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CATHOLIC UNIVERSITY**



**SEMMELWEIS
UNIVERSITY**



Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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NEURAL INTERFACES AND PROSTHESES

Neurális interfészek és protézisek

LESSON 11

Prostheses Working on EEG and Single Cell Principles

(EEG és egysejt elven működő protézisek)

BALÁZS DOMBOVÁRI & GYÖRGY KARMOS

IN THIS LECTURE YOU'LL LEARN:

- Definition of Brain-computer interface (BCI)
- The classification of BCIs
- Types of non-invasive BCI systems
- Types of invasive BCI system

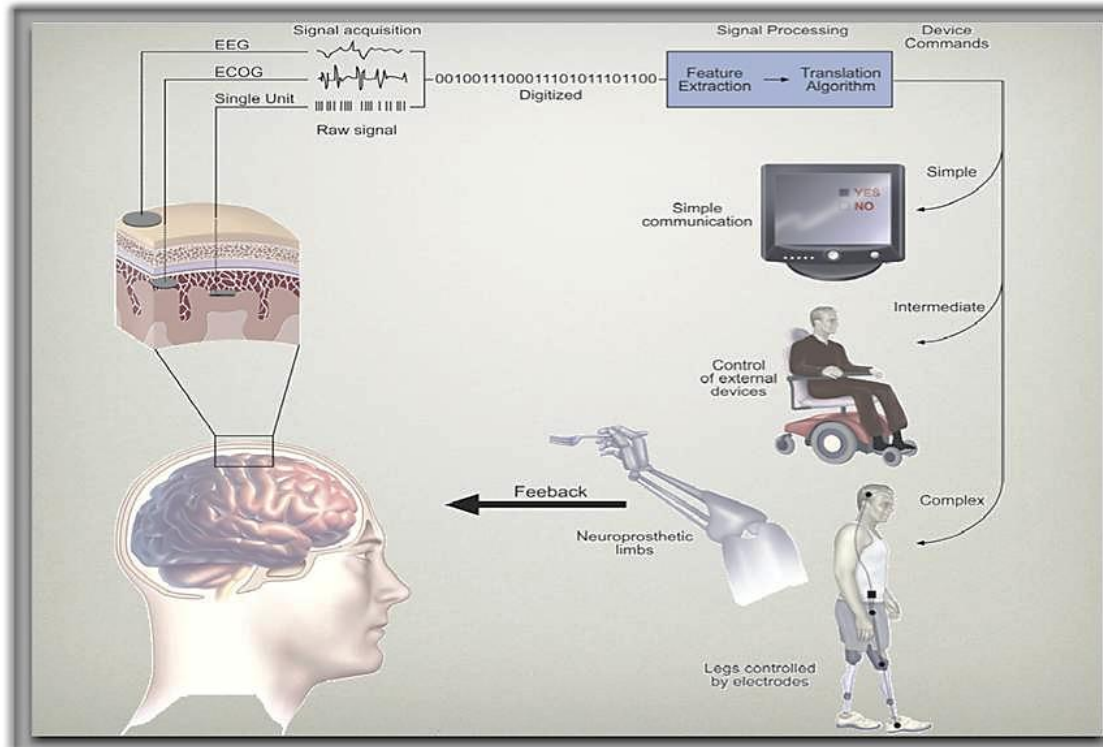
INTRODUCTION

Encouraged by growing recognition of the needs and potentials of people with severe neuromuscular disorders, such as amyotrophic lateral sclerosis, brainstem stroke and spinal cord injury, BCI research programs concentrated on developing new communication and control technologies.

The original goal was to develop a system which is capable to translate the basic wishes of completely paralyzed (locked-in) patients. Nowadays BCIs determine the intents of the patients from several electrophysiological signals (See in the previous lecture: *Physiological Basis Of Brain-Computer Interface*).

Recently the area of BCI applications increased involving the rehabilitation of stroke patients, control of prosthetic devices. Another new area of BCI application is the games and virtual reality. The present day BCI systems are in experimental phase but some noninvasive BCIs are already commercially available.

ESSENTIAL COMPONENTS OF A BCI SYSTEM



<http://www.etsu.edu/cas/bcilab/>

BCI systems comprise four main components (1) electrodes to record brain activity, (2) a ‘decoder’ algorithm that processes the activity to extract control signals about the presumed intentions of the BCI user, (3) an effector to implement the desired action extracted by the decoder, and (4) sensory feedback about the resulting effector action that closes the control loop.

CLASSIFICATION OF BCIS

We separate non-invasive from invasive BCIs:

Non-invasive BCI techniques use brain activity recorded with sensors outside the body boundaries. These may work with:

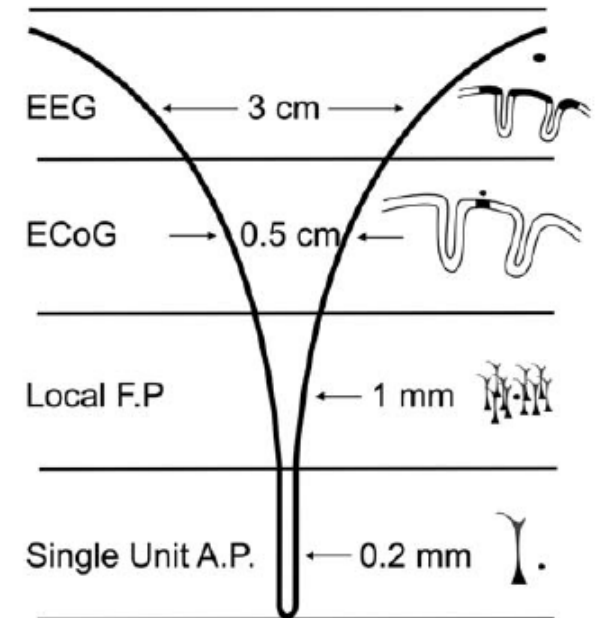
- EEG principle:
 - Slow cortical potentials (SCP),
 - Oscillatory EEG activity,
 - Event-related synchronizations (ERS) and desynchronizations (ERD),
 - Event-related brain potentials (e.g P300, SSVEP),
- BOLD response in fMRI
- Near-infrared spectroscopy (NIRS) measuring cortical blood flow
(The last two type of BCIs are not discussed in this course.)

CLASSIFICATION OF BCIS

Invasive BCI techniques use signals recorded by brain implanted micro- or macroelectrodes:

- Electroencephalogram.
- Synaptic or extracellular local field potential
- Action potentials from neurons or neural fibers

The spatial resolutions of these methods are different.



Schwartz et al., Neuron, 2006

CLASSIFICATION OF BCIS (CONT.)

Recording method	Advantages	Disadvantages
Electroencephalogram	easy and non-invasive	limited topographical resolution and frequency range; may be contaminated by artifacts such as electromyographic (EMG) activity from cranial muscles or electrooculographic (EOG) activity.
Electrocorticogram	better topographical resolution and frequency range	requires implantation of electrode arrays on the cortical surface, which has as yet been done only for short periods (e.g., a few days or weeks) in Humans
Intracortical recording	provides the highest resolution signals	requires insertion of multiple electrode arrays within brain tissue and faces as yet unresolved problems in minimizing tissue damage and scarring and ensuring long-term recording stability.

PROSTHESES WORKING ON EEG PRINCIPLE

A History of EEG-Based Neuroprosthetics

1963 EEG operates typewriter (Grey Walter)

1972 Visual evoked potential used to navigate maze (Vidal)

1980 Slow cortical potentials control virtual rocketship (Birbaumer)

1988 P300 evoked potential used to operate simple word processor (Donchin)

1991-94 Sensorimotor rhythms control 1- and 2D cursor movement (Wolpaw/McFarland)

1998 An ALS patient uses slow cortical potentials to write a letter (Birbaumer)

2000 A SCI Patient uses SMRs to control a simple orthosis (Pfurtscheller)

2004 An adaptive SMR BCI provides better 2-D control (Wolpaw/McFarland)

2006 A few ALS patients begin home use of a P300 BCI (Vaughan/Wolpaw)

<http://www.nyas.org/MediaPlayer.aspx?mid=110a9ade-277d-4b7b-a401-b1906fea9afd>

EEG-BASED BCIs GENERATES CONTINUOUS OUTPUT SIGNALS THAT DRIVE COMPUTER CURSORS

Several principles of operation have been suggested for such systems. Some groups suggested using slow cortical potentials or mu and beta rhythms.

In an attempt to direct the cursor to a particular location on the screen, the subjects often use motor imagery, for example, imagine moving the foot or hand.

Computer algorithms were developed that detect event-related desynchronization (ERD) and synchronization (ERS) of the EEGs associated with such imagery.

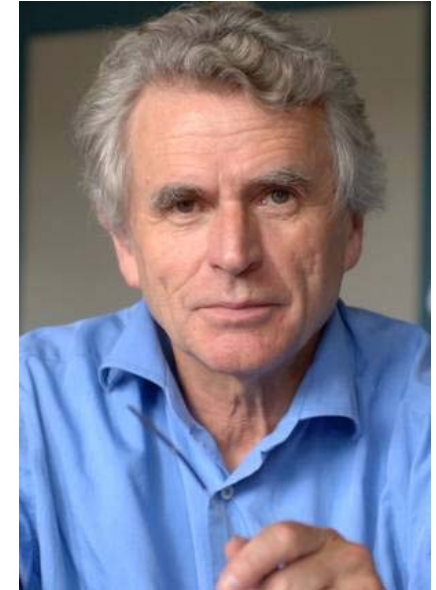
Event-related potentials like P300 and visual steady state response are also used as input for BCIs.

NON-INVASIVE BCI BASED ON SLOW CORTICAL POTENTIAL (SCP)

Birbaumer and colleagues were the first who developed BCI system for ALS (in details see in previous lecture) patients, Their system used slow potential changes.

Slow cortical potentials are low frequency potentials (e.g., less than 1 Hz) recorded from the scalp and are associated with various cognitive or sensory-motor events. Decreased cortical activation is associated with scalp positivity and increased activation is associated with negativity.

Patients are trained to modify SCPs based on feedback and use this paradigm for BCI-based communication (Thought Translation Device).



Niels Birbaumer
Professor and Director
Institute of Medical Psychology
and Behavioral Neurobiology,
University of Tübingen,
Faculty of Medicine.

