BME 701
Examples of Biomedical Instrumentation

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Instrumentation in Cardiology

The major cellular components of the heart are:

- working muscle of the atria & ventricles
- specialized conduction cells
- pacemaker cells

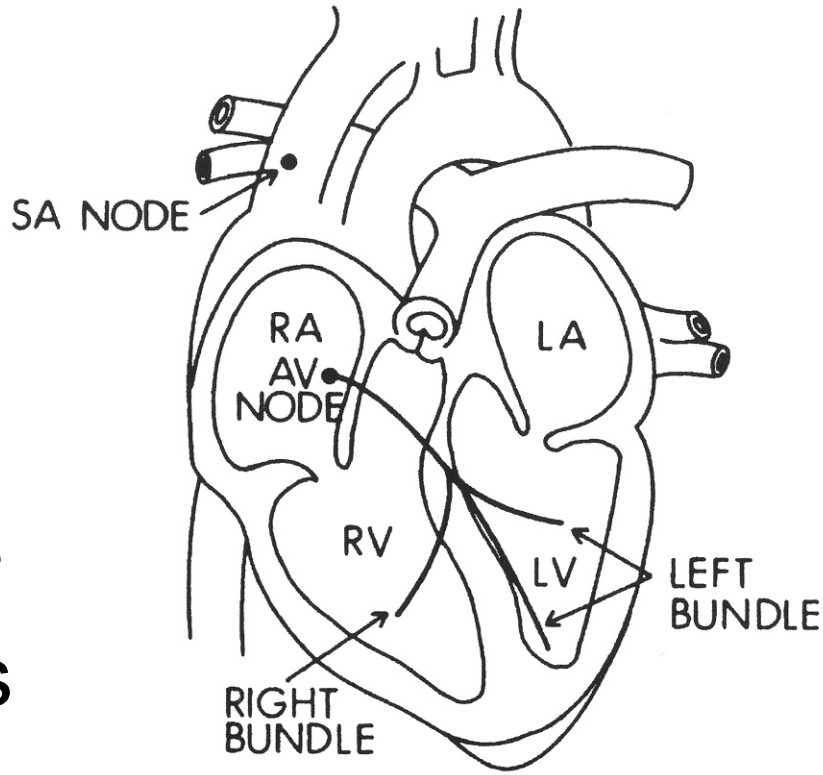


Figure 9.1. Pacemaker (SA node) and specialized conductile regions (AV node, right and left bundles) of the mammalian heart.

ECG measurement and analysis (cont.):

Analysis of the heart vector is achieved by considering the geometry of the standard leads and the corresponding lead vectors.

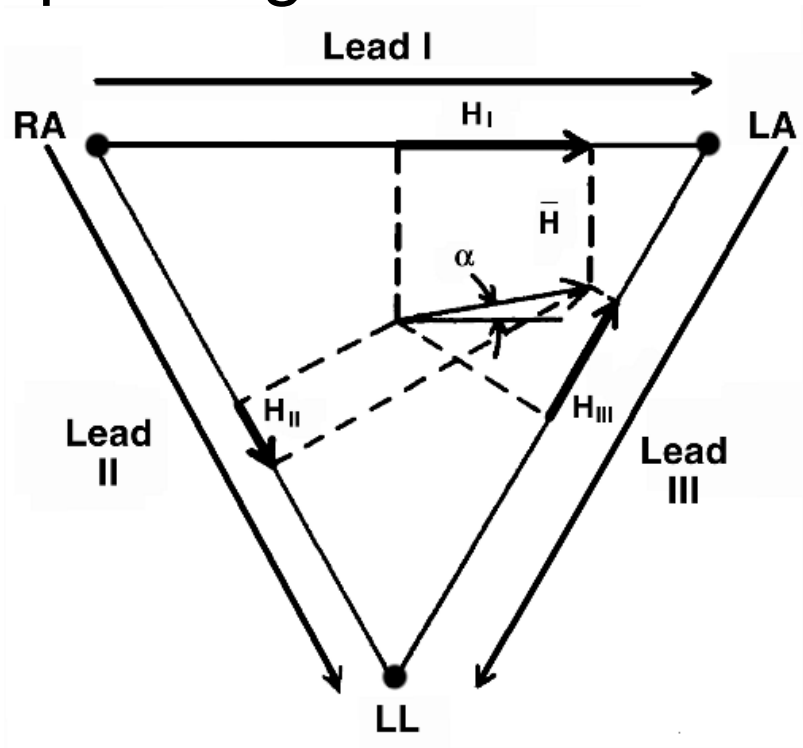


Figure 9.27. The Einthoven Triangle. The sides of the equilateral triangle describe the lead vectors for the limb leads, as shown. For the heart vector, $\overline{H}$, its projections on the triangle sides are labeled H_{I}, H_{II}, and H_{III} (choosing the subscript according to the respective lead); the sign of the lead voltages is found from the dot product of these projections and the corresponding lead vector (e.g., $V_{\mathrm{I}} = \overline{H}_{\mathrm{I}} \cdot \overline{L}_{\mathrm{I}}$). Note that in the illustrated case V_{I} is positive, V_{III} negative, and V_{II} positive. For simplicity in drawing, the lead vectors were given unit magnitudes.

Recorded ECG Signal

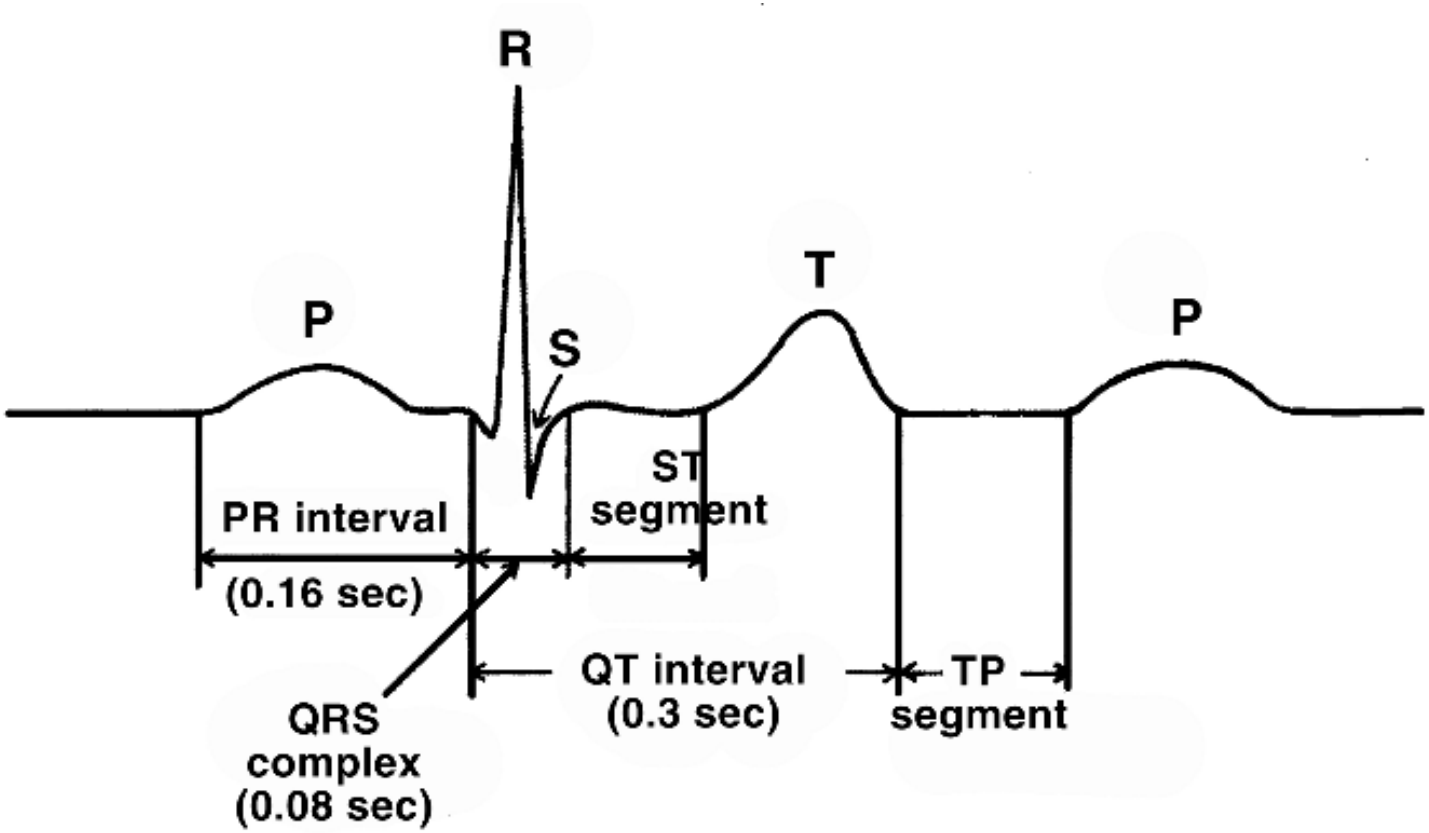
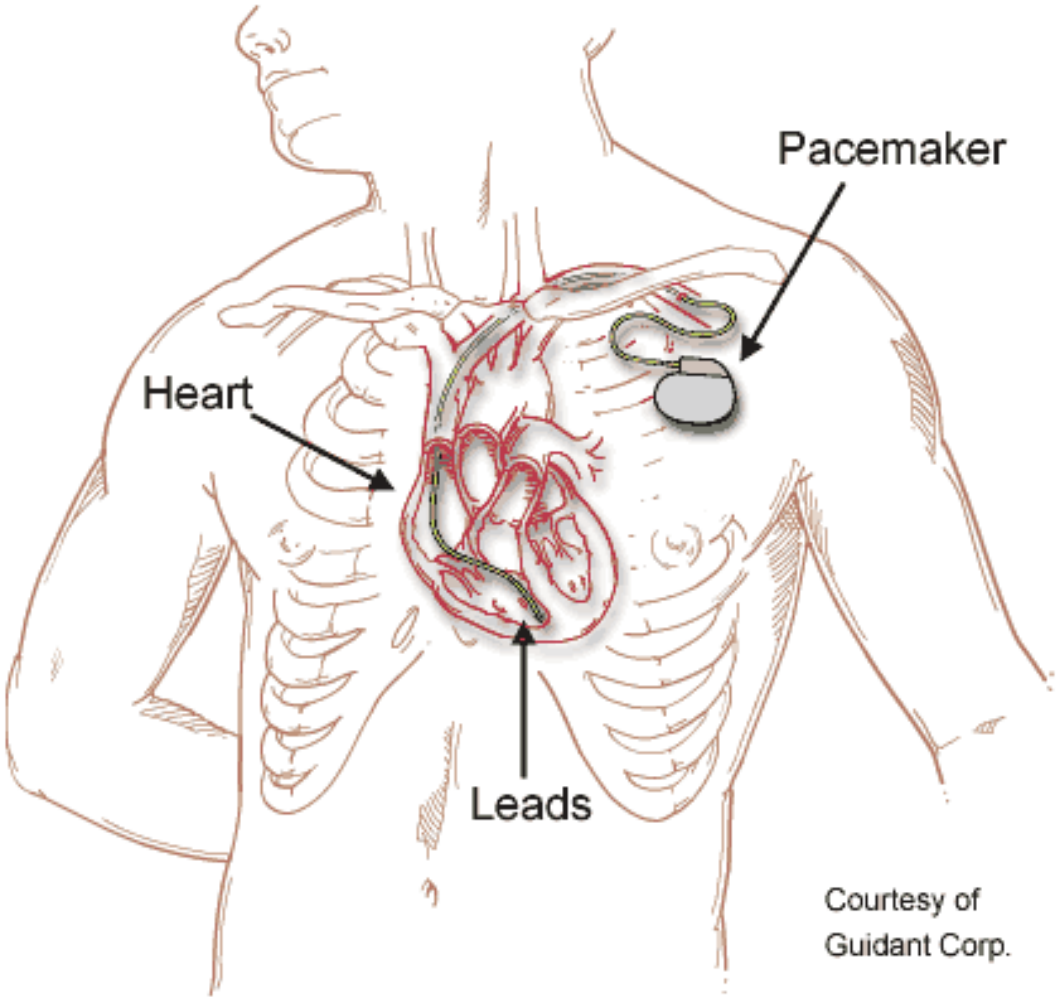


Figure 9.24. Significant Features of Standard (Scalar) Electrocardiogram. Durations given are typical values.

