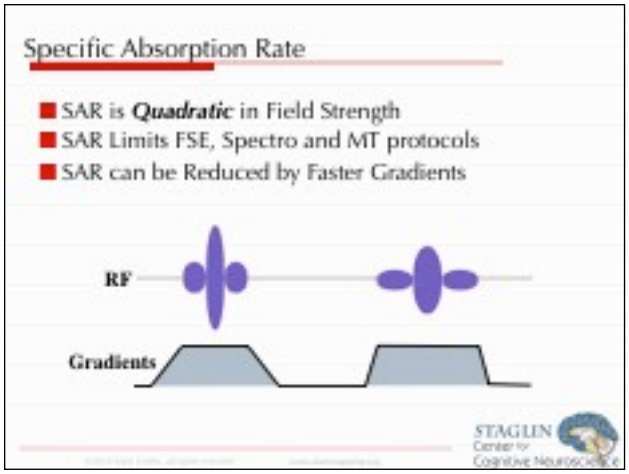
It is unfortunately not unusual for subjects and patients to receive very serious burns during scanning – almost always as the result of someone using an improper and unsafe device in the instrument. Standard EKG leads have led to many serious burns, as have physiological monitoring devices not designed specifically for MRI use. Surgical halos that are not marked MR Safe are



Please remember these rules for RF safety:

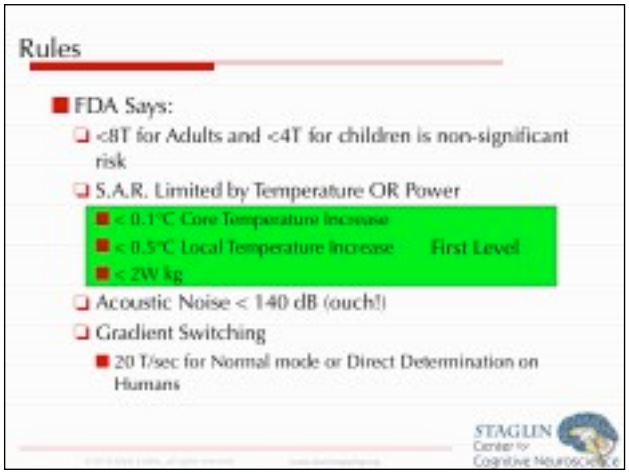
Avoid skin to skin contact that might create a low resistance electrical current loop

At radio frequencies, current can pass through a vacuum and across insulated wires. Keep a sufficient distance between



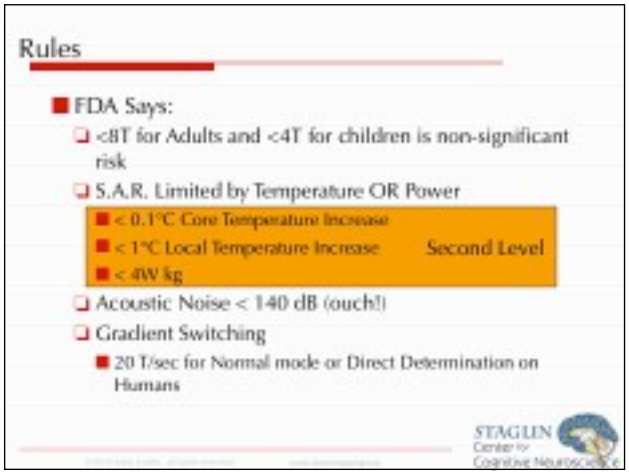
SAR grows with the square of the field strength. Compared to operation at 1.5 Tesla, the equivalent imaging sequence at 3 Tesla deposits four times the power. Operation at 7 Tesla uses more than 20 times as much power.

SAR limits imposed by the scanner software and may result in specific limitations to certain MR pulse

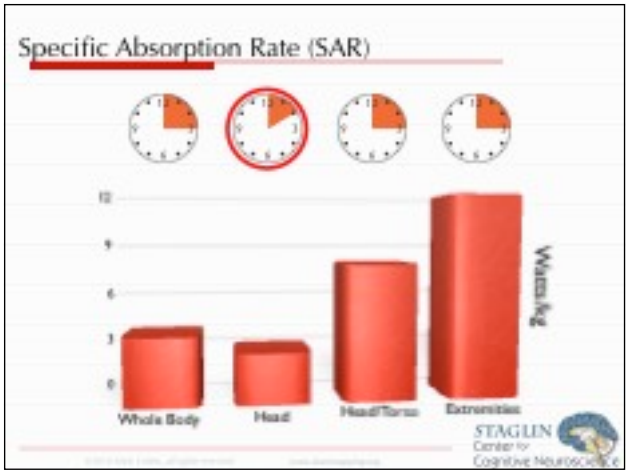


To avoid injuries, the S.A.R. and other exposures delivered during an MRI exam are limited by several national and international bodies. In particular, the US FDA has published these standards:

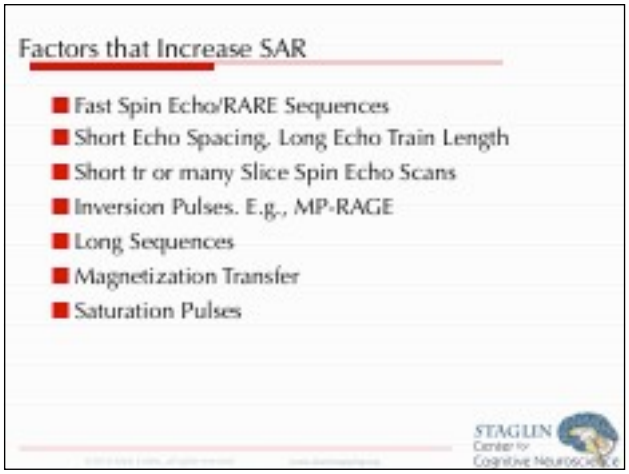
Operation at less than 8 Tesla for adults and less than 4 Tesla for children is considered a non-significant risk.



The FDA allows the use of larger RF power in the event that the scans are medically supervised, or if there is existing IRB approval for research use. The Second level limits for S.A.R. are 4 Watts/kg.



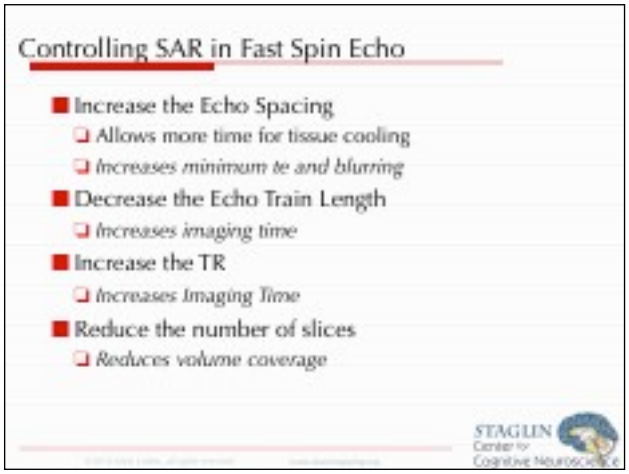
In addition to the maximum power limit, the FDA limits the duration of exposure to the RF power to fifteen minutes at the approved level for all body parts except the head, where the limit is a ten minute continuous exposure. This allows the body a cool down period between scans so that the natural cooling of the body can compensate for any temperature increase. The FDA does not specify the



Specific Absorption Rate is increased by several user adjustable parameters.

Fast Spin Echo, or RARE, sequences use long trains of very brief high flip angle 180° RF pulses and therefore deposit considerable RF energy.

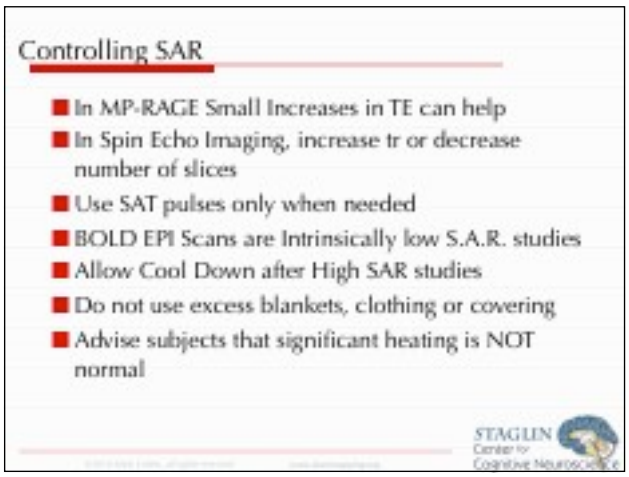
Within such sequences, very short echo spacing and/or long echo train lengths



For example, in Fast Spin Echo sequences the echo spacing parameter may be increased at a slight cost in minimum te and additional blurring.