THOUGHT TRANSLATION DEVICE (TTD)

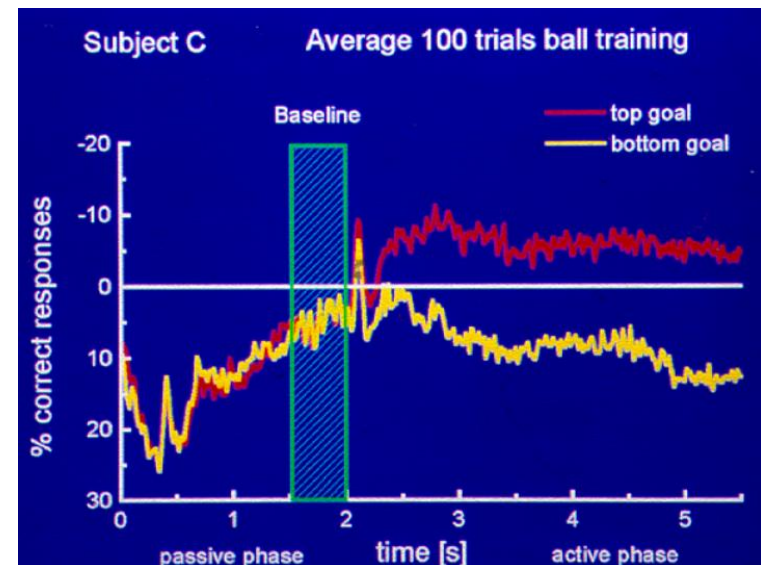
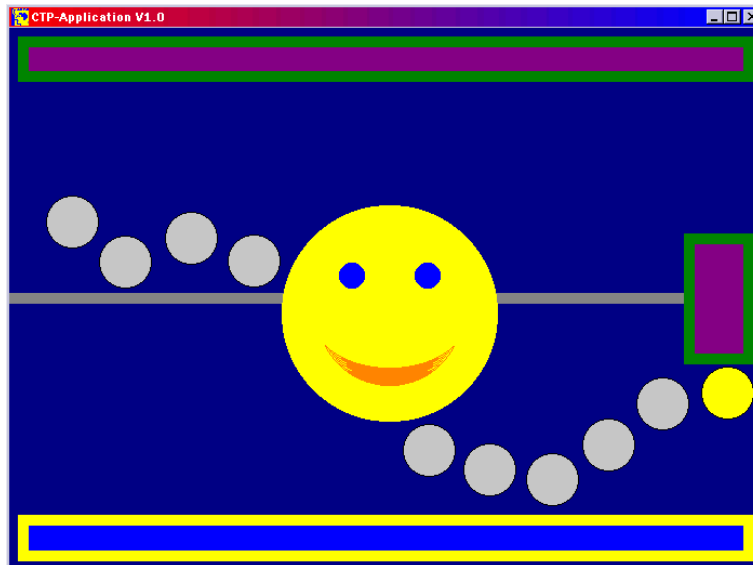
TTD is a Brain-Computer Interface for the completely paralyzed (LIS) patients using slow-cortical potentials (SCP) to move a cursor on a monitor to select letters. TTD is a feedback device which enables people to respond by voluntary SCP changes.

During the training phase, the self-regulation of SCPs is learned through visual-auditory feedback and positive reinforcement. During the spelling phase, patients select letters or words with their SCPs.

A psychophysiological system for detection of cognitive functioning in completely paralyzed patients is an integral part of the TTD.

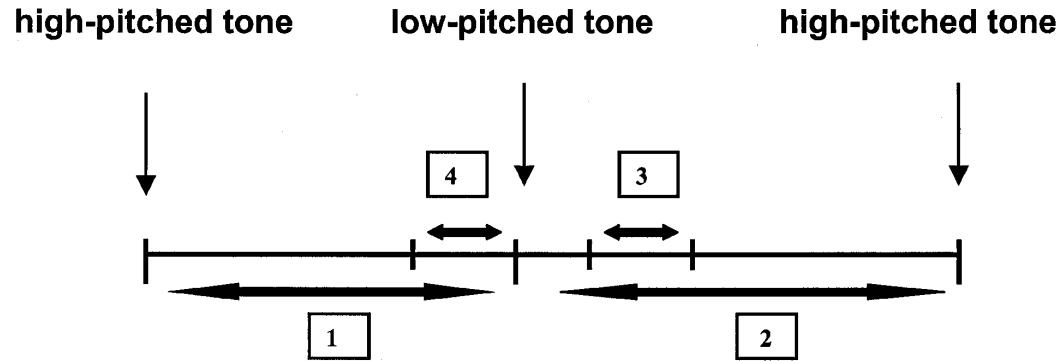
THOUGHT TRANSLATION DEVICE (TTD)

In the standard form, users receive visual feedback about their performance from a computer screen with two choices on bottom and on top (see left picture). The user's corresponding SCP responses are on the right picture. Selection takes around four seconds. TTDs with auditory or even tactile feedback are also available.



http://videlectures.net/bbci09_birbaumer_bip/

THOUGHT TRANSLATION DEVICE (TTD)



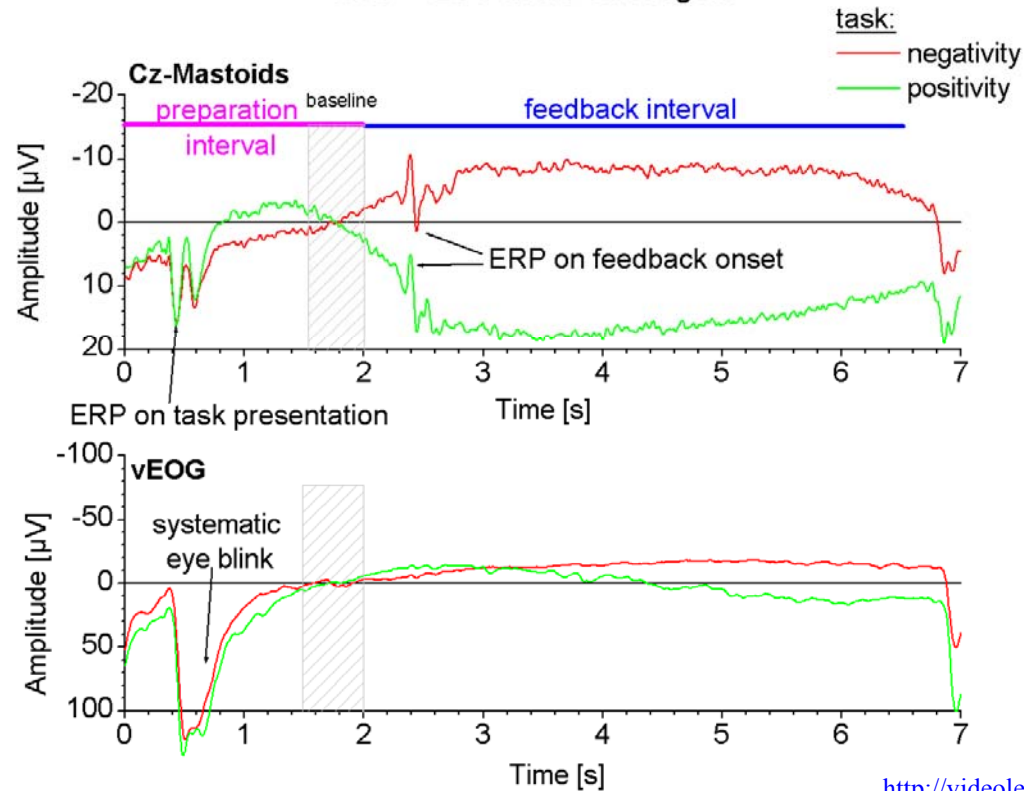
- | | | |
|----------|---------------------------------|---------------------------------|
| 1 | passive phase: | 2 seconds |
| 2 | active (feedback) phase: | 2 to 6 seconds |
| 3 | cursor movement: | 0.5 seconds to 6 seconds |
| 4 | baseline | 0.5 seconds |

http://videlectures.net/bbci09_birbaumer_bip/

Time course of a selection cycle. It begins with a warning high-pitched tone, the feedback phase is marked with a low-pitched tone.

THOUGHT TRANSLATION DEVICE (TTD)

SCP Training with BCI 2000: VP 3 S 2
259 + 231 trials averaged



http://videlectures.net/bbci09_birbaumer_bip/

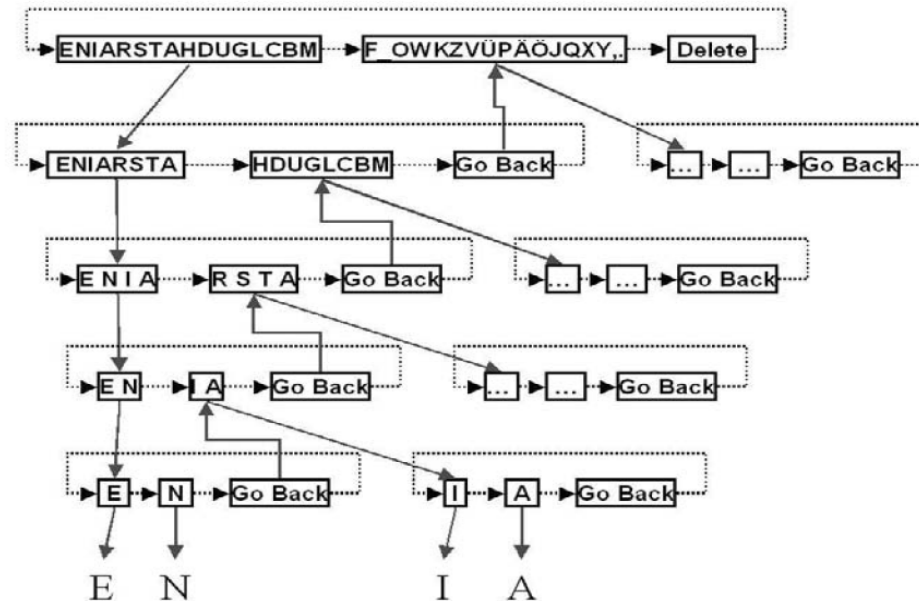
LANGUAGE SUPPORT PROGRAM

Trial	Letter Bank on the Screen	Response Type
1	ENIRSTAHDUGLCBMF	Selection
2	ENIRSTAH	Selection
3	ENIR	Non-response
4	STAH	Selection
5	ST	Non-response
6	AH	Selection
7	A	Non-response
8	H	Selection

http://videlectures.net/bbci09_birbaumer_bip/

Thought translation device makes possible letter selection. The string of letters can be divide into halves by the up or down shift of the SCP. This way the totally paralyzed patient can write or give commands.

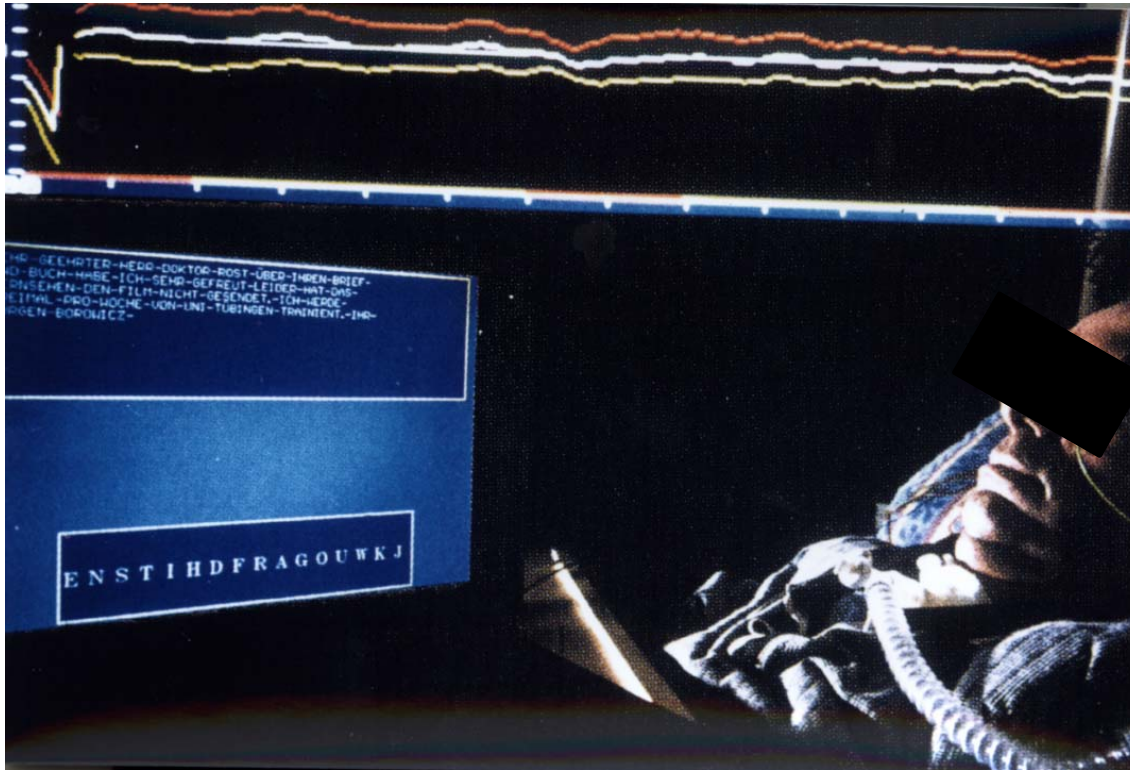
SCHEMATIC STRUCTURE OF THE LANGUAGE SUPPORT PROGRAM



Boxes show letter sets offered during one trial; solid arrows show the subsequent presentation when a select response is produced; dotted arrows show the presentation following a reject response. At all except the uppermost level, failure to select one of the two choices results in the presentation of a “go back” option taking the user back to the previous level.