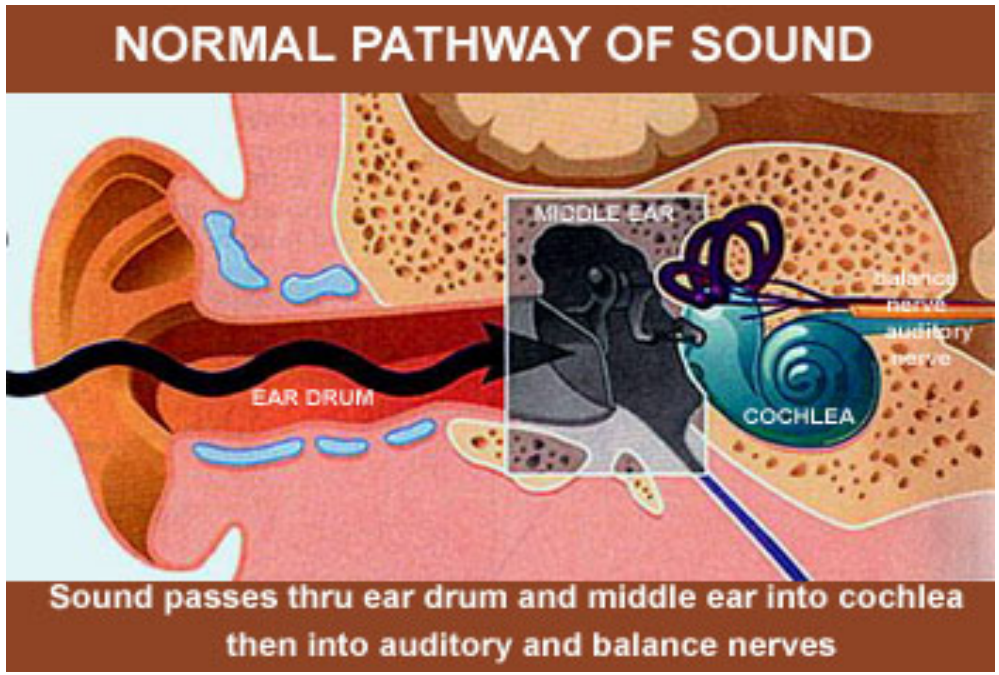
Cardiac Pacemaker



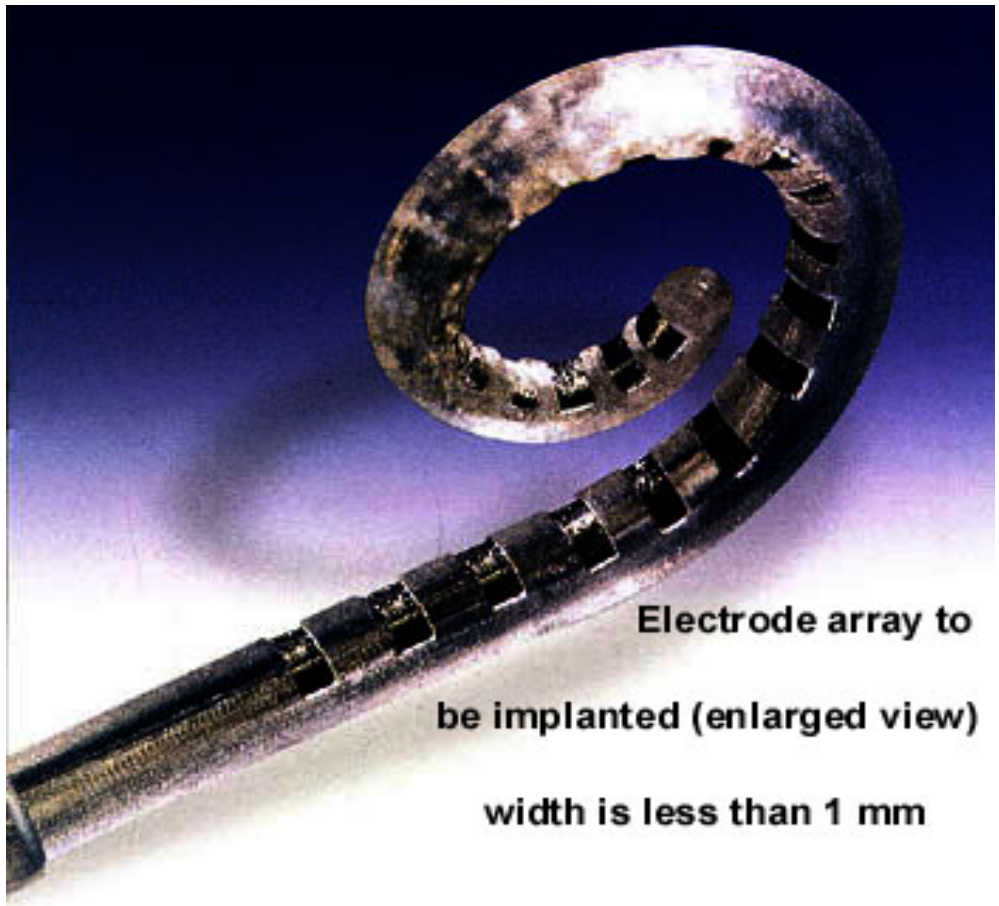
Other Examples of Electrostimulation

- Auditory Enhancement/Prosthetics
- Visual Prosthetics
- Neuromuscular Control
- Muscle maintenance

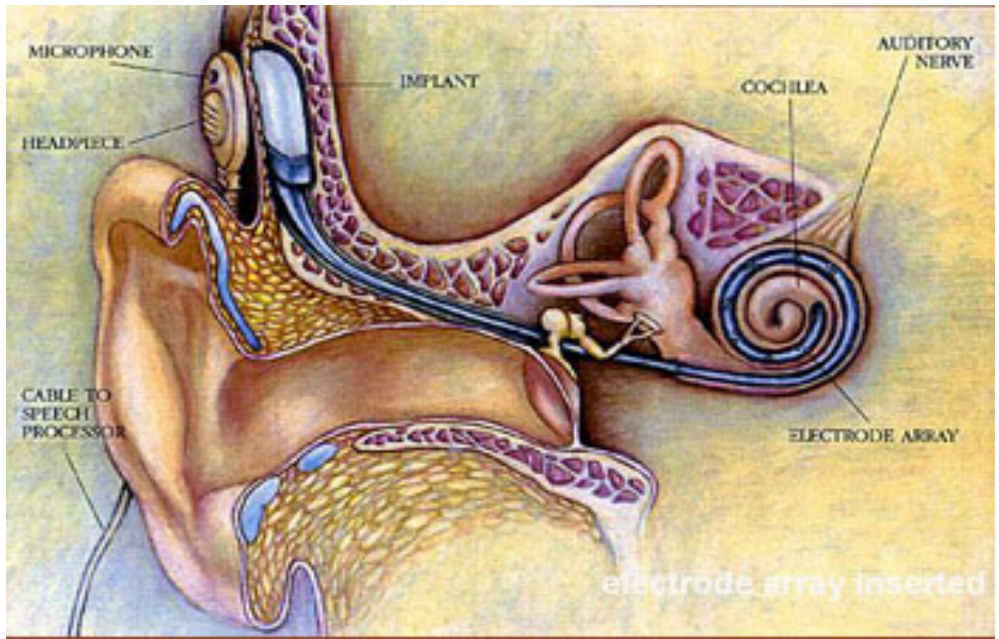
Prosthetic Advances
(Cochlear Implant)