Decreasing the echo train length will reduce S.A.R., but will also result in a longer imaging time.

Increasing the tr helps, but also increases



Other High SAR sequences also have adjustable parameters. We have found that even small increases in te can reduce SAR to acceptable levels in MP-RAGE sequences

In conventional spin echo sequences tr may be increased, or the number of slices decreased.

Thermoregulation Problems

- Diabetes
- Obese
- Cardiovascular Disease
- Fever
- Hypertension
- Old Age
- Diuretics
- Beta Blockers
- Sedatives
- Muscle Relaxers

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Certain individuals are at much higher risk of problems from S.A.R. Specifically, these conditions may present additional cause for concern:

Diabetes
Obesity
Cardiovascular disease
Fever
Hypertension

Acoustic Noise

- Ear Protection is Always Required
- Ear Plugs and/or Noise Reducing Headset
- Always Ask Subject about Noise Level

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Again, the scanner is noisy. Without earplugs the noise levels can create hearing loss. Be sure that you give your subjects ear protection of some sort.

Unsafe Populations

- Mechanical
  - Aneurysm Clips
  - Shrapnel in Eyes or Brain
  - Recent Implants in Soft Tissue
  - Piercings (?)
- Thermal
  - Implanted Leads or Wires
  - Certain Makeup
  - Hair Weaves
  - Almost ANY Electrical Conductor

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There are certain subjects who should never be scanned.

Mechanical problems include: Aneurysm clips from recent surgeries; Metal shrapnel in the eyes or brain (which have led to blindness in the MRI in the past); Recent implants of any kind in soft tissues; Body piercings – if possible these should be removed prior to scanning

Device Hazards

- Movement or Displacement
- Heating
- Altered Device Performance
- Artifacts

Common Problems include
- Aneurysm Clips
- Stents
- Pacemakers
- Surgical Wires
- Dental Appliances
- Shunts/Drains
- Heart Valve Prosthetics
- NeuroStimulators
- Permanent Contraceptives

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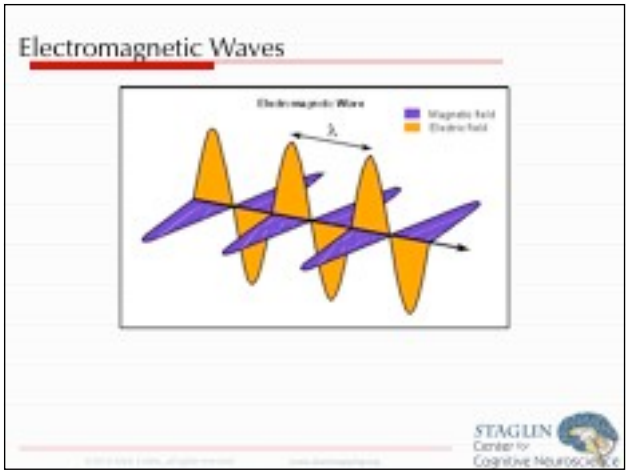
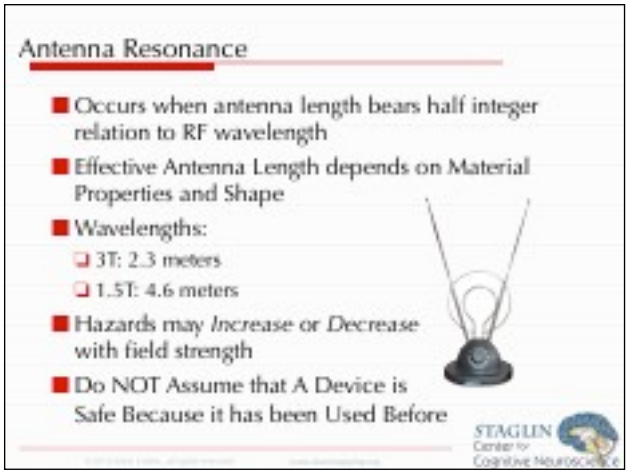
Foreign devices cause a host of difficulties including
– displacement within the body causing bleeds and other problems
– heating as mentioned previously
– altered imaging performance and
– many imaging artifacts.