http://videlectures.net/bbci09_birbaumer_bip/

LANGUAGE SUPPORT PROGRAM



http://videolectures.net/bbci09_birbaumer_bip/

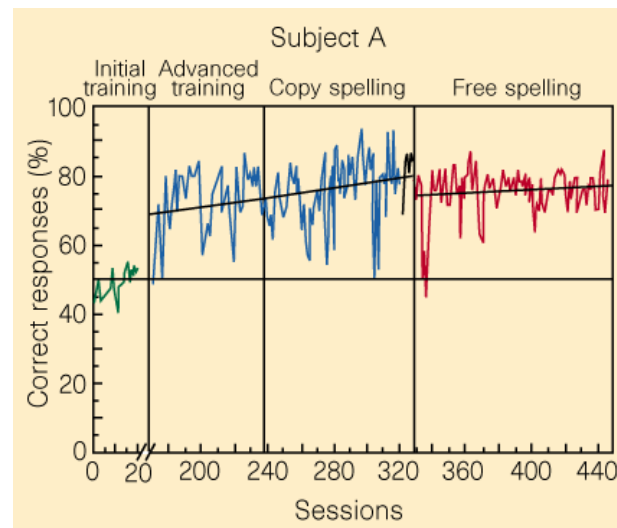
A patient in front of the monitor of the Thought Translation Device.

LANGUAGE SUPPORT PROGRAM

LIEBER-HERR-BIRBAUMER-

HOFFENTLICH-KOMMEN-SIE-MICH-BESUCHEN,-WENN-DIESER-BRIEF-SIE-ERREICHT-HAT-.ICH-DANKE-IHNEN-UND-IHREM-TEAM-UND-BESONDERS-FRAU-KÜBLER-SEHR-HERZLICH,-DENN-SIE-ALLE-HABEN-MICH-ZUM-ABC-SCHÜTZEN-GEMACHT,-DER-OFT-DIE-RICHTIGEN-BUCHSTABEN-TRIFFT.FRAU-KÜBLER-IST-EINE-MOTIVATIONSKÜNSTLERIN.OHNE-SIE-WÄRE-DIESER-BRIEF-NICHT-ZUSTANDE-GEKOMMEN.-ER-MUSS-GEFEIERT-WERDEN.-DAZU-MÖCHTE-ICH-SIE-UND-IHR-TEAM-HERZLICH-EINLADEN-.EINE-GELEGENHEIT-FINDET-SICH-HOFFENTLICH-BALD.

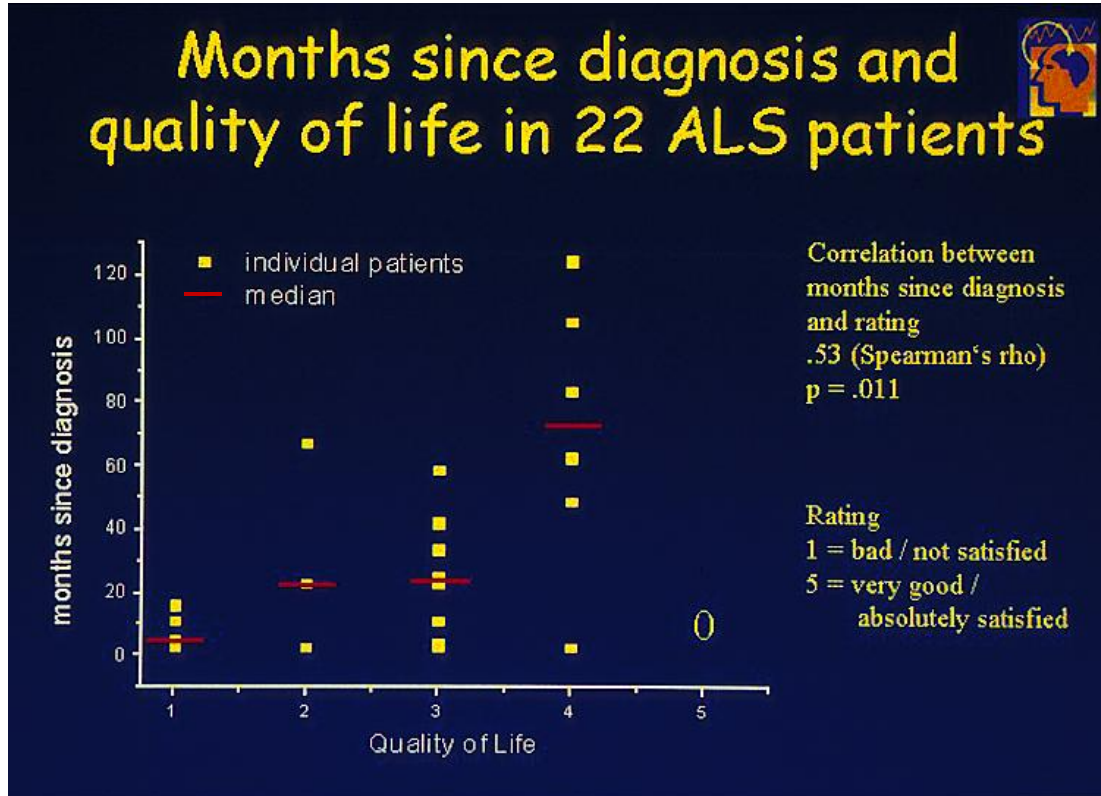
MIT-BESTEN-GRÜSSEN-
IHR-HANS-PETER-SALZMANN



Birbaumer et al., Nature, 1999

Letter written by an ALS patient. The acquire of the language support program needs a long training period when the patient learns the letter selection. This letter was written in about eight hours.

QUALITY OF LIFE OF ALS PATIENTS



The self rated quality of life of the ALS patients improve in time and as a result of the possibility of communication by BCI.

http://videlectures.net/bbci09_birbaumer_bip/

EVENT-RELATED DESYNCHRONIZATION (ERD) AND EVENT-RELATED SYNCHRONIZATION (ERS)

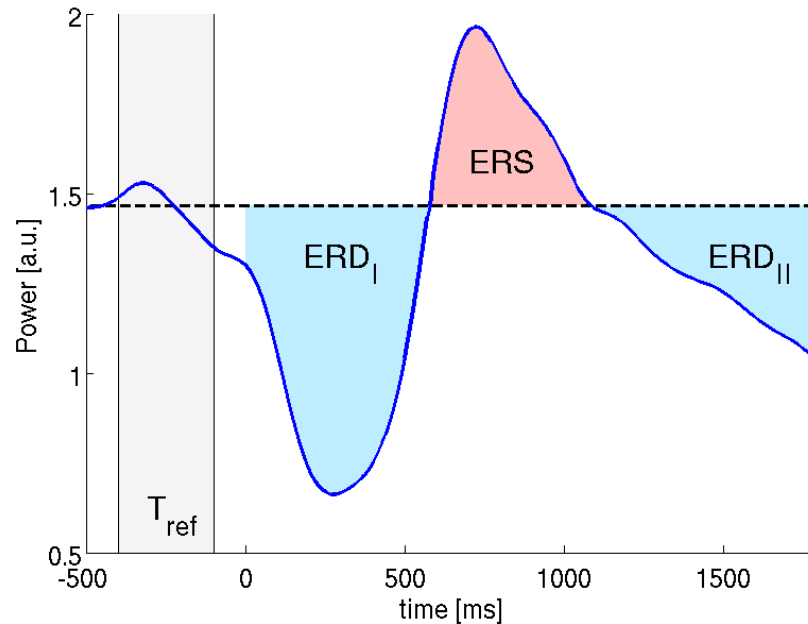
ERD is amplitude attenuation and ERS is amplitude enhancement of a certain EEG rhythm time locked to an event. To improve the signal-to-noise ratio simple averaging over trials cannot be applied. To overcome this problem Pfurtscheller introduced a non-stationary analysis method based on an event-related paradigm.

The ERD/ERS can be estimated in subject-dependent frequency bands. The outcome of the ERD analysis resembles in some way an averaged evoked response signal with a temporal profile depending on the mean power ratio of the EEG in the actual measurement interval and a reference interval.



Gert Pfurtscheller
Professor Emeritus
Institute for Knowledge Discovery
Lab. of Brain-Computer Interfaces
Graz University of Technology

EVENT-RELATED DESYNCHRONIZATION AND EVENT-RELATED SYNCHRONIZATION



ERD measures the deviation of the event-related dynamics (blue solid line) from a constant baseline level (black dashed line) that is obtained as averaged power in the reference period T_{ref} .

Lemm S. et al. PLoS Comput Biol, 2009

CHARACTERISTICS OF THE ERD/ERS

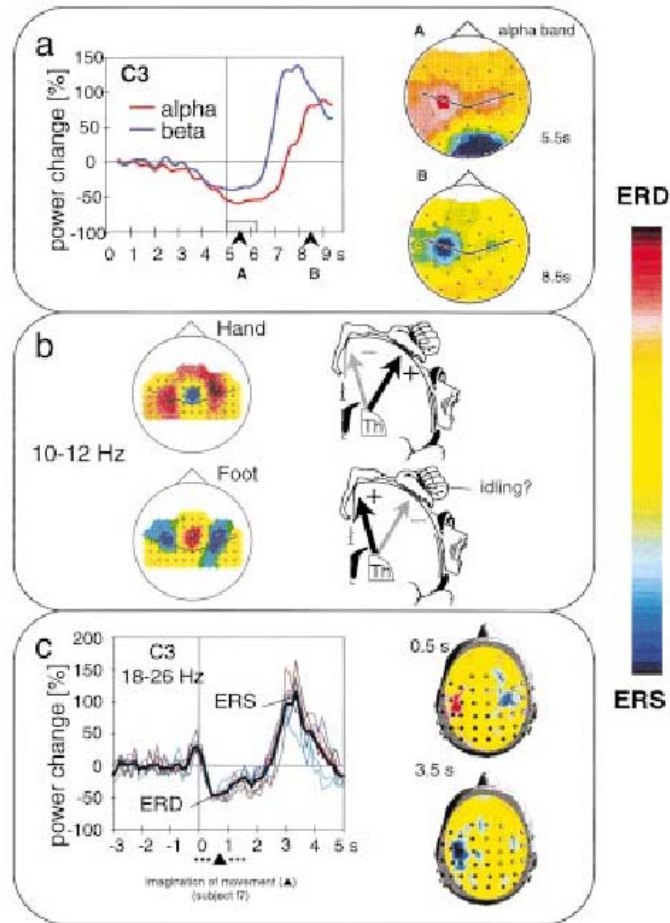
ERD and ERS appear above the motor area of the neocortex at self-paced movements. The localization of ERD as well as the ERS corresponds to the cortical representation of the given movement.

ERD is amplitude attenuation in the alpha band before and at the beginning of the movement; ERS is amplitude enhancement in the beta band after the completion of the movement.

The ERD and ESD also develop at passive movements and movements imagination without the real movement. This means that they can be used in totally paralyzed patients as an input to a BCI system.