Cochlear Stimulating Electrode

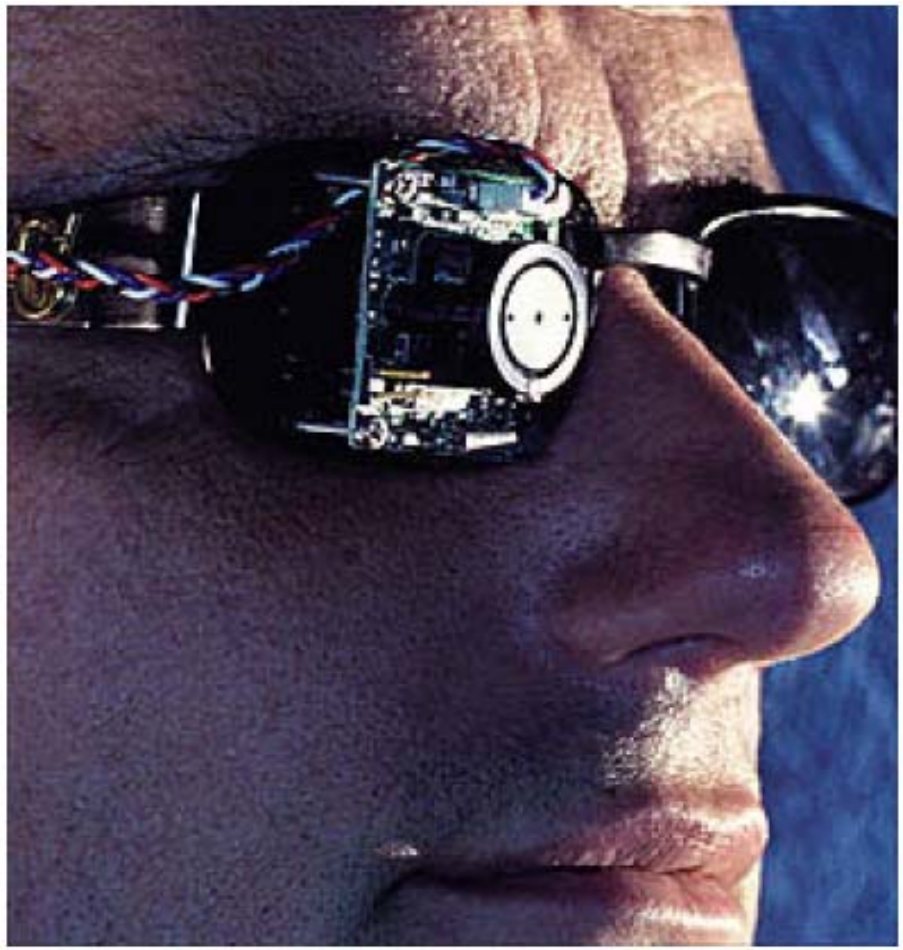


Implanted System

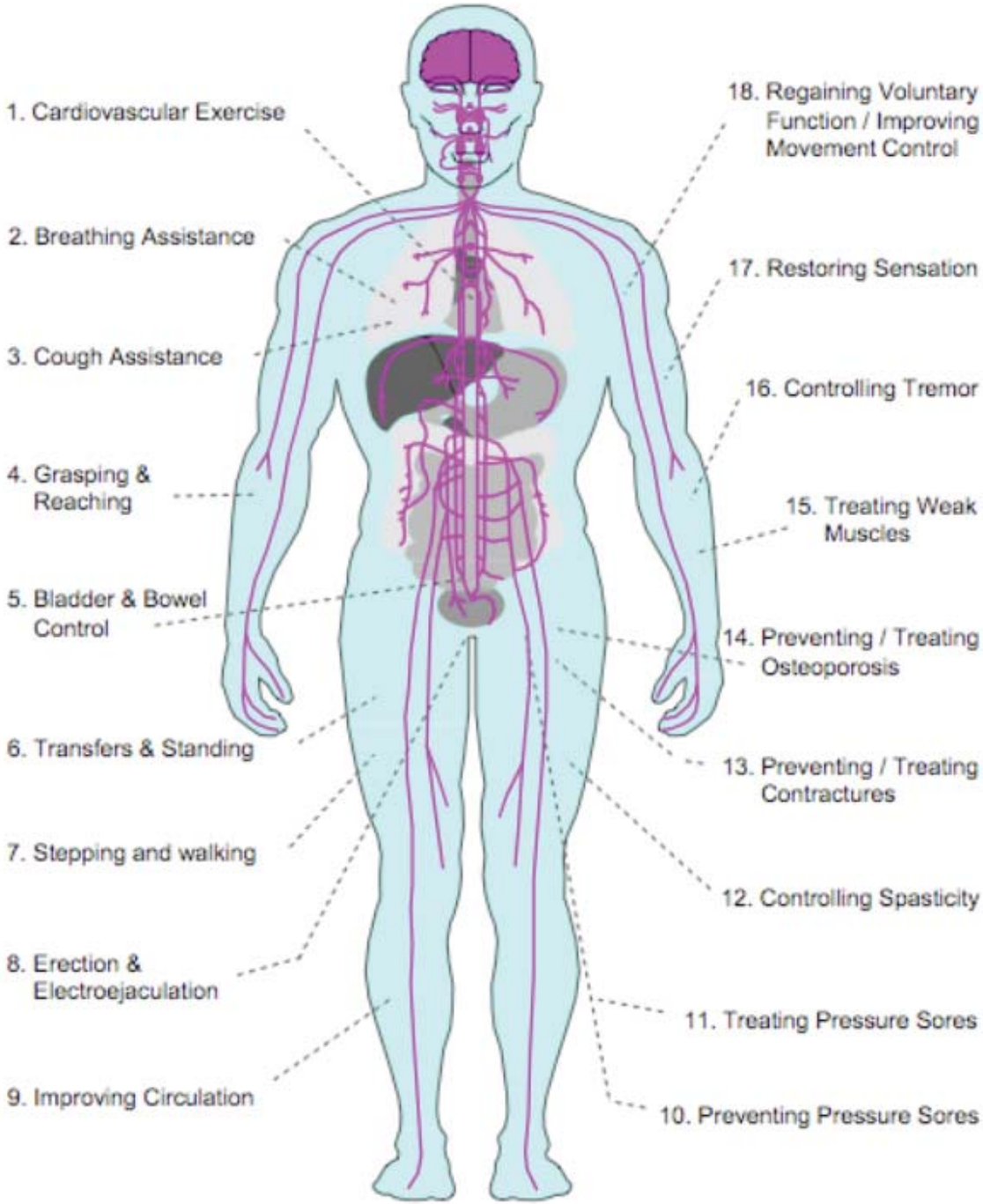


Schematic of cochlear implant; note electrode array inserted into cochlea.

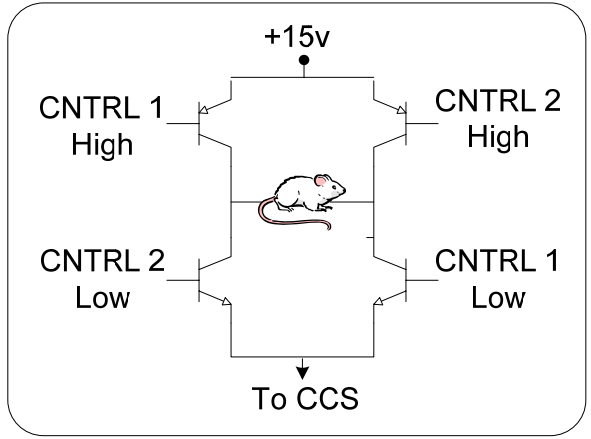
Prosthetic Advances
(Visual – Artificial Retina)



Direct Brain Stimulation


1. Cardiovascular Exercise
2. Breathing Assistance
3. Cough Assistance
4. Grasping & Reaching
5. Bladder & Bowel Control
6. Transfers & Standing
7. Stepping and walking
8. Erection & Electroejaculation
9. Improving Circulation
18. Regaining Voluntary Function / Improving Movement Control
17. Restoring Sensation
16. Controlling Tremor
15. Treating Weak Muscles
14. Preventing / Treating Osteoporosis
13. Preventing / Treating Contractures
12. Controlling Spasticity
11. Treating Pressure Sores
10. Preventing Pressure Sores

Rat Muscle Stimulator



5V power isolator

To constant current source and H-bridge components

PC

USB

Microcontroller

Optocoupler

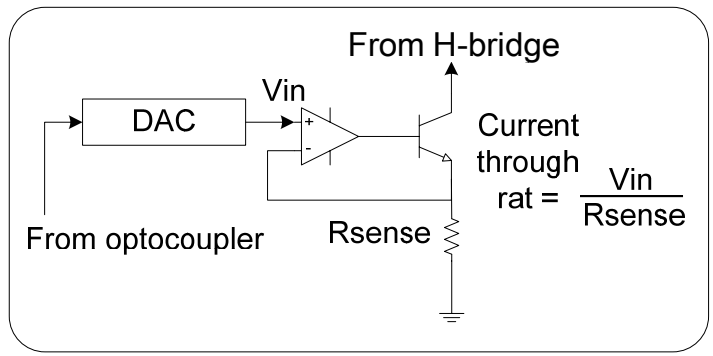
H-bridge

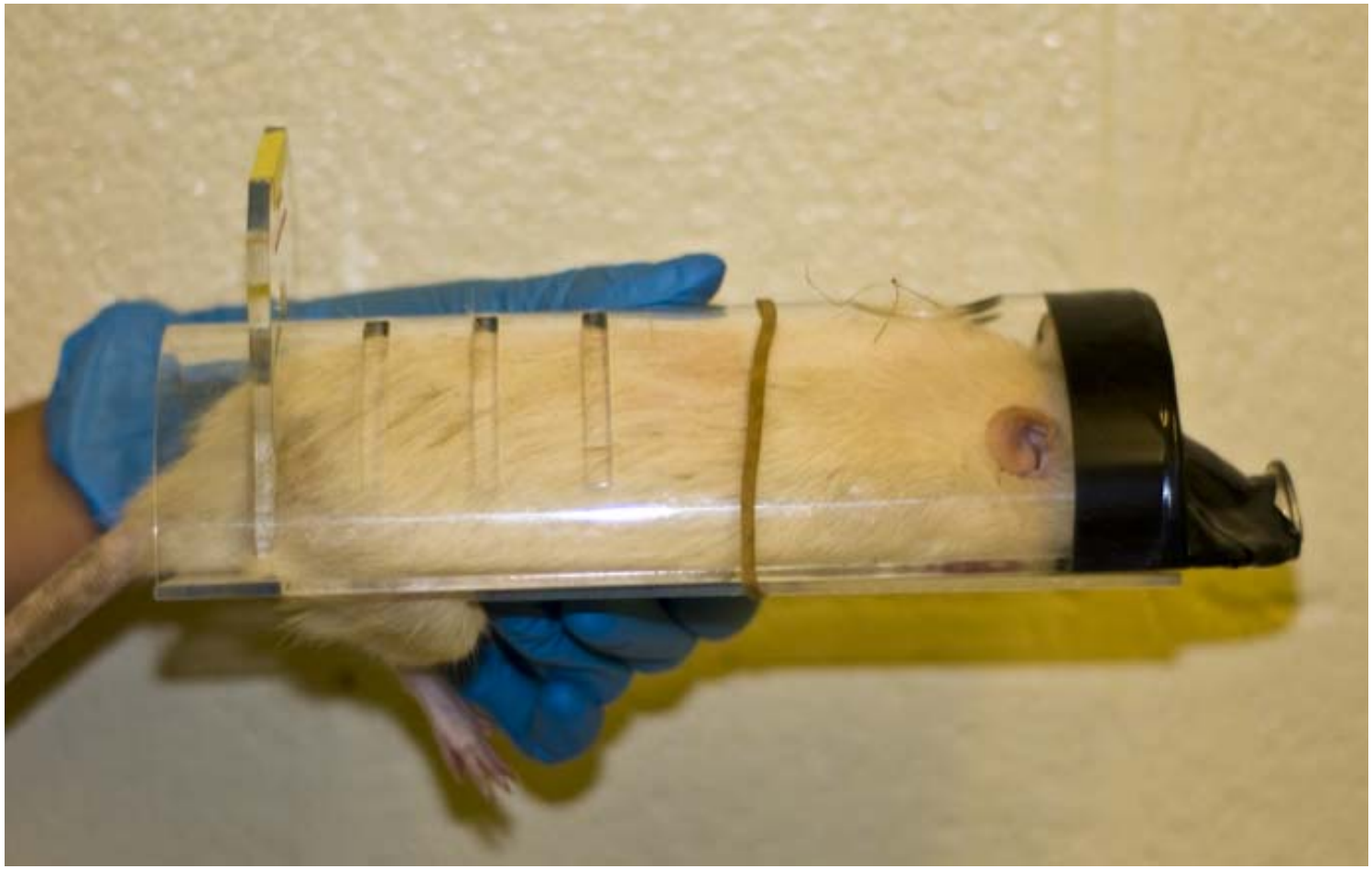
Inside the H-bridge

Optocoupler

Constant current source

Inside the constant current source (CCS)





Recording Electrophysiological Signals

- ECG Recording/Computer Analysis
- EMG Recording/Computer Analysis
- **EEG Recording/Computer Analysis**
- GSR Recording/ Manual Analysis "Polygraph Lie Detector"
- Sleep Recording/ "Computer Analysis" of EEG, ECG, EMG, Respiration, SaO_2