For us, the “Reference Manual for Magnetic Resonance Safety, implants and

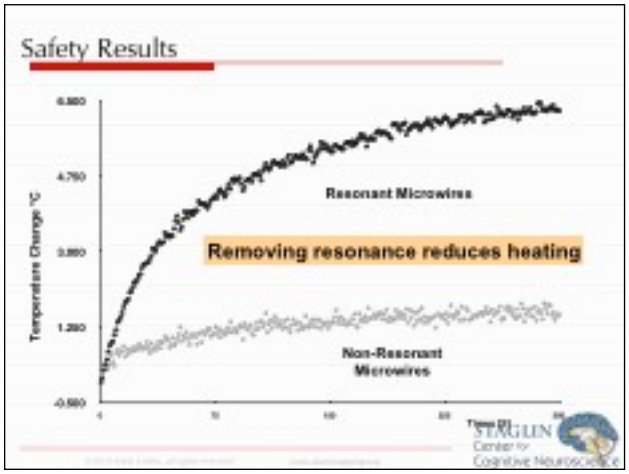


RF travels in the form a an electromagnetic wave. The wavelength, denoted here with a Greek lambda, depends on the RF frequency and the speed of light.

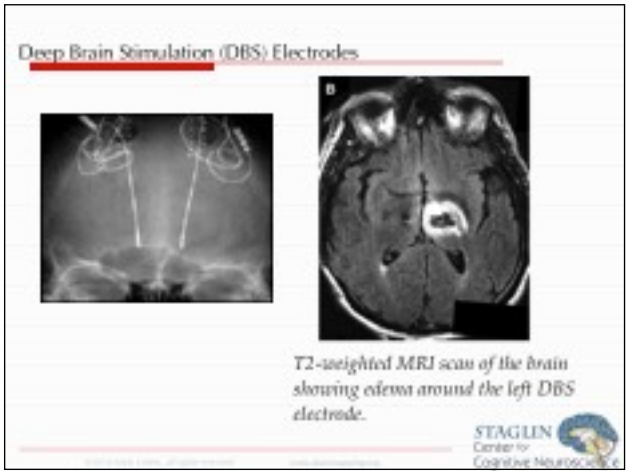


The phenomenon of coil heating is often very complex. Almost any conductor is capable of acting as an antenna.

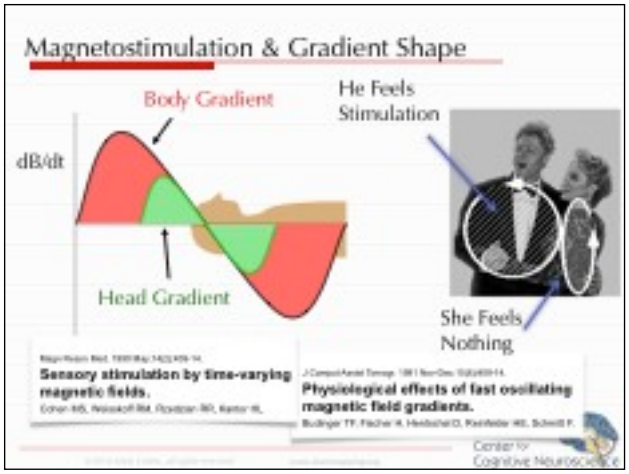
When the effective length of the conductor becomes comparable to the RF wavelength (or to half of the wavelength) a resonance condition may occur in which large currents are passed. These currents can pass through body tissues and can



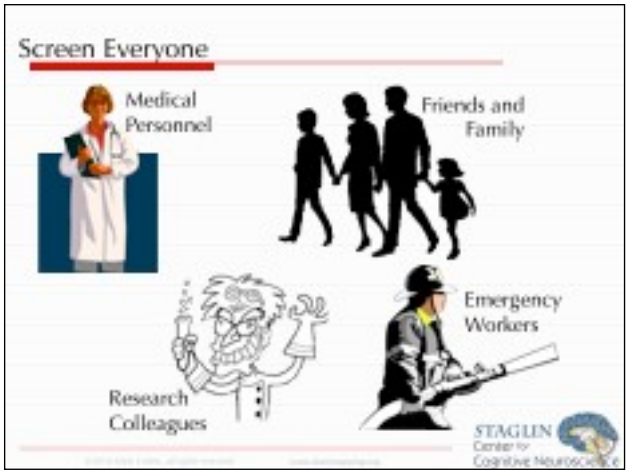
These data, collected at UCLA, demonstrate the temperature changes created during an MRI scan. The only difference between these data sets was the actual length of the wire leads, bringing the system from a safe to a very unsafe range of operation.