The Pfurtscheller group used the ERD/ERS to control a hand orthosis in a tetraplegic patient with high level spinal cord injury.

CHARACTERISTICS OF THE ERD/ERS



- (a) Grand average ERD curves calculated in the alpha and beta bands in a **right hand movement task** (left side). Grand average maps calculated for a 125 ms interval during movement (A) and after movement-offset in the recovery period (B) (right side).
- (b) Maps displaying ERD and ERS for an interval of 125 ms during voluntary movement of the **hand** (left, upper panel) and movement of the **foot** (left, lower panel). The motor homunculus with a possible mechanism of cortical activation/deactivation gated by thalamic structures is shown on the right.
- (c) Superimposed ERD curves with beta rebound from eight sessions with **right motor imagery** in one subject. Analyzed frequency band 18 ± 26 Hz, EEG recorded from electrode position C3. In addition to the individual curves also the grand average ERD curve is plotted (left side). ERD maps from one session displaying simultaneous contralateral ERD and ipsilateral ERS during and contralateral ERS after motor imagery (right side). The scalp electrode positions are marked, (modified from Pfurtscheller et al., 1997c). 'Red' indicates power decrease or ERD and 'blue' power increase or ERS.

Pfurtscheller and Lopes da Silva, Clin. Neurophysiol. 1999

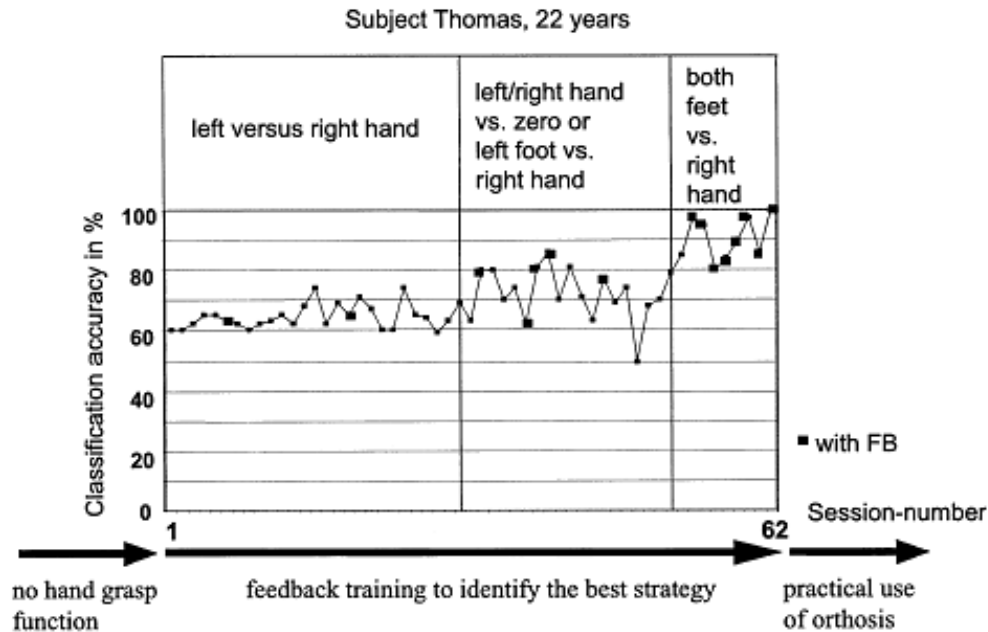
HAND ORTHOSIS IN A TETRAPLEGIC PATIENT CONTROLLED BY BRAIN OSCILLATION



Pfurtscheller et al., Neuroscience Letters, 2000

Patient T.S. with hardware components of the portable brain-computer interface. On the patient's left hand, the electrical driven hand orthosis can be seen.

HAND ORTHOSIS IN A TETRAPLEGIC PATIENT CONTROLLED BY BRAIN OSCILLATION

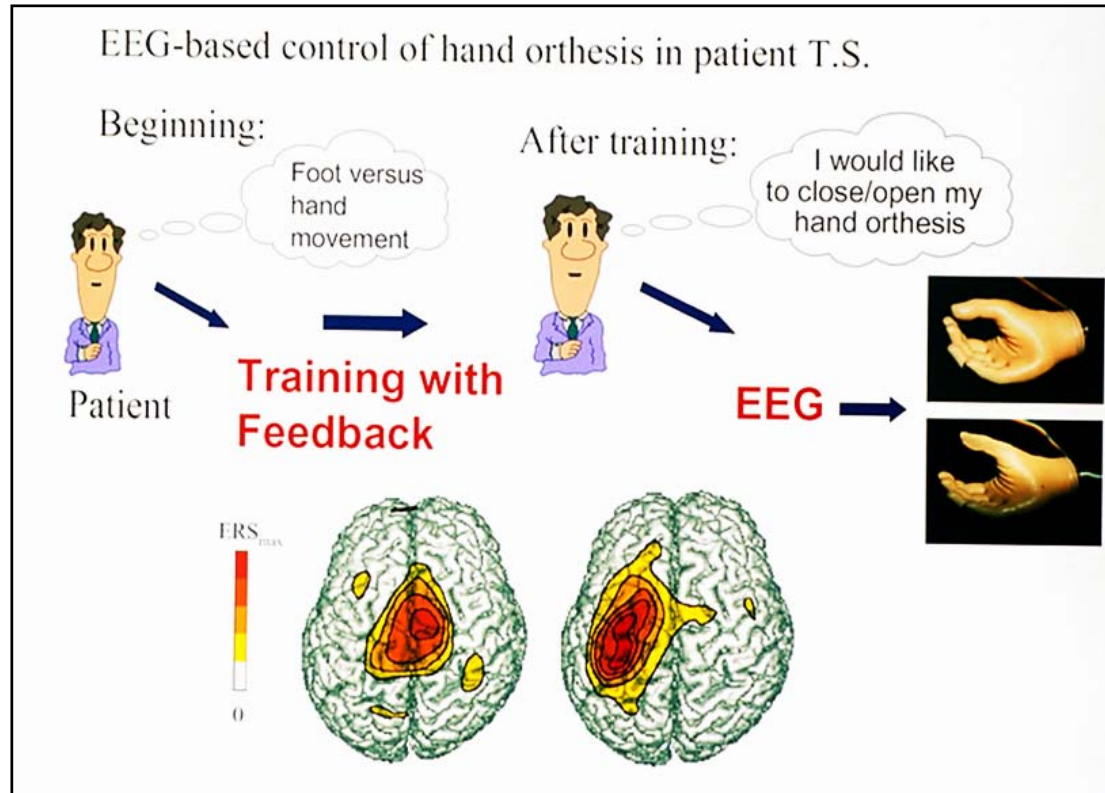


Time courses of the band power in the reactive beta frequency range for three characteristic sessions (# 33, 55 and 62). Classification accuracy (calculated for 160 trials per session) over a time span of 5 months.

FB indicates sessions with feedback. T.S. started with a classification accuracy of about 65% and ended with an accuracy of nearly 100%.

Pfurtscheller et al., Neuroscience Letters, 2000

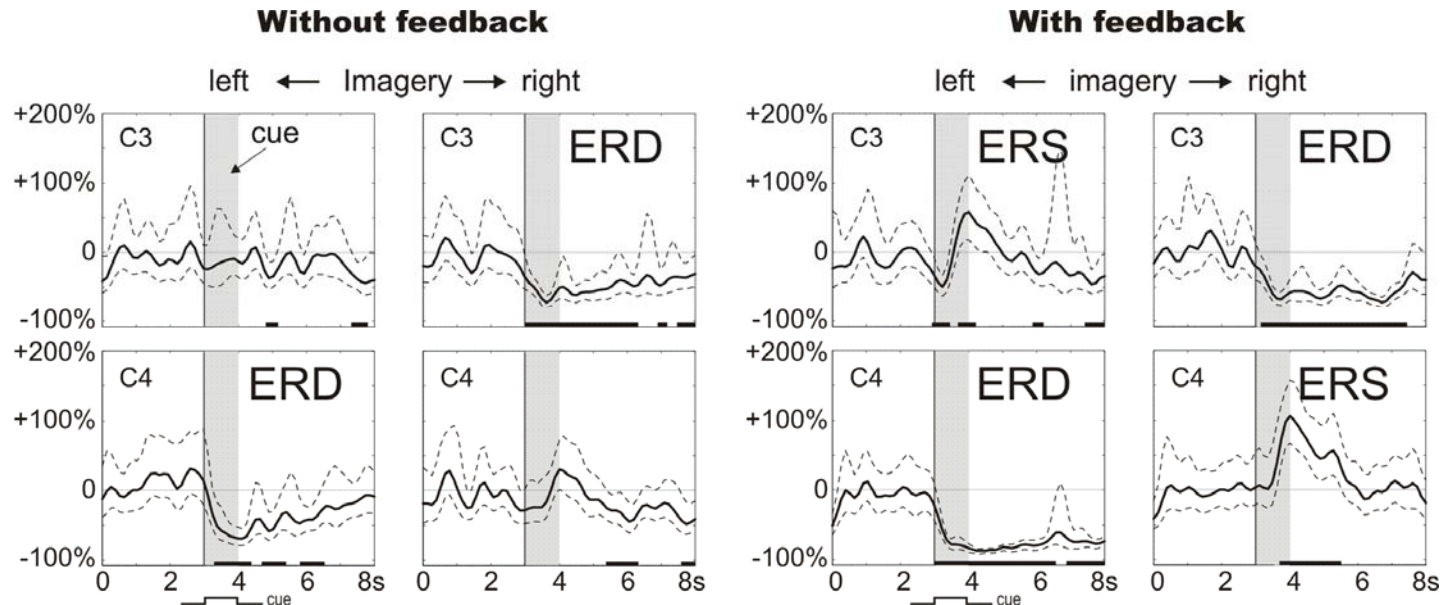
HAND ORTHOSIS IN A TETRAPLEGIC PATIENT CONTROLLED BY BRAIN OSCILLATION



Pfurtscheller et al., Neuroscience Letters, 2000

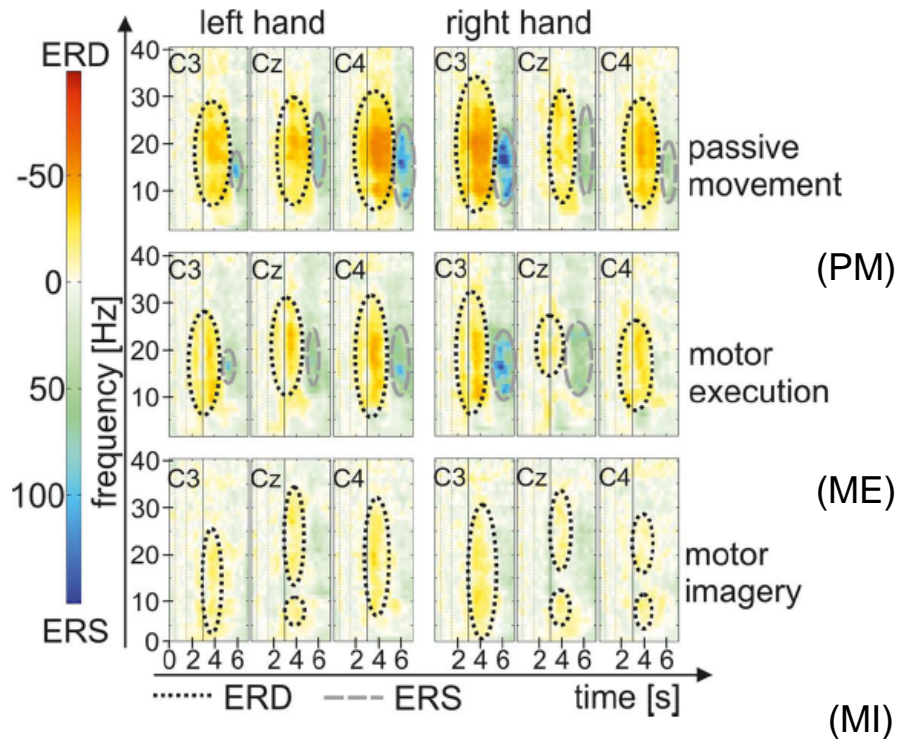
THE ROLE OF FEEDBACK IN LEARNING

ERD/ERS PARADIGM



Band power (11-13 Hz) time courses $\pm 95\%$ confidence interval displaying ERD and ERS from training session without feedback (left) and session with feedback (right). These data are from one able-bodied subject while he imagined left and right hand movement. Grey areas indicate the time of cue presentation. Sites C3 and C4 are located over the left and right sensorimotor areas of the brain, respectively.