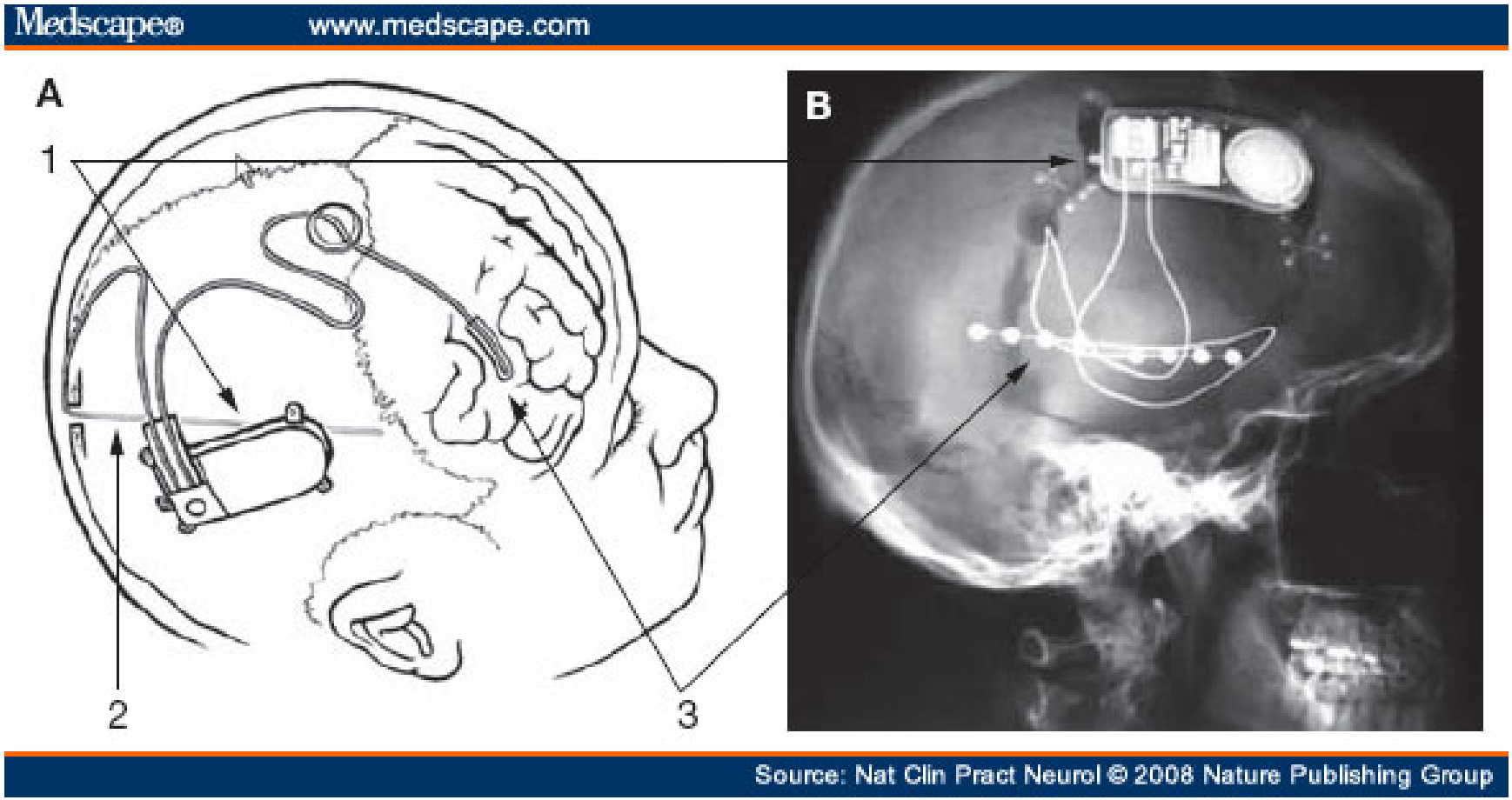
Instrumentation for Recording from and Stimulating the Brain

- For therapy or diagnostics
- Epilepsy Control
- Movement tremors/rigidity from Parkinsonism
- Mood disorders – ECT, phrenic stimulation, rTMS stimulation

Epilepsy EEG Signal

6. Record of a subject with seizure activity during sleep. The system detects the initial three spikes in 1 sec at the start of the sei-

Closed Loop Epilepsy Treatment



Movement Disorders
(Parkinsonism)

- Resulting from loss of neurons in substantia nigra (SNc) which produces dopamine
- Treated with dopamine agonist (short lived), monoamine oxidase inhibitor (less effective), dopamine precursor L-DOPA (gold standard)
- Biggest challenge is dose regulation (half-life of L-DOPA is 90 min)
- Less and less effective as deterioration of substantia nigra continues

Basal Ganglia

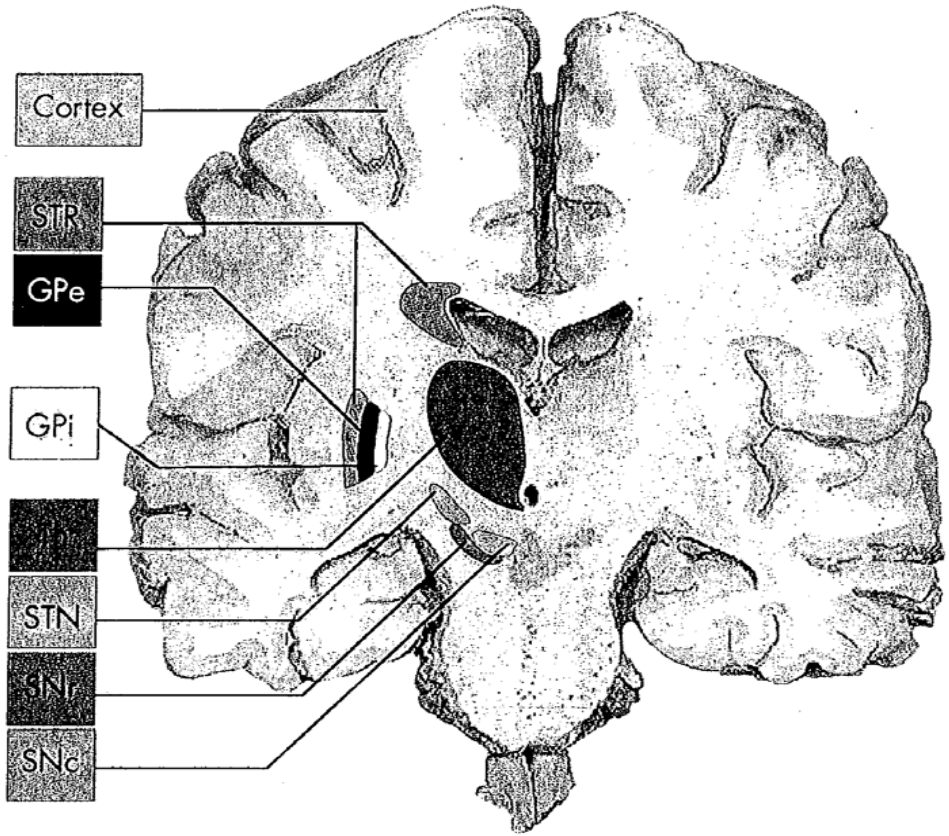


Figure 1 - Coronal (frontal) section of the brain showing the different structures in the basal ganglia. STR, striatum; GPe, globus pallidus pars externa; GPi, globus pallidus pars interna; Th, thalamus; STN, subthalamic nucleus; SNc, substantia nigra pars compacta; SNr, substantia nigra pars reticulata[14].

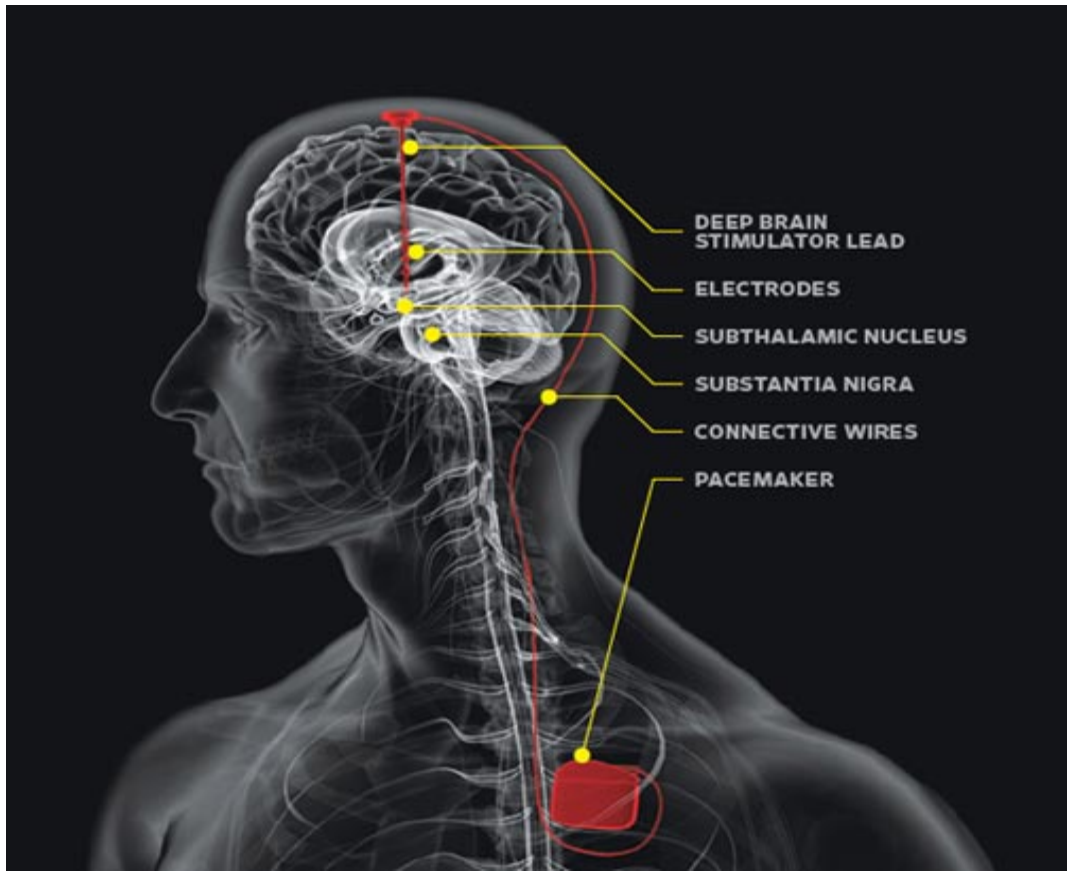
Deep Brain Stimulation

- Instead of ablation (to relieve tremor)
- First reported in 1987 with thalamus stimulation
- Globus pallidus next site with some success
- Subthalamic nucleus (1998) most successful with immediate relief of symptoms when stimulator turned on
- Stimulation of 60–200 μs pulses at >100 Hz
- Hypothesized result is inhibition, same as ablation

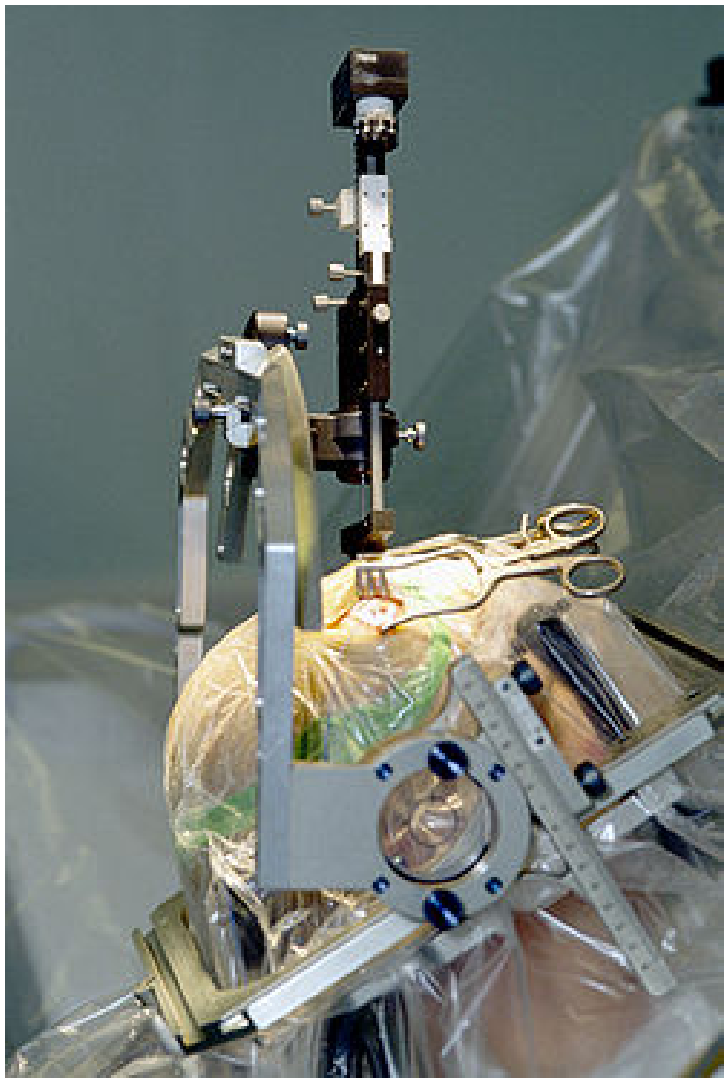
Basic Stimulator

- Medtronic Kinetra Stimulator
- Treat Parkinson or other Movement Disorders

System to Control Movement Disorders



Electrode Insertion



Electrodes for Depression

EM Treatment of Depression

- Acute and Maintenance ECT “gold standard”? Maintenance (10 treatments) as effective as medication but 46% relapse
- Vagal Nerve Stimulation (implant) Mixed results
- Repetitive Transcranial Magnetic Stimulation (“non-invasive”) Mixed Results

