Transcranial Magnetic Stimulation (TMS)

History of TMS

Modern Era

1985 Barker et al., non-invasive, painless, cortical stimulation with magnetic fields

1984 David Cohen, 1988 Shoogo Ueno, the idea and realization of the figure-of-eight coil

1987/88 Cadwell Laboratories Inc., repetitive stimulation with water-cooled coil

Transcranial Magnetic Stimulation (TMS)

- Rapid magnetic field changes >> electric current
- Magnetic field created at scalp with figure-8 coil
- Electric current induced in neurons in cortex
  - Adds noise, disrupts coordinated activity
  - Temporary “lesion”
    - Without the kind of compensation that develops w/ long-term lesions

Rapid-onset brief electrical current generated in coil

- Produces rapid-onset brief magnetic field pulse (up to 2 Tesla)
- Induces rapid-onset brief electrical field
- Induces rapid-onset brief electrical current in brain (mostly cortex)
- Which has an effect on some task


TMS: Terminology

TMS: general term for all modes of transcranial magnetic stimulation
rTMS: repetitive magnetic stimulation
Single-pulse TMS: non-repetitive TMS
Low-frequency (slow) TMS: repetition rate below 1 Hz
High-frequency (rapid-rate) TMS: repetition rate above 1 Hz
Dual (paired)-pulse TMS: stimulation with two distinct stimuli through the same coil at a range of different intervals; the intensities can be varied independently
Double TMS: stimulation with two stimulation coils applied to different cerebral loci; the timing and stimulus intensity are adjusted separately
Multichannel TMS: TMS with multiple (say, 20-100) coils that are independently controlled
TMS mapping: performed by changing the coil position above the head while observing its effects

http://www.biomag.hus.fi/tms/terminology.html

TMS: Basic Idea

• Apply to different areas of scalp & see what functions disrupted
  – Disruption does NOT mean brain regions directly under coil responsible for function
  – Only that it’s involved somehow in the function
  – OR connected to regions involved in the function
    • Get distal effects through connections (“diaschisis”)
  – Necessary (sort of) but not sufficient

Repetitive versus Single Pulse TMS

• Many early studies used rapidly repeated trains of magnetic pulses
  – Because single pulses weren’t found to have much effect on gross measures of behaviour

• More recently, single pulse studies have found effects with constrained hypotheses & more sensitive behavioural measures
  – Can time single pulse at different steps in a process to see when it has the most effect
    • Mostly studying vision & motor processes
    • Also working memory (encoding, maintenance, retrieval)


A [17F]-fluoromethane PET/TMS study of effective connectivity

Ferrarelli et al Brain Research Bulletin 2004

Safety

If used properly, single-pulse TMS has no known harmful side effects. TMS has been used since 1985 and today some 3,000 stimulators are in use. Protocols should always exclude patients and volunteers with:

- intracranial metallic or magnetic pieces - The magnetic field present in TMS will generate forces on objects exposed to it: magnetic objects will be attracted and nonmagnetic repelled. The force may be substantial, but decreases quickly with decreasing cross-sectional area and conductivity of the object and with distance from the coil.
- pacemaker, or any other implanted device - The magnetic field pulse will disturb nearby electronic devices.

http://www.biomag.hus.fi/tms/safety.html

Ferrarelli et al Brain Research Bulletin 2004

Safety

- Single-pulse TMS has produced seizures in patients, but not in normal subjects
- rTMS has caused seizures in patients and in normal volunteers
- Hearing loss - During TMS there will be a loud clicking sound from the coil. The peak sound pressure is 120-130 dB 10 cm from the coil. Most sound energy is in the frequency range 2-7 kHz where the human ear is the most sensitive. The noise may exceed criteria limits for sensorineural hearing loss.
- Heating of the brain - Heating of the brain is unlikely to cause deleterious effects. Theoretical power dissipation from TMS is few milliwatts at 1 Hz, while the brain’s metabolic power is 13 W
- Headache - A frequent harmless, but uncomfortable, effect is a mild headache, which is probably caused by activation of scalp and neck muscles.
- Engineering safety - TMS equipment operates at lethal voltages of up to 4 kV. It is hence important not to keep coffee cups or ice bags on the stimulator.
Safety

Recent literature lists indicative ranges for safe use of rTMS. The following parameters are of main importance:

- Stimulus strength
- Repetition rate
- Train duration
- Train interval
- Total number of pulses


Summary: TMS

- High spatial and temporal resolution
- Can be used repeatedly in humans
- Provides information about the functional significance of a brain region (“virtual lesion technique”)
- Restricted to brain regions close to the skull
- Difficult to interfere with higher order cognitive processes – distributed processes?