CHARACTERISTICS OF THE ERD/ERS



Grand average (15 participants) time frequency maps of PM, ME, and MI are plotted for the left and right hand. The ERD/ERS pattern for the different motor tasks show ERD during movement or movement imagination, especially in α - and β -frequency bands, which turns to an ERS after termination of movement. *The patterns are most pronounced during PM followed by ME and weakest during MI. After MI only weak ERS can be observed.*

Kaiser et al. Front. Neurosci. (2011) 5:86. doi: 10.3389/fnins.2011.00086

More about the Graz BCI group can be found at their homepage: <http://bci.tugraz.at>

P300-BASED BCI

This type of BCI uses the P300 component of the event-related brain potential.

The P300 BCI system described by the Donchin's group consists a matrix of letters or other symbols on the monitor. Rows or columns of the matrix are flashing randomly in rapid succession.

The flashing letter or symbol that the user wants to select produces a P300 potential. By detecting this P300 potential, the BCI system can determine the user's choice.



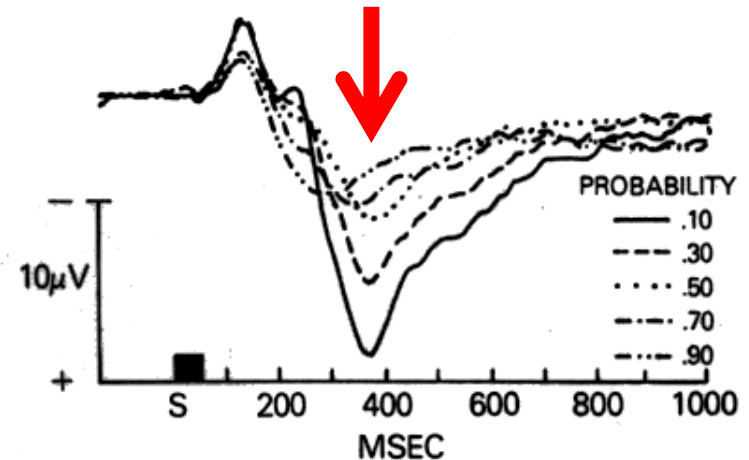
Emanuel Donchin
Emeritus Professor
Department of Psychology
Univ. of Illinois in Urbana-Champaign

CHARACTERISTICS OF THE P300

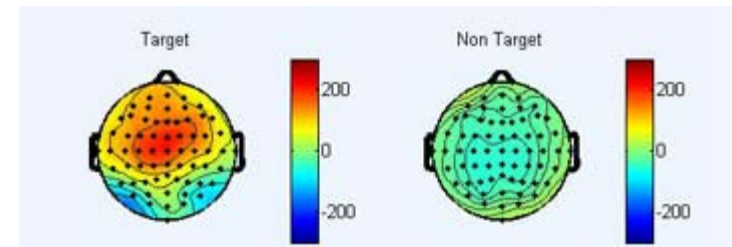
Amplitude of P300 is sensitive to stimulus probability, meaning of the stimulus, and the psychological resources allocated to the processing of it. The more complex are the stimuli to be processed the latency of the P300 is longer.

The P300 has a distinct scalp distribution.
It is typically largest over the Pz site.

P300 BCIs require no training.

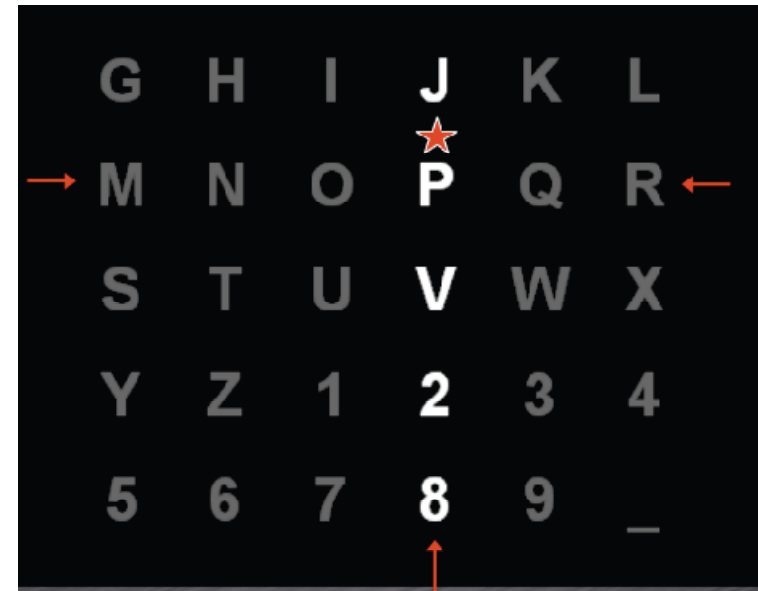


Johnson 1986



LETTER MATRIX USED BY THE DONCHIN GROUP

Choose one letter or command					
A	G	M	S	Y	*
B	H	N	T	Z	*
C	I	O	U	*	TALK
D	J	P	V	FLN	SPAC
E	K	Q	W	*	BKSP
F	L	R	X	SPL	QUIT



Farwell and Donchin, *Electroenceph. clin. Neurophys.*, 1988

The rows and the columns of the matrix are briefly flashed in sequence. The user is asked to count each flash of one element, called the “target,” and ignore other flashes. 6x6 matrix, 100 ms flash, ISI (inter stimulus interval): 175-250 ms

DEMONSTRATION OF P300-BASED BCI

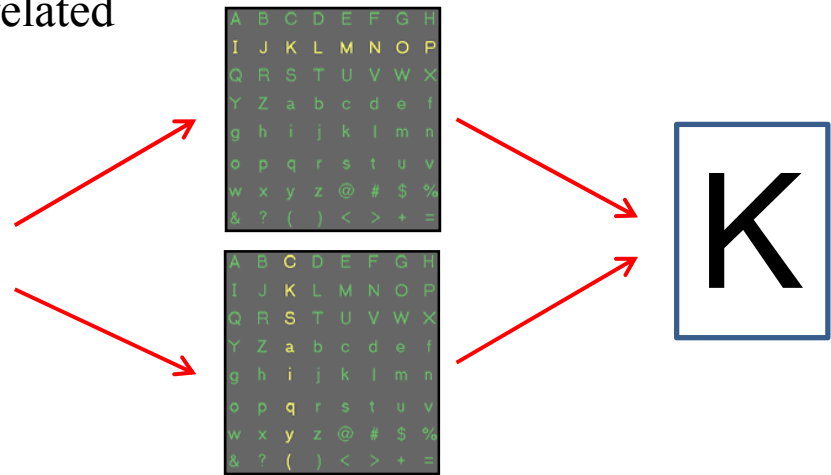
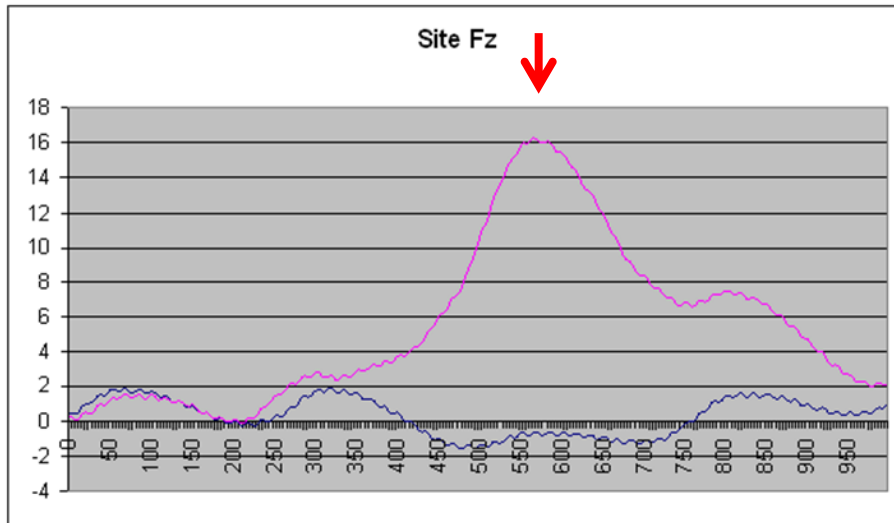


The P300 BCI does not need long training, different laboratories introduced and it is widely used as prototype of BCI.

<http://www.physorg.com/news159453062.html>

P300 BCI can be used to control robot arm:

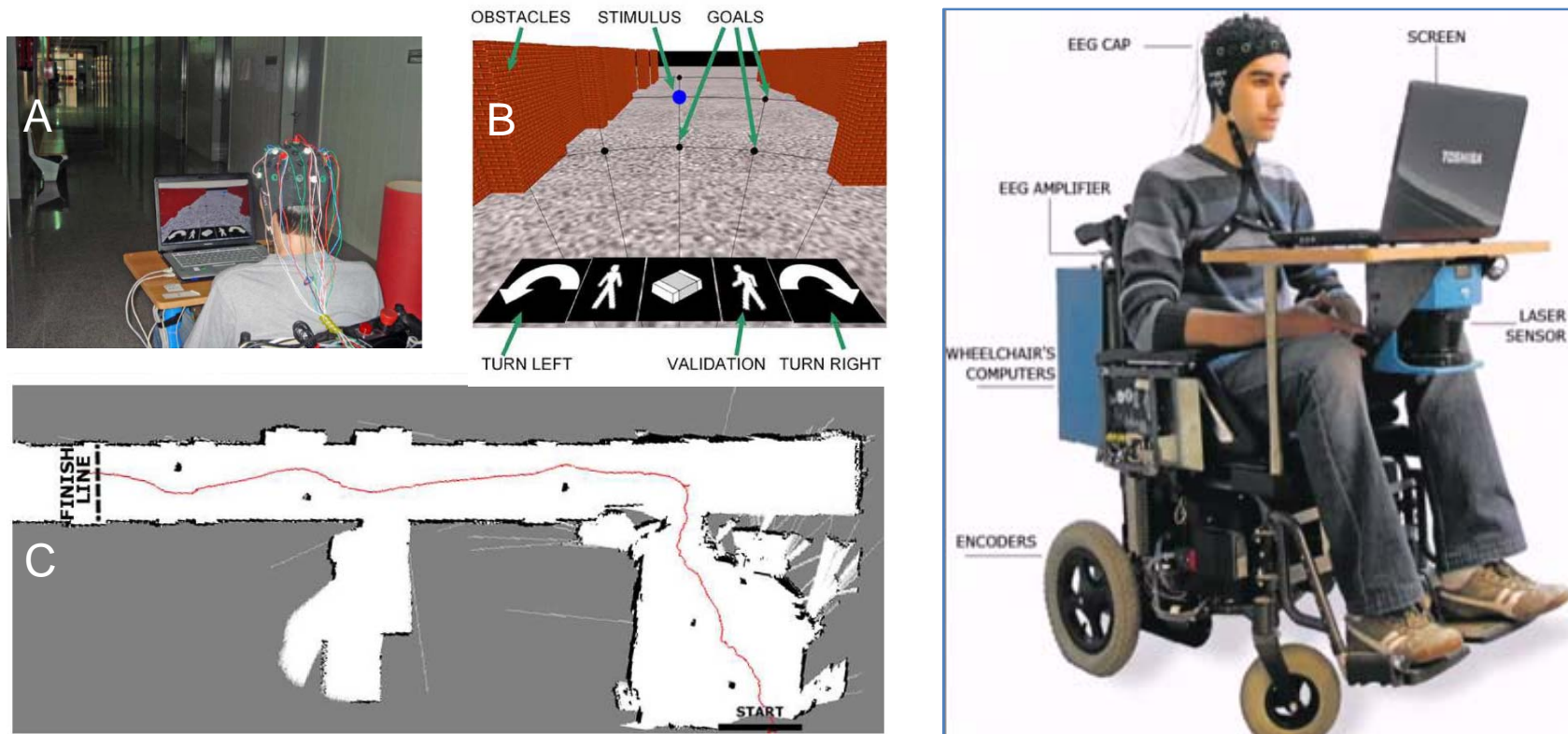
<http://www.youtube.com/watch?v=hs5L6EmOB2M&feature=related>



<http://www.scribd.com/doc/27142772/BCI-Systems>

Averaged data from a P300 BCI at the NextFest Expo (Allison, 2004)

P300 BCI CONTROLLED WHEELCHAIR



A-B: Information represented in the visual display, which is an environment abstraction displayed from the user's point of view. Stimuli are flashing dots showing the directions. C: Map generated by the autonomous navigation system and the trajectory of the wheelchair in one real experiment.