Problems Encountered

- Complexity of Brain (anatomical, neurophysiological) especially of frontal lobes
- Treatment mechanisms little understood (animal research suggests some mechanisms but human mostly hypotheses)
- Hardware well developed and flexible but treatment protocols either too rigid or too flexible
- Patient selection

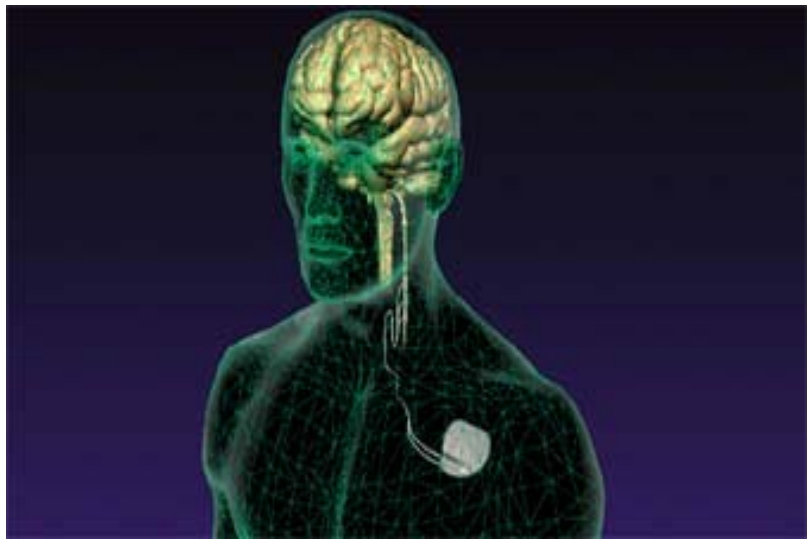
VNS: Vagal Nerve Stimulation Possible Mechanisms

- Alters CSF concentrations of neurotransmitters (e.g. GABBA) or their metabolites
- Alters functional activity of orbital frontal cortex, insula, thalamus, hypothalamus, etc.
- Anticonvulsants have been shown to have therapeutic value in mood disorders

VNS: Vagal Nerve Stimulation Clinical Results

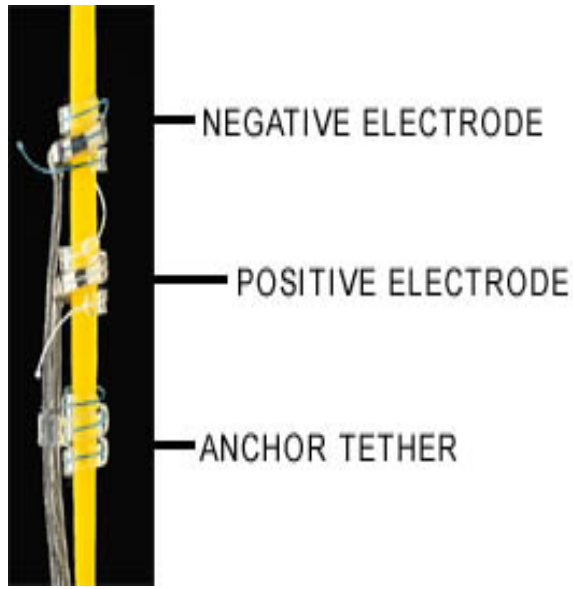
- Reduction in epileptic seizures (29,000 Cyberonics implants by 2005) few side effects
- 21 centre trial for major treatment-resistant depression 222 patients (Rush et al, Biol Psychiatry 2005)
- After 10 weeks 15% responded ($\geq$ 50% improvement in HRSD) in treatment group vs 10% responded in sham group (not sig.)
- Longer term response rates more encouraging

Cyberonics VNS System



- Pacemaker similar to cardiac pacemaker
- Cuff electrodes on left vagal nerve
- Patient or caregiver parameter adjustment via magnetic field

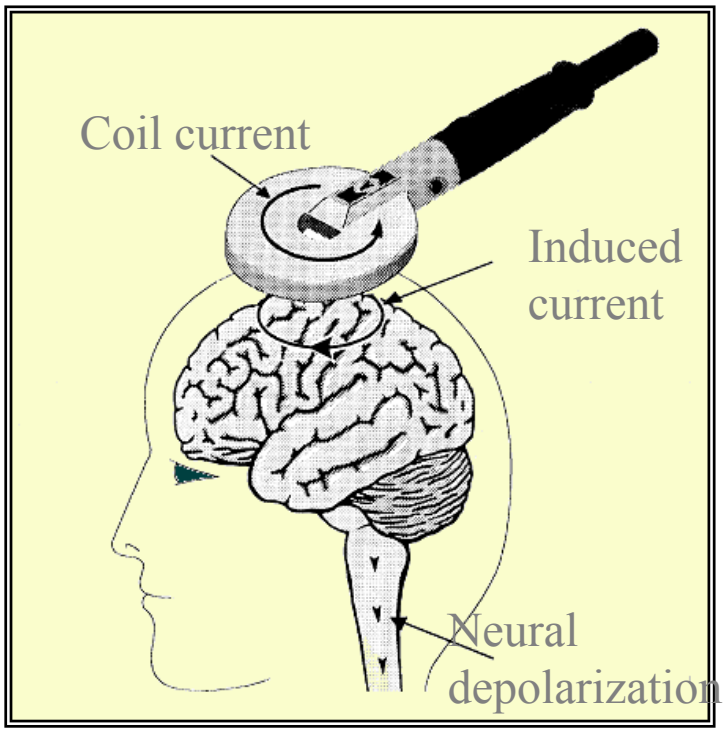
Pacemaker and Electrodes

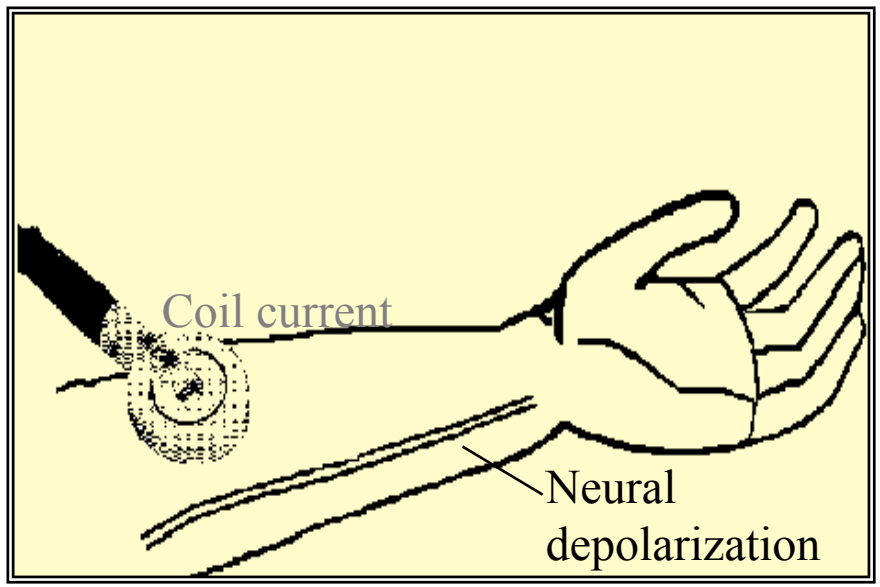


rTMS: Repetitive Trans-Cranial Magnetic Stimulation

- Treat severely depressed patients who are resistant to pharmacology
- Alternative is periodic applications of electro-shock (ECT) treatment
- 30% of patients respond
- Would like to increase percentage of responders

Magnetic Nerve Stimulation (MNS)