Implanted wires present a special hazard. For example, the systems used for deep brain stimulation are supplied with excess wire length. When implanting the electrodes the physician is given little instruction in how to manage the remaining wire. In the case shown here, the physician looped the excess wire in the head. The MRI image at the right shows severe burns in the brain that

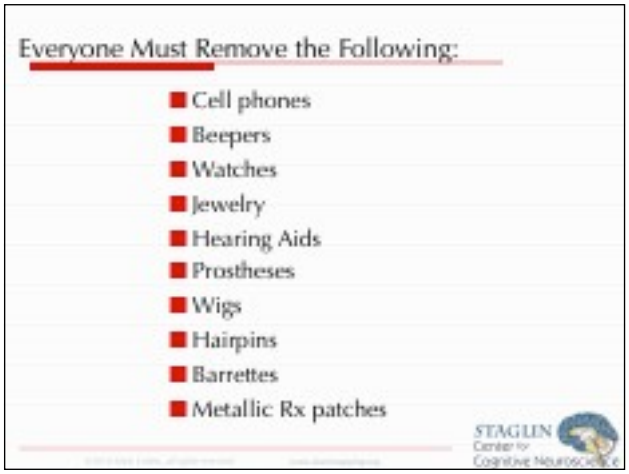


When operating, the MRI scanner uses gradient coils to create time varying magnetic fields that are used for spatial localization. These time varying fields are of much lower frequency than the RF fields and do not result in heating. However, as they go through the body, they can cause relatively large currents to flow. These currents have been shown to result in sensory stimulation when the



Anyone entering the imaging suite must be screened, including:

- Medical Personnel – The presence of a white coat does not convey knowledge of MRI safety
- Friends and Family – who generally do not belong in the Scanner suite
- Your Research colleagues and Emergency Workers



Remember to carefully ask each subject about:

- Metallic foreign bodies
- Permanent cosmetics or tattoos
- Prior surgeries
- Possible pregnancy
- The use of a wig or hair weave.

Pregnancy

- No Known Pregnancy Effects
- ISMRM and ACR:
  - MRI Is Acceptable in Pregnancy to Address Clinically-Important Questions
  - Acceptable Regardless of Trimester
  - Informed Consent Should be Obtained

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Although there is no known risk to mother or fetus as a result of MRI scanning, imaging of pregnant subjects is highly discouraged, though in rare cases may be given special approval.

The American College of Radiology and the International Society for Magnetic Resonance in Medicine have issued these guidelines:

Subject Consent

- Consent is Required for ALL Human Subjects at the Staglin Center.
- IRB Documents must be Current and on File Prior to Scanning.
- Subject Consent Should be Obtained in Private
  - Personal Medical Information is Confidential
  - Some Questions may be Personal
- Subjects Should not be Exposed to Extra Risk for Research Scans.
- Any Potential Safety Risk Must be Evaluated by Senior Personnel.

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Informed consent is mandatory for all human subjects at the Staglin Center for Cognitive Neuroscience for both MRI and for EEG.

In order to be allowed to schedule human exams, you must have current and valid IRB documents on file with the center.

Despite the way it may have appeared in

Subject Preparation

Ask subjects to wear loose comfortable clothing:

- Sweat Pants
- Track Suits
- T-Shirts
- Scrubs

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Your subject's physical and emotional comfort are an important part of safe scanning. Before inviting subjects to the lab, you should ask subjects to wear loose and comfortable clothing such as sweat clothes, track suits, t-shirts or scrubs.

Subject Preparation

Remove all:

- Metallic Personal Belongings
- Hearing Aids
- Watches
- Jewelry
- Clothing with Metal Fasteners
- Makeup

Avoid drinking coffee. Void before scanning.

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In all cases, prior to scanning, your subject's must remove all

Metallic personal belongings

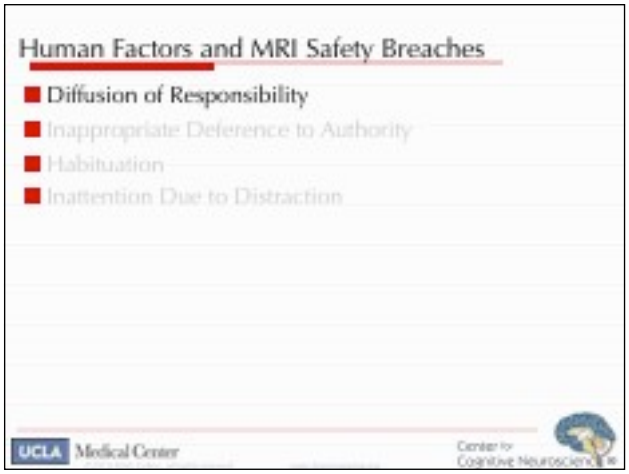
Hearing aids

Watches

Jewelry

Human Factors and MRI Safety Breaches

When mistakes are made by individuals who have had appropriate MRI safety training, in other words, “human error”, we look for human factors that contribute to or cause these errors. The most common factors contributions include:
1) Diffusion of responsibility
2) Inappropriately deference to authority



Social psychologists hypothesize that the greater number of individuals present, the less responsibility each one feels for taking action.