<http://webdiis.unizar.es/~jminguez/wheelchair> Iturrate et al., IEEE Trans. Robotics, 2009, 25: 614-627.

BCI BASED ON MU RHYTHM

Different noninvasive BCI methods were developed in the Wolpaw laboratory. They use the mu rhythm of the EEG. Mu rhythm is a 8-14 Hz “idling” rhythm found over primary motor/somatosensory cortex. These areas are located around the central sulcus. The mu rhythm is largest over central sites such as C3, Cz, or C4. Mu rhythm is often called sensorimotor rhythm (SMR).

Mu activity is visible before a voluntary movement, sometimes 2 seconds before it begins. Mu activity reflects movement planning and execution.

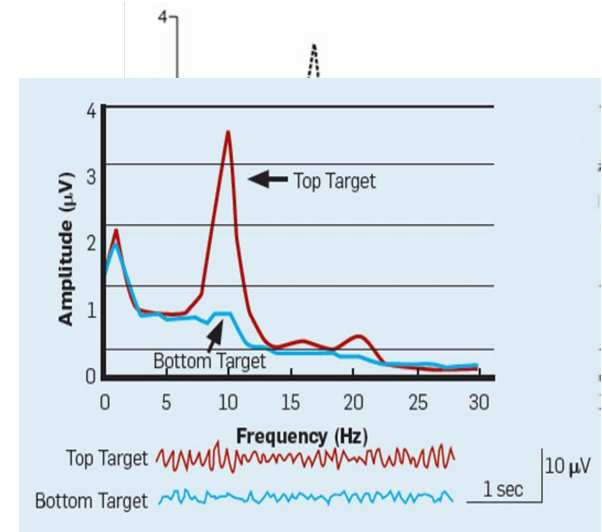
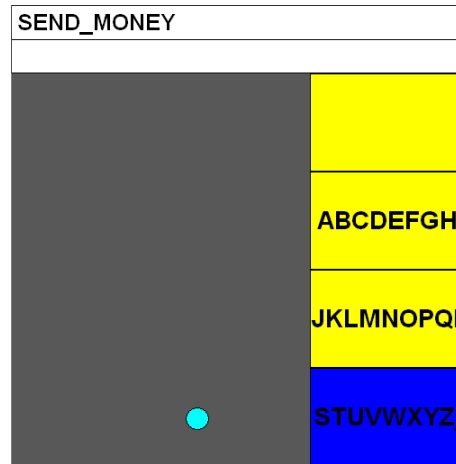
Mu activity can be voluntarily controlled by movement related imagery. This becomes easier in trained subjects. With continued practice, this control tends to become automatic, as is the case with many motor skills and imagery becomes unnecessary.



Jonathan R. Wolpaw, M.D.
Chief,

Laboratory of Neural Injury and Repair
Wadsworth Center, NYS Dept. of Health
Albany, NY

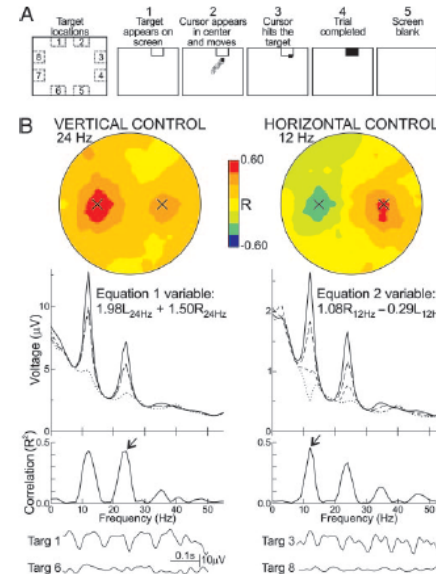
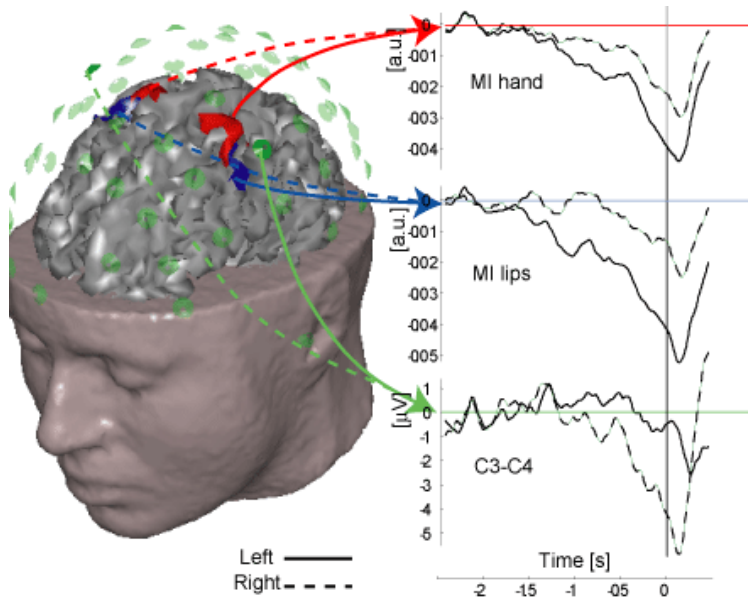
BCI BASED ON MU RHYTHM



Wolpaw et al., IEEE Trans. on Rehab. Enging., 2000

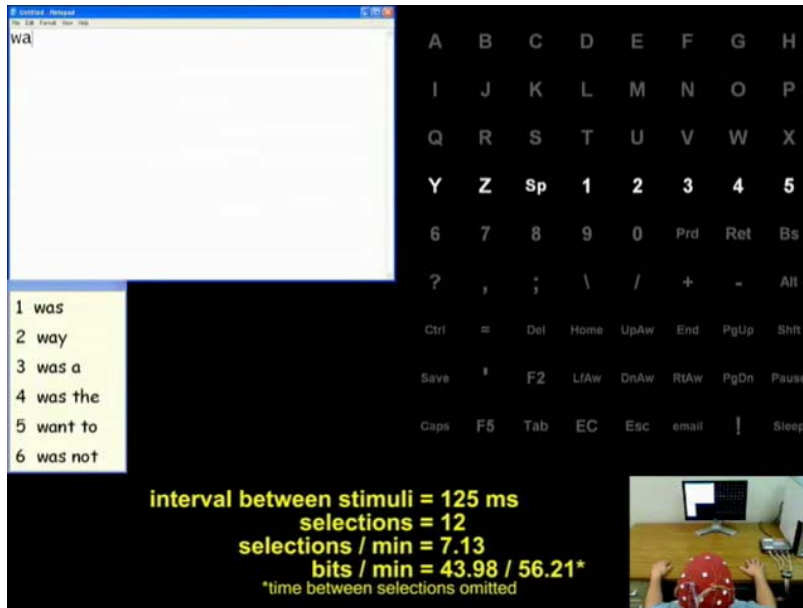
In the early Wadsworth BCI letter speller the users directed a ball by the mu rhythm. The ball was moving through the screen and the user had to move it to the up or down, pointing the letter string containing the selected letter. The mu rhythm and the ERD/ERS BCI are similar but ERD/ERS is elicited by external stimuli while mu rhythm is modulated spontaneous activity.

BCI BASED ON MU RHYTHM



In a 2D version the users learned to control mu activity over both hemispheres, adding left-right control. In the Wadsworth laboratory first developed 3D BCI with noninvasive EEG technique.

WADSWORTH BCI SYSTEMS

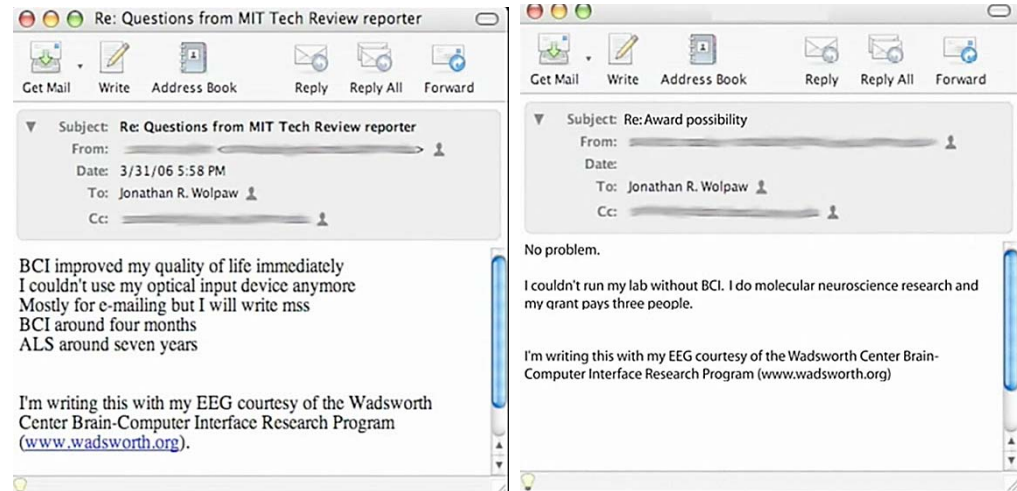


http://www.wadsworth.org/bci/wm_video.html

The Wolpaw group further developed the P300 letter spelling system with a predictive speller, speeding up the system to 7 selection per min.