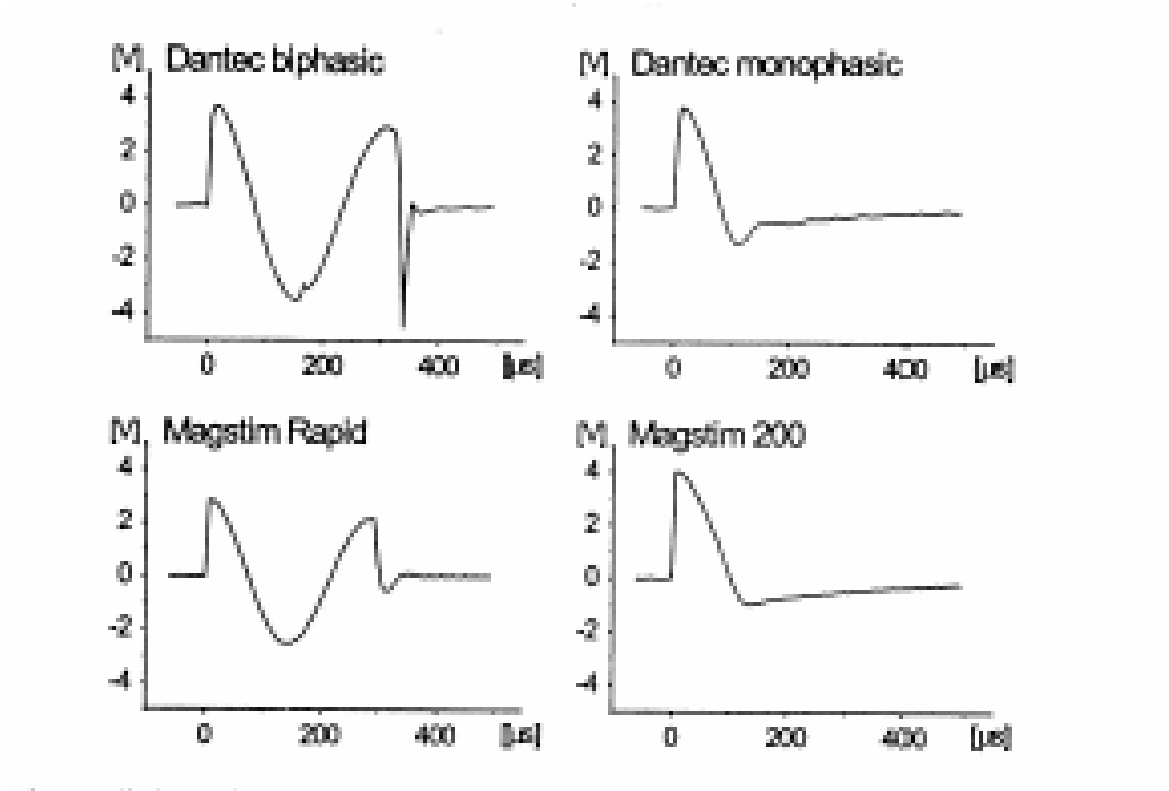




Current Commercial Machines

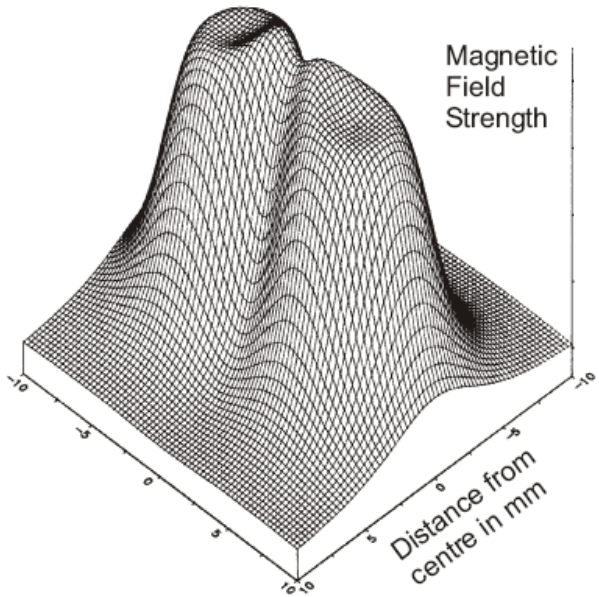
- Example Magstim

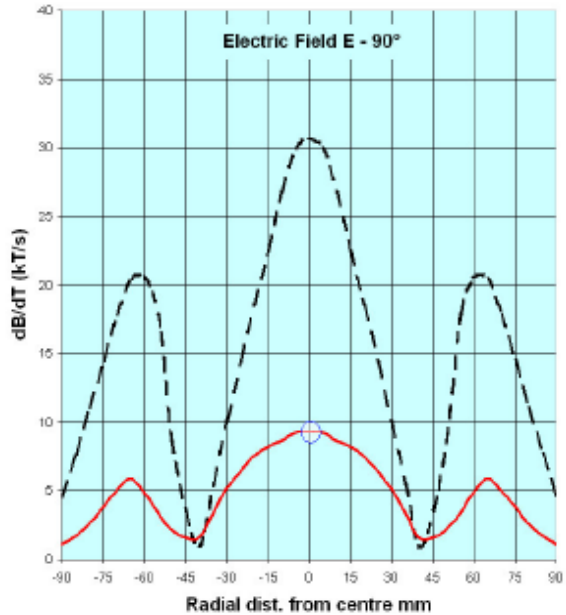
Stimulus Waveforms



Magnetic Field

Source: Medtronic, 2004





Source: Medtronic, 2004

Source: Medtronic, 2004

Treatment Protocol

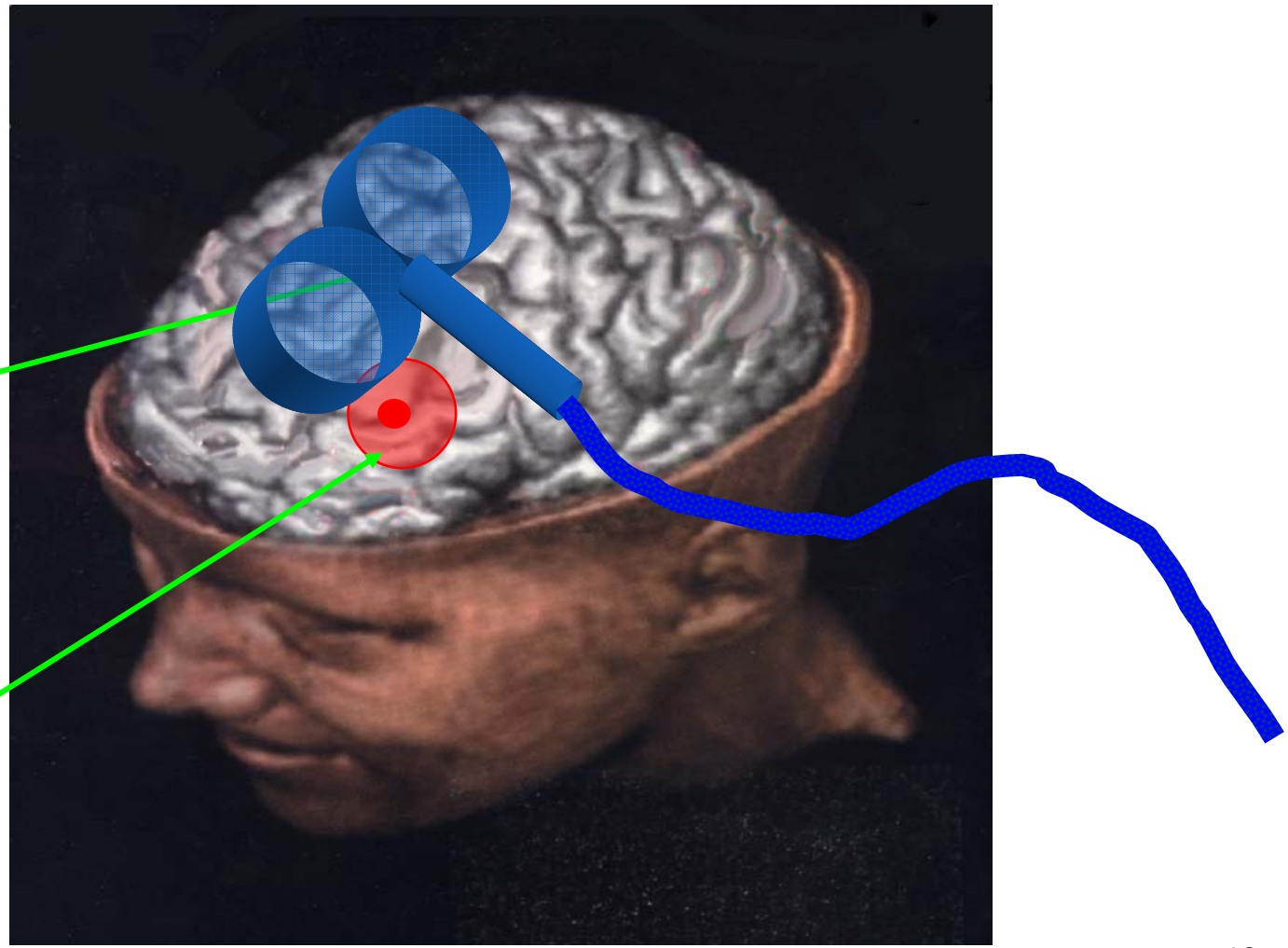
- Find left thenar (abductor pollicis brevis) motor cortex stimulation point by monitoring M-wave of right thenar muscle
- Stimulate left frontal lobe (F3) at point 5 cm anterior to this site on a sagittal line
- Using a fixed % (80 – 120) of thenar threshold amplitude stimulate at 8 to 10 Hz for fixed periods up to 1800 stimuli; several clinics 3000 stimuli
- Repeat 4 to 5 times/week for 5 weeks

Clinical Treatment

Research Challenges (Objectives)

- Develop quantitative method for predicting which patients will respond to rTMS (use pre treatment EEG parameters, QEEG)
- Develop quantitative method for determining best site of stimulation
- Determine effects of changing stimulus amplitude and frequency

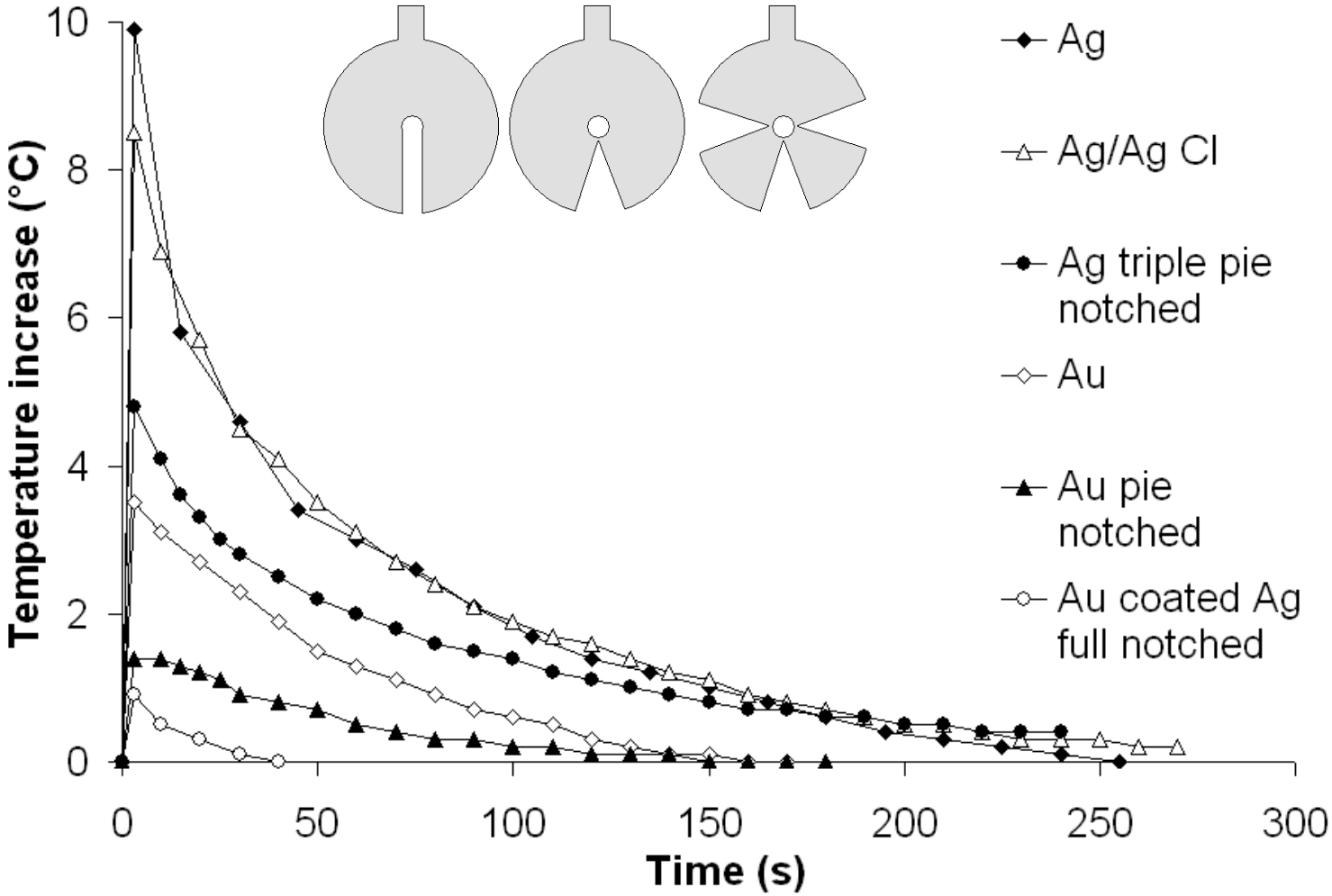
Those with correctable pathophysiology may not respond as standard methods place the coil in the wrong spot (we are not very good at predicting RESPONSE using QEEG)



Magnetically Evoked Potentials (MEP)