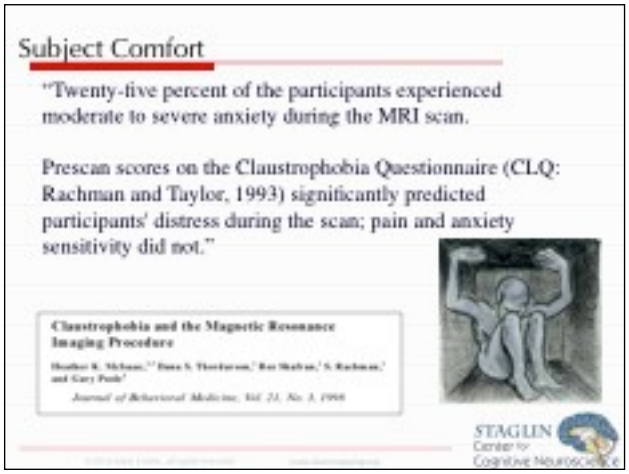
If multiple people are present for an MRI scan, there is the potential for the same diffusion of responsibility. For this reason, for every scan, one person should be the designated safety person

When a senior investigator, lab chief, etc…, enters the MRI suite, there may be an assumption that, since that senior person knows better, and that the safety designee need not stop, question or interview him or her. This is the most likely reason that Michael Colombini was killed in the MR suite. The designated safety officer is responsible for screening all personnel entering the scanner

Habit takes many forms. For instance, some protocols involve scanning individuals multiple times longitudinally. Investigators (and patients) may complain about going through the same screening forms again and again. We have had a case in which someone coming in for a follow-up scan had a pacemaker installed in the interim. Only a last minute, off the cuff, question saved that person from

In one frightening safety violation at UCLA that nearly had catastrophic effects, two safety-trained MRI investigators were trying secure a patient in the head coil by using tape. Unable to tear it correctly, one of the investigators said "just a second", ran into the console room and grabbed a pair of scissors which were instantly drawn into the magnet, breaking into many pieces. Luckily the patient table

Even well trained investigators make life-threatening errors. In these cases the personnel almost always "know better", but act in error. Assigning clear responsibility, being absolutely consistent, and focusing on safety alone during those periods when subjects and investigators are entering the scanner building, can prevent human factors mistakes



Claustrophobia is a very common event during MRI studies occurring in some forms in as many as 25% of clinical exams.

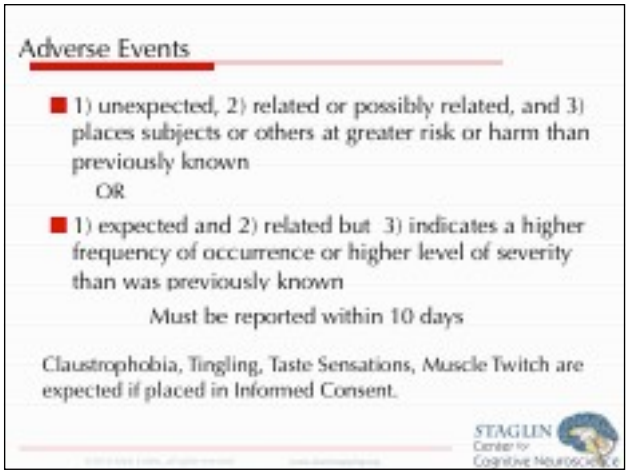
It is apparently far less common in functional MRI and research scans, perhaps because the subjects are in closer contact with the experimenter during the exam

Several general guidelines can help to reduce the probability of claustrophobia in your subjects.