<http://www.npr.org/2011/05/12/135598390/mind-reading-technology-turns-thought-into-action>

WADSWORTH HOME BCI SYSTEM

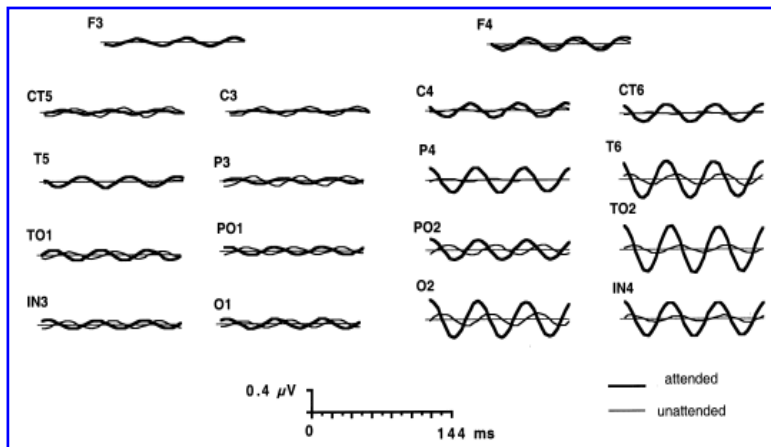


Recently the Wadsworth group begun to provide severely disabled users with in-home P300-based BCI systems to use for daily communication and control tasks. A 49-year-old scientist with ALS has used this BCI system on a daily basis for approximately three years, finding it superior to his eyegaze system (a letter-selection device based on eye-gaze direction) and using it from four to six hours per day for email and other communication purposes. http://www.wadsworth.org/bci/wm_video.html

<http://www.cbsnews.com/video/watch/?id=5228109n>

Vaughan et al., IEEE Transactions on Rehab. Engin., 2006, 14: 229–233.

BCI BASED ON STEADY STATE VISUAL EVOKED POTENTIALS (SSVEP)



This response is evoked by flickering lights in the range of 4-40 Hz.

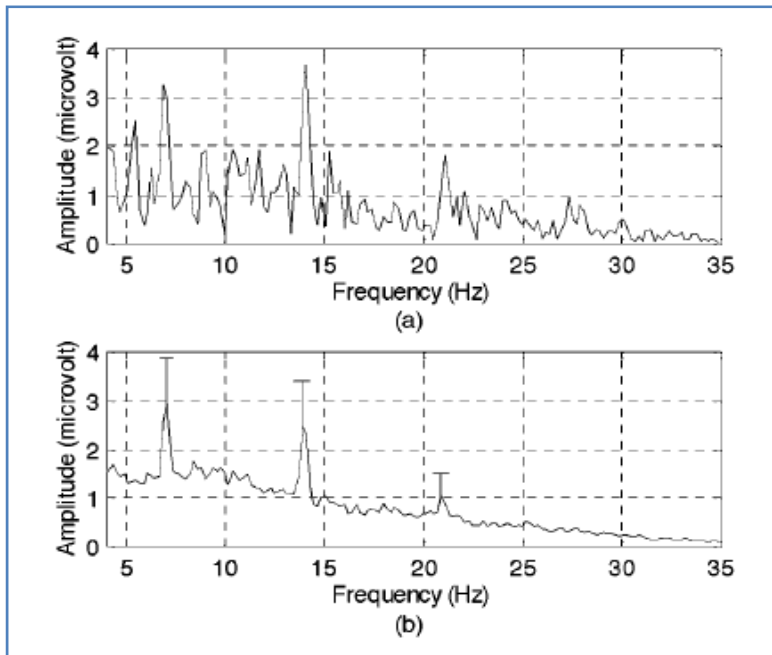
Steady state response (SSR) is sine wave like oscillation with frequency of the repetitive stimuli. It can be studied in the frequency domain (FFT). It may also be elicited by auditory and somatosensory stimuli.

Nearly all subjects seem to have this activity. SSVEP requires no training. Selective attention can enhance SSVEP.

Averaged SSVEP waveform elicited by a flickering bar in the left visual field. Bold lines show SSVEP when the left visual field was attended, while the thin lines show the SSVEP to the same stimulus when the right visual field was attended.

Müller and Hillyard, Clin Neurophysiol., 2000

BCI BASED ON STEADY STATE VISUAL EVOKED POTENTIALS (SSVEP)

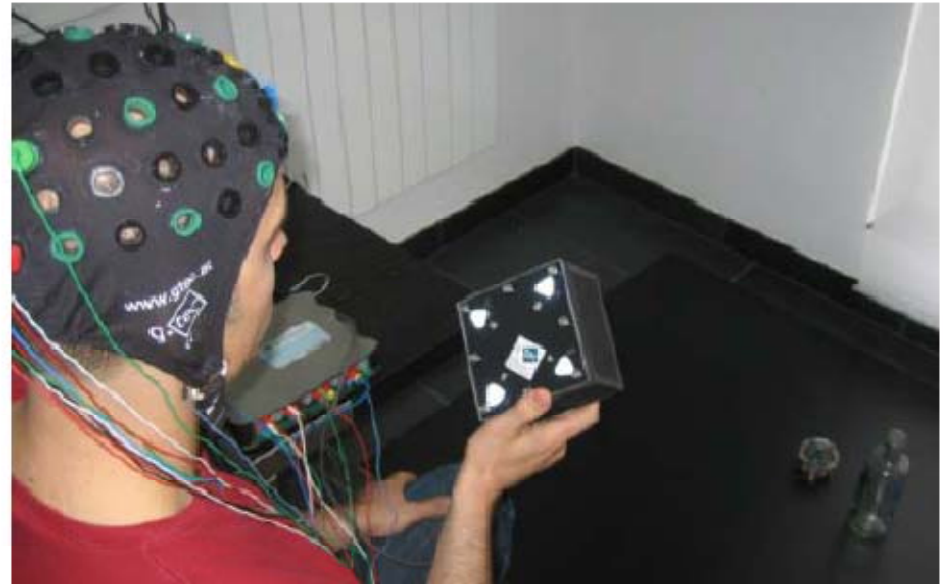
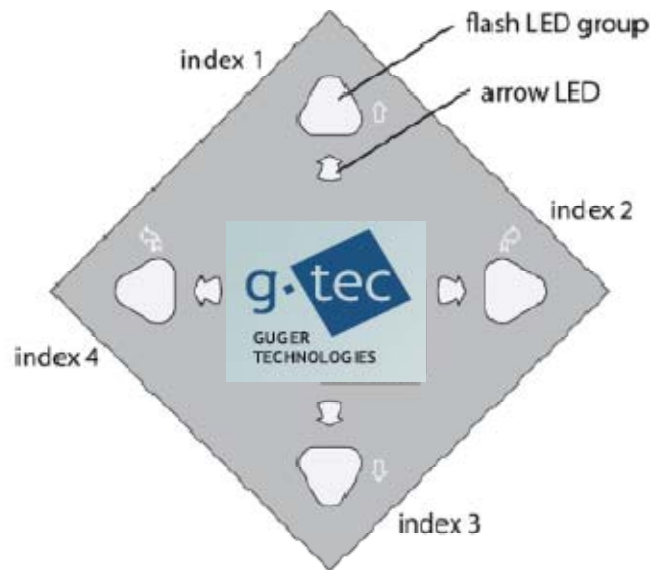


Amplitude spectrum of SSVEP to 7 Hz stimulation .
a: single trial spectrum
b: average of 40 trials, vertical lines give SD

Two or more light source flashing with different repetition rates can be used to elicit SSVEPs with increased amplitude in the frequency of the attended light source.

The early BCI literature stated that it is necessary to shift gaze to the selected light source. According this SSVEP BCIs are “dependent” meaning they depend on muscle activity. If true, SSVEP BCIs would not work in locked in patients. Recent studies indicated that gaze is not an essential factor.

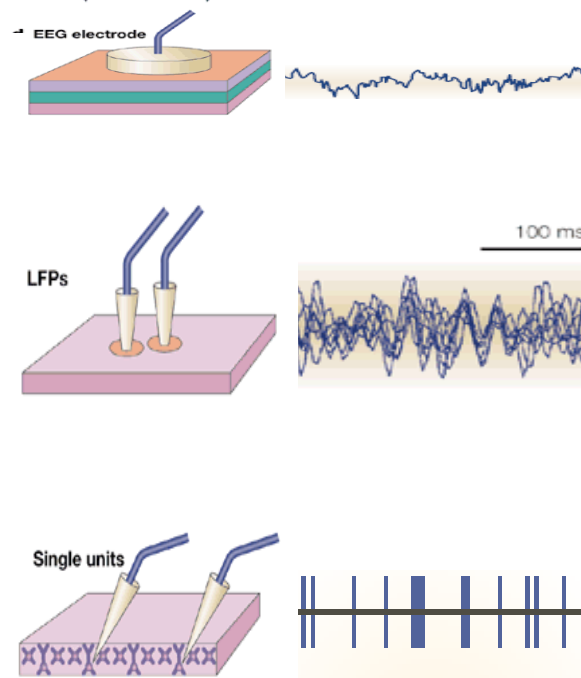
BCI BASED ON STEADY STATE VISUAL EVOKED POTENTIALS (SSVEP)



<http://www.gtec.at/Download>

Small robot controlled by SSVEP BCI. Four LED light source flashing with different repetition rate. See video at:
<http://www.gtec.at/content/download/1855/11541/version/4/>

INVASIVE BCI TECHNIQUES

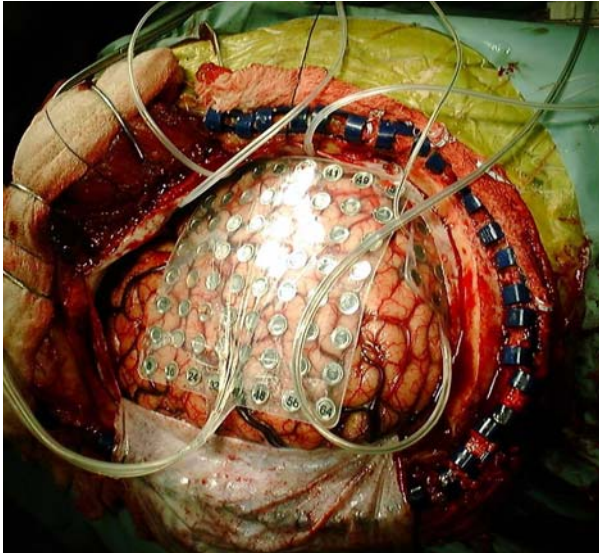


The limitations of noninvasive EEG-based BCI systems is the distances between the recording electrodes on the scalp and the underlying cortical tissue. This is why the signal amplitude is small the bandwidth is limited and S/N ratio is low.

The advantage of the invasive techniques is that the recording electrodes are on the surface of the neocortex or in the neural tissue.

The ECoG are often called semi-invasive because the electrodes are not inserted into the tissue.

BCI BASED ON ELECTROCORTICOGRAM (ECoG)



Subdural electrode grid placed on the cortical surface.

BCIs based on ECoG are working on the same principles as the EEG BCIs. ECoG BCI research has almost exclusively been performed on epilepsy patients, in whom subdural grids are clinically placed over suspected epileptogenic foci.

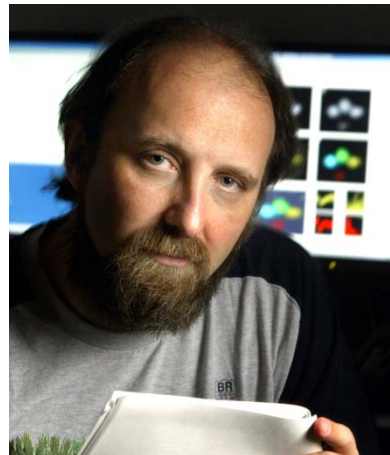
Advantage of ECoG based systems is that electrodes are on the cortical surface, yielding a much finer spatial resolution on the order of mm as well as the ability to record higher-frequency (10–200 Hz) content in the signal.

It was found that patients could quickly learn to modulate high-frequency gamma rhythms in both motor cortical areas and in Broca's speech area to control a one-dimensional computer cursor in real time.