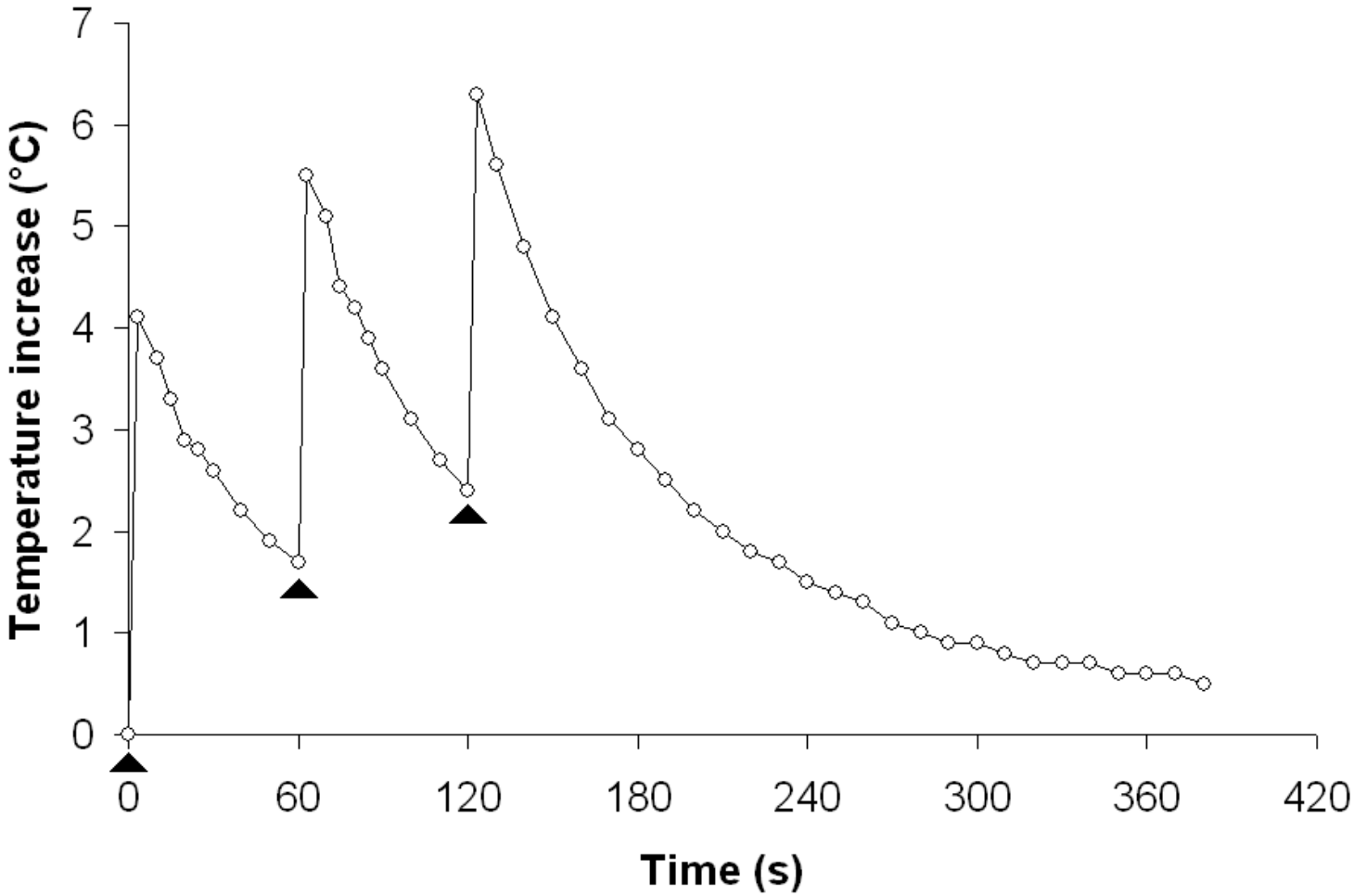
- Assume the neural tissue is a stochastic system
- Require multiple stimuli and synchronous averaging of evoked potentials
- Heating of EEG electrodes during stimulus train
- Saturation of amplifiers by magnetic stimulus artifact

Electrode Materials



3s at 20Hz at 85% intensity, r = -30mm

rTMS Trains of Stimuli

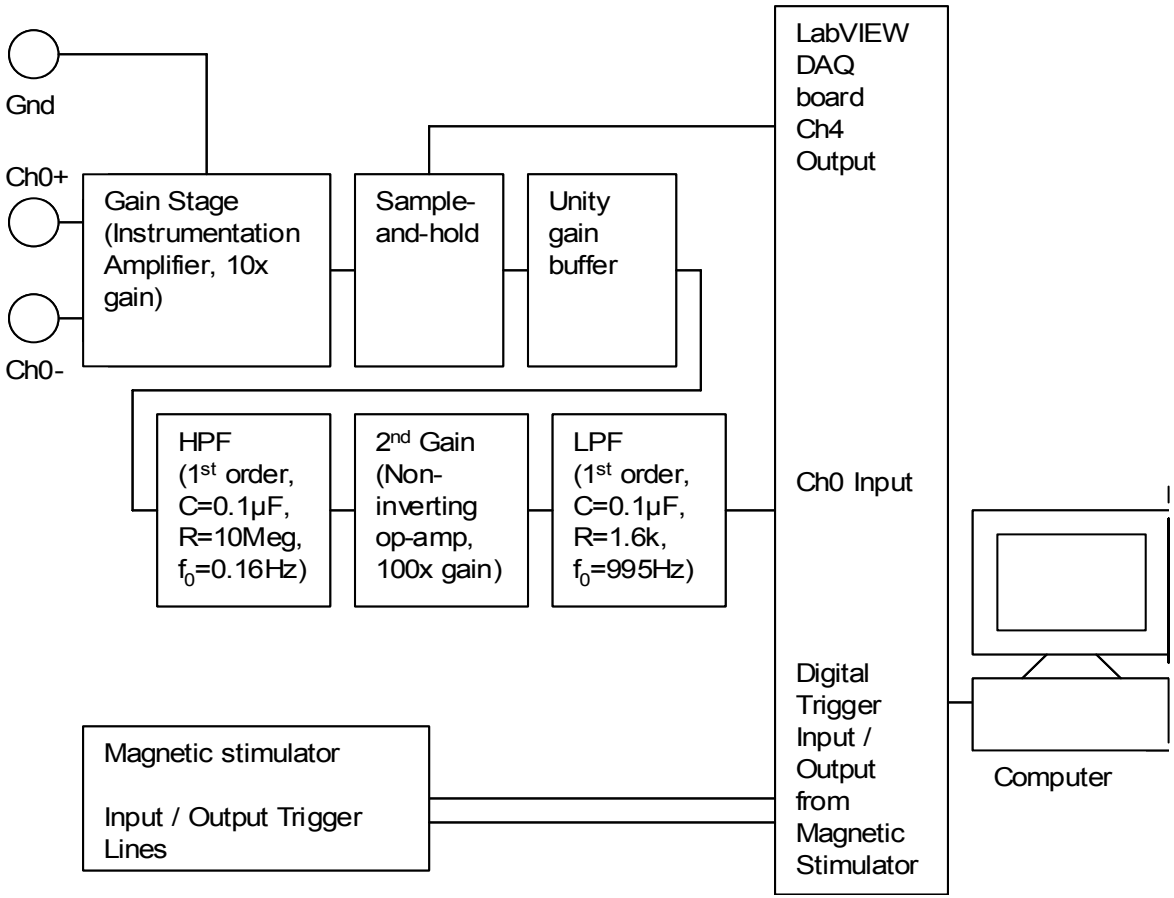


Au electrode, 3s at 20Hz at 85% intensity, trains at 0, 60, 120s

Artifact Blocking

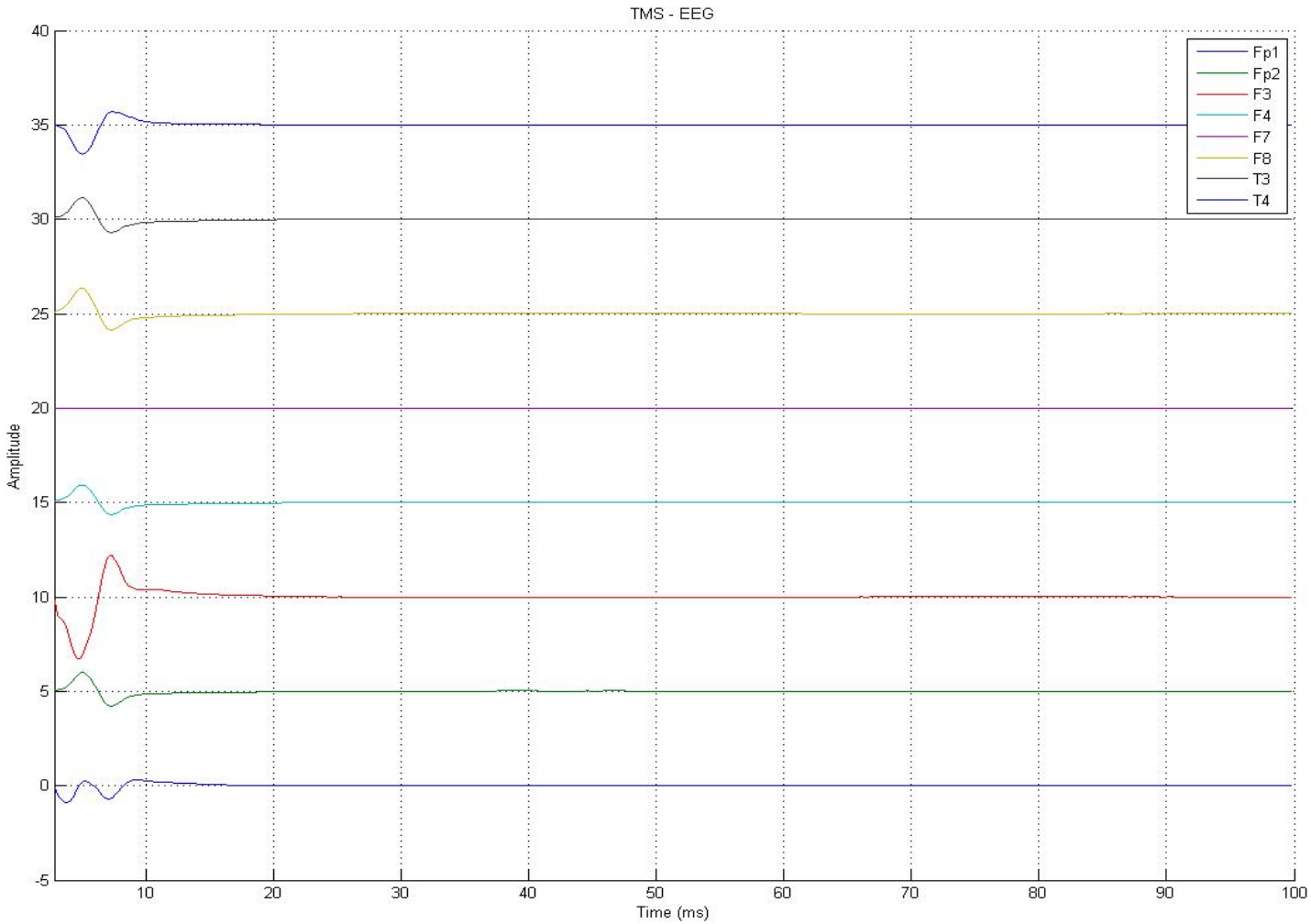
- Various methods have been used:
  - Low slew rate amplifiers (Thut, 2005, Ives, 2006)
    - First 30ms of signal lost and bandwidth reduced
  - High bandwidth amplifiers (Fuggetta, 2005)
    - First 15ms of signal lost
  - Switching off the amplifiers (Shutter, 2006)
    - First 200ms of signal lost
  - Sample-and-hold circuit (Ilmoniemi, 1997)
    - Works, published results ignore or mask first 10 ms