- Make sure that they are not physically uncomfortable by asking them not to drink lots of liquids before the exam and to empty their bladders
- Avoid the subjects becoming too warm or uncomfortable by ensuring that they

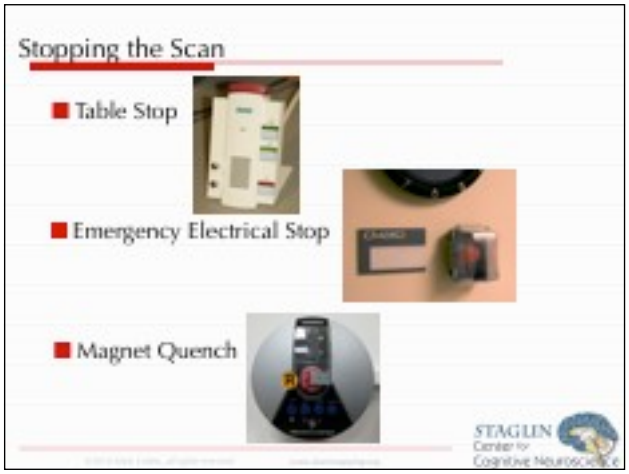
In all cases, prior to scanning, your subject's must remove all

Metallic personal belongings,
Hearing aids,
Watches,
Jewelry,
Clothing with metal fasteners and
Metallic makeup.



The Office for the protection of research subjects has very clear guidelines on the mandatory reporting of adverse events. Please note that most such events are not reportable if they are noted in the informed consent and do not occur with excessive frequency.

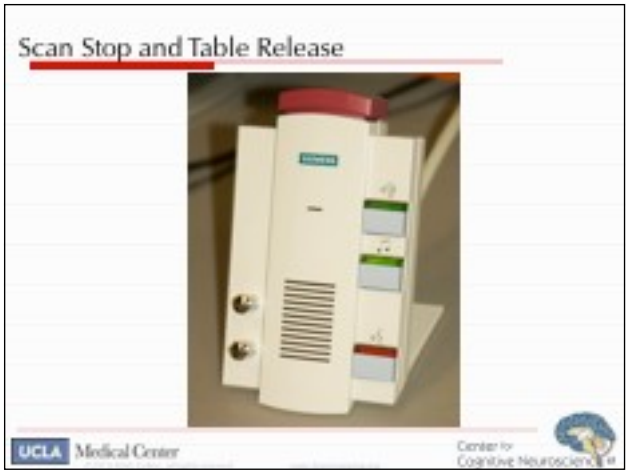
Therefore, you should be sure to include common minor effects in your informed



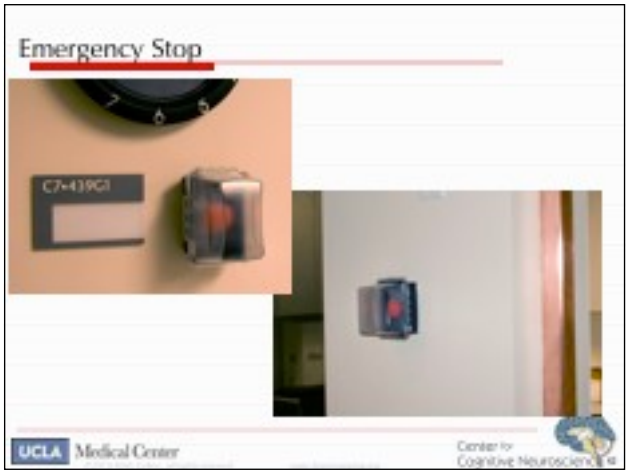
There are several conditions in which the MR instrument must be stopped.

In the event that a person, or a piece of equipment becomes trapped by the patient table, you can press the table stop button. This stops the table motion and disengages the table. If the subject must be removed rapidly from the magnet, pressing the table stop button releases

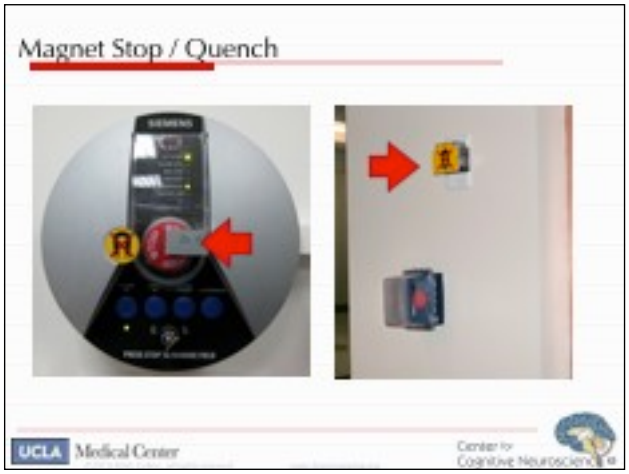
This photograph of the console room at the Staglin center shows the location of the principal emergency controls. An electrical and table stop button is located immediately to the right of the magnet room door. The intercom device will also act as a stop button. The Alarm box, just to the right of the window, contains a magnet quench button.