Systems Approach

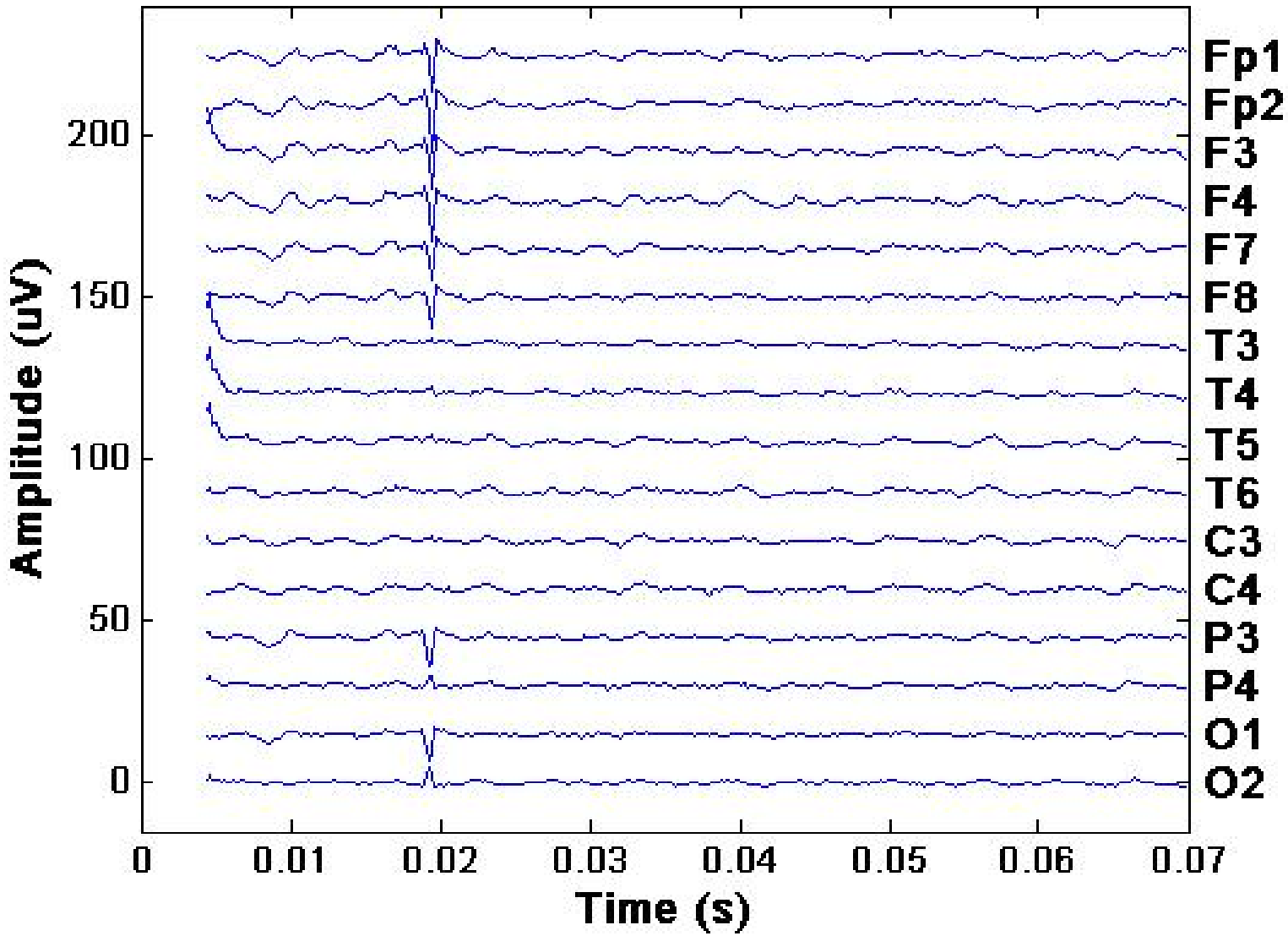


8 Channel Average Results

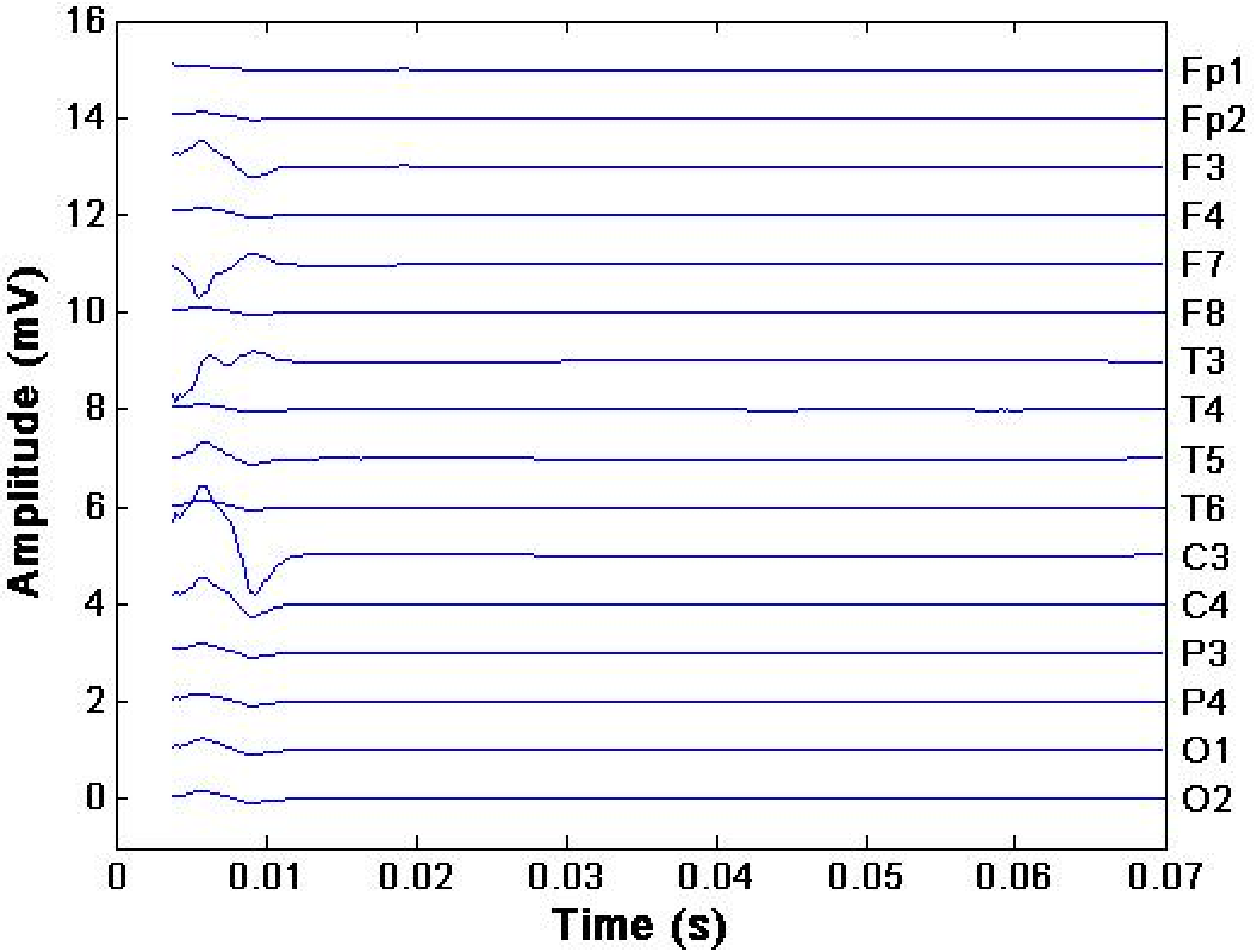
8 Hz, 10 sec, Brodmann 46, 69% max, scale mv



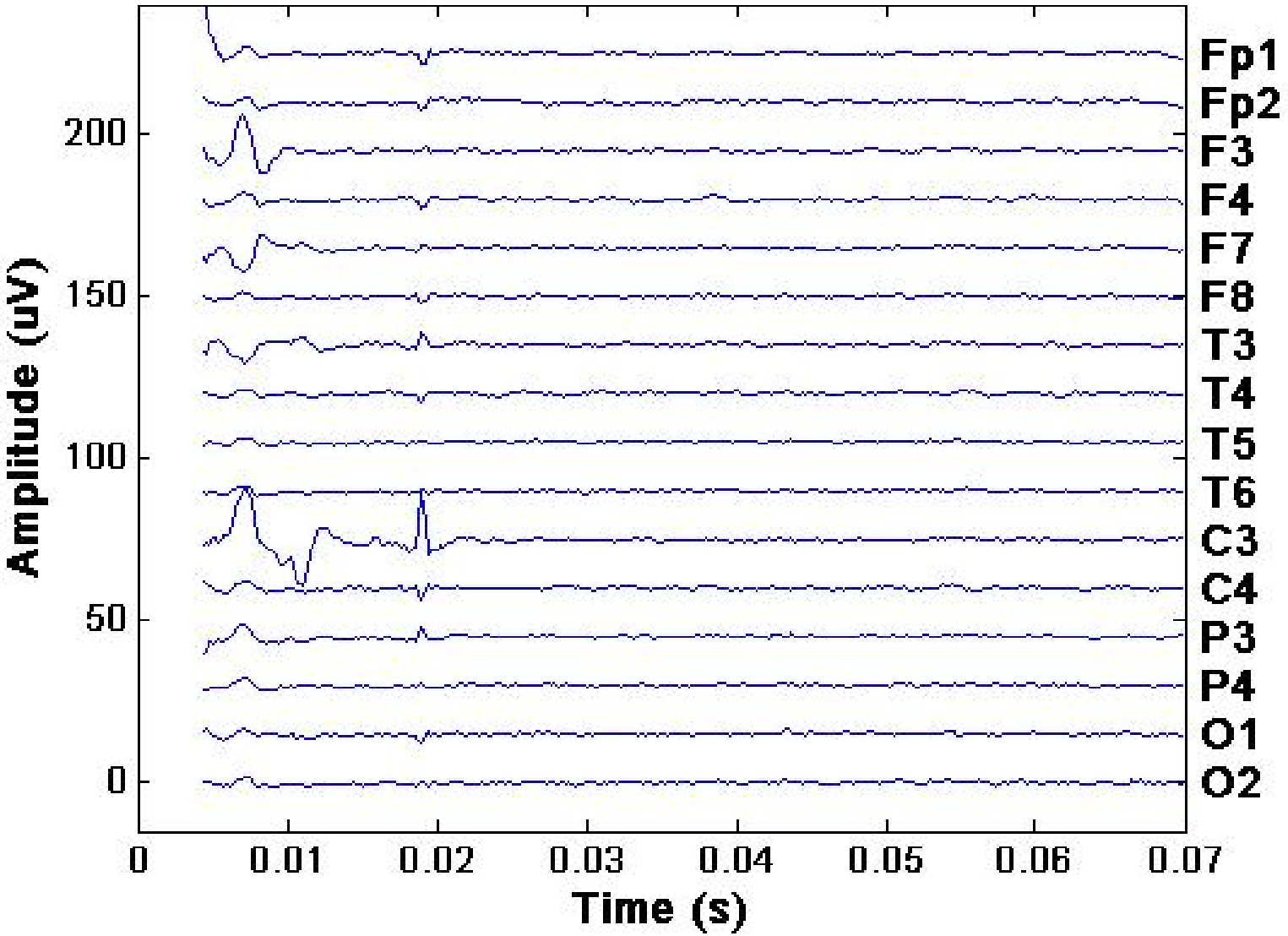
Sham Response to rTMS “Clicks”



Muscle Responses during 10 Hz Left-sided Stimulation



Brain Response to 80 pulses at Left B46



Brain Response to 60 Pulses at Right B46