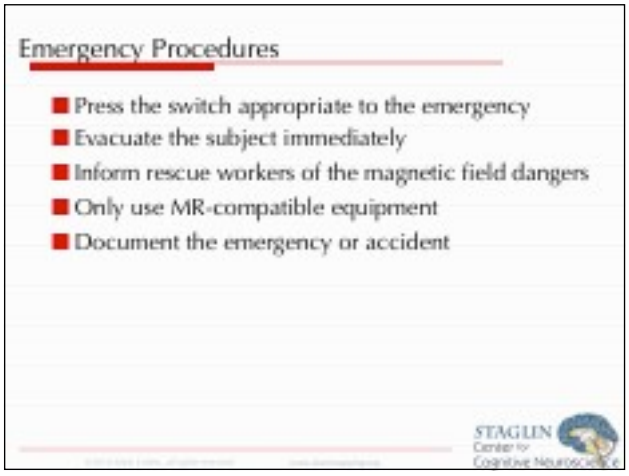
Depressing the button on top of the intercom unit executes a stop command.



The two emergency electrical stop button are located just to the side of the magnet room door, both inside and outside of the magnet room.
To use either of these, you must lift the cover first.



Magnet quench buttons are located both inside and outside of the magnet room and are labeled clearly in yellow. Remember that these are to be pressed only in the event of specific emergencies that require instant shutdown of the magnetic field. Pressing these button releases all of the liquid helium in the system in a controlled, but unrecoverable, manner



In the Event of a Quench

- Subject and MR personnel vacate room **Immediately**
- Inform rescue workers **Immediately**
- Inform service engineers **Immediately.**

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The Biggest Risk

- The Biggest Risk is Inattentiveness
- Never Defer Responsibility for Safety to Someone Else in the Room

Aug. 1, 2001 Michael Colombini was undergoing an MRI, or magnetic resonance imaging, at Westchester County Medical Center last Friday when an oxygen canister was turned into a guided missile by the powerful MRI magnet. The canister was drawn into the magnet core while the boy was in the machine. The result was a fatal blow to the child's head.

The nurse who carried the oxygen canister into the room where Colombini was being scanned mistakenly believed the canister was made of a nonmagnetic material, like aluminum.

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While the MRI devices are not intrinsically safe, by far the biggest risks in MR imaging are the result of inattentiveness on the part of the operator.

Always be alert to potential safety problems. In general, it is a good idea to have a single individual chiefly responsible for safety when scanning as a group or team, however, any trained

Our Goal

- ZERO SAFETY INCIDENTS.

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To date, there have been few if any reports of serious safety problems from non-medical research use of MR imaging. This is remarkable, as many novices and non-professionals now perform MR scans.

You should be aware that a single serious event will not result simply in the loss of your privileges but potentially in the loss

Safety Resources

http://www.semel.ucla.edu/staglin

MRIsafety.com

IMRSER

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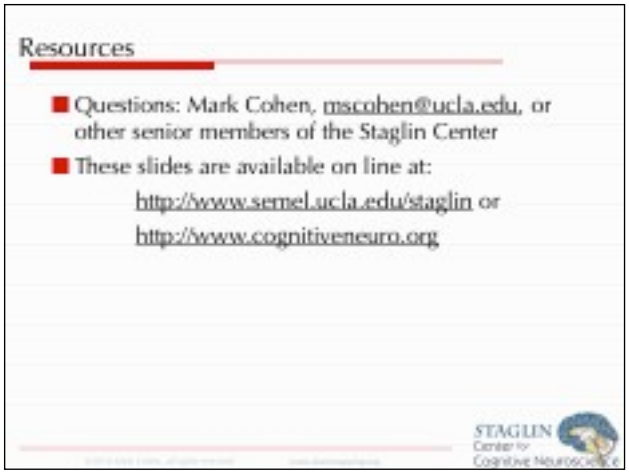

If you have any questions about this material, please contact Mark Cohen (mscohen@ucla.edu) or other senior personnel in the center. We are eager to help and we will share your questions, and our answers, for other users in the future.

The slides associated with this video can be found online at the Staglin center