BCI TECHNIQUES BASED ON RECORDING NEURONAL ACTION POTENTIALS



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Miguel A. L. Nicolelis,
Anne W. Deane Professor
Dept. of Neurobiology
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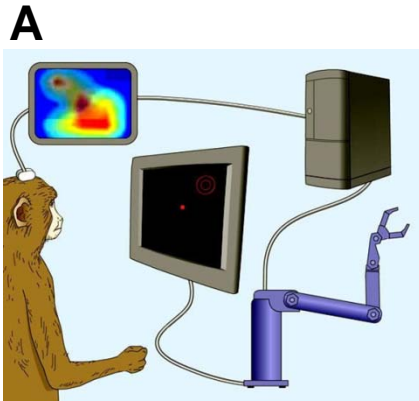


Richard A. Andersen
James G. Boswell Prof. of Neuroscience
Division of Biology
California Inst. of Technology

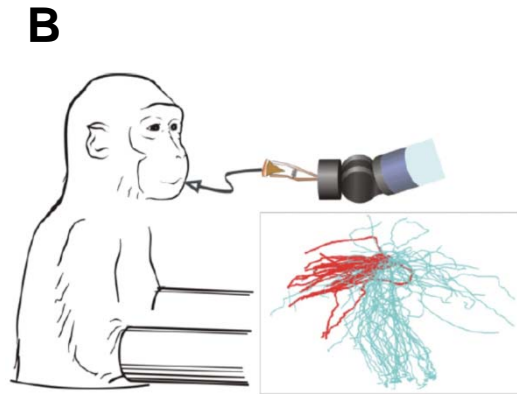
Three pioneers of cortical motor prostheses in primates.

They developed technology to record cortical single unit activity in primates and transform it to a signal that controls robotic arm.

CORTICAL MOTOR BCI IN PRIMATES



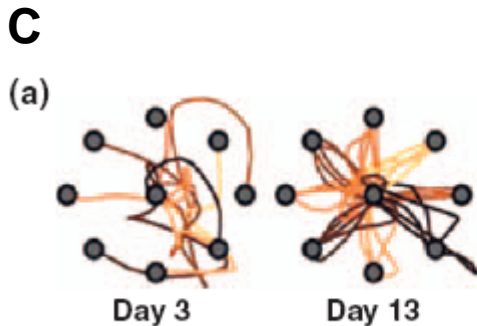
<http://www.nicolelislab.net/>



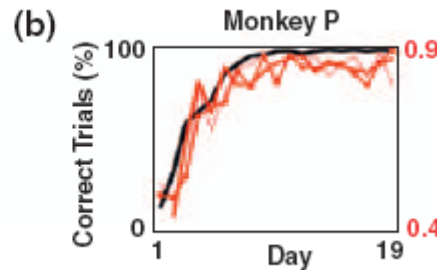
Helms Tillery et al., Rev. in Neurosci., 2003

A: Schematic arrangement of the experimental setup.

B: Delivering food to the mouth using a cortically controlled robotic arm. The diagram outlines the arrangement, with a piece of orange clipped into the robot end effector. The inset diagram shows 10 minutes worth of cortical control trajectories from a central start location.



Green and Kalaska TINS, 2011



C: Behavioral performance improvements in monkeys during BCI control (a) Example of single-trial cursor trajectories during initial (left) and late (right) stages of BCI control learning. (b) The success rate across daily training sessions.

NEUROTROPHIC ELECTRODE

Philip R. Kennedy developed a special glass microelectrode for chronic recording of neuronal activity. Kennedy and colleagues cortically implanted these microelectrodes filled with neurotrophic growth factor first into animals. The axon of the neurons targeted by the electrodes grow into them and allows recording of the spike activity.

After a series of successful animal experiments they got FDA license to implant the neurotropic electrode into the brains of several ALS patients from 1998. This implantation requires major surgery lasting about 10 hours.

Neural activity has been recorded with this type of electrodes in ALS patients for five years.

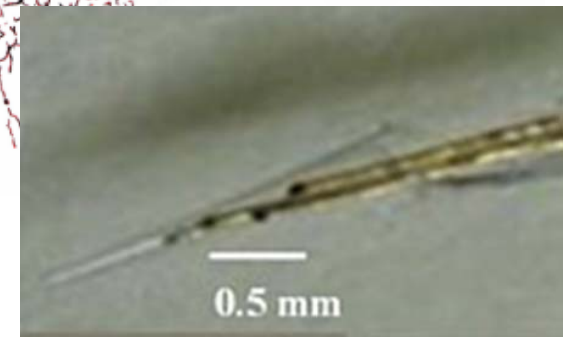
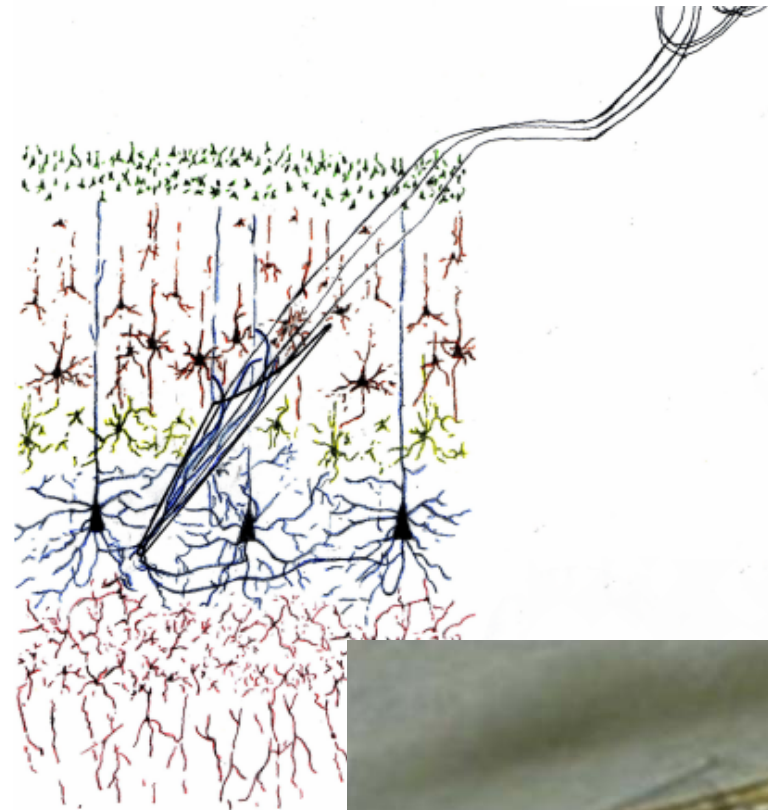


Philip R. Kennedy M.D.
Neural Signals Inc.
Duluth, Ga.

NEUROTROPHIC ELECTRODE

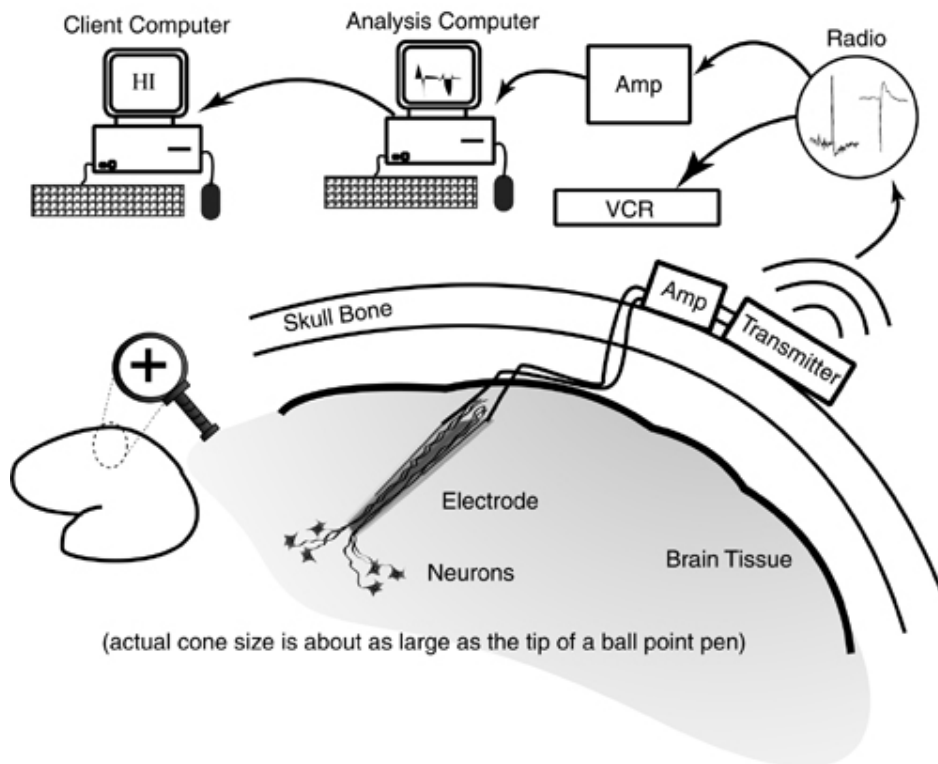
The six layers of cortex are diagrammed with the electrode tip in position near layer five that contains corticospinal tract pyramidal cells.

Neurites are shown growing into the tip, through the cone, and out the top end so as to hold the glass cone tip in position.



Bartels et al., J. Neurosci. Methods, 2008

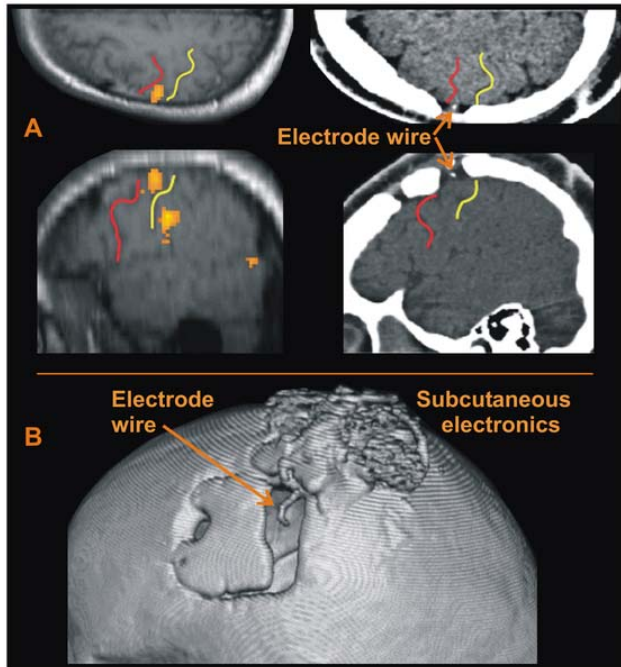
NEUROTROPHIC ELECTRODE SYSTEM



The wires coming out from the cone is attached to amplifiers and FM transmitters located on the skull, under the scalp. No wires or batteries are used. Power is provided by a power induction system. The neural signals are transmitted to and processed by a computer to activate a switch or drive a cursor and hence provide communication.

<http://www.nyas.org/MediaPlayer.aspx?mid=915927ef-477a-4830-beff-0fafade6860f>

BCI FOR REAL-TIME SPEECH SYNTHESIS



A: Left panels: Axial (top) and sagittal (bottom) fMRI slices showing brain activation along the precentral gyrus during attempted word generation prior to implantation. Red lines denote pre-central sulcus; yellow lines denote central sulcus. Right panels: Corresponding images from a post-implant CT scan showing location of electrode.
B: 3D CT image showing electrode wire entering dura mater.

A consortium led by Kennedy developed BCI method for speech sound production. Neurotrophic Electrode were implanted in the speech-related region of the left precentral gyrus of a human volunteer suffering from locked-in syndrome. Neural signals generated during attempted speech were used to drive a speech synthesizer. Volunteer's vowel productions with the synthesizer improved quickly with practice, with a 25% improvement.

They concluded that neural prostheses may have the potential to provide near-conversational synthetic speech output for individuals with severely impaired speech motor control.

www.speechprosthesis.org

Guenther et al., PLoS ONE 2009, 4(12): e8218doi:10.1371/journal.pone.0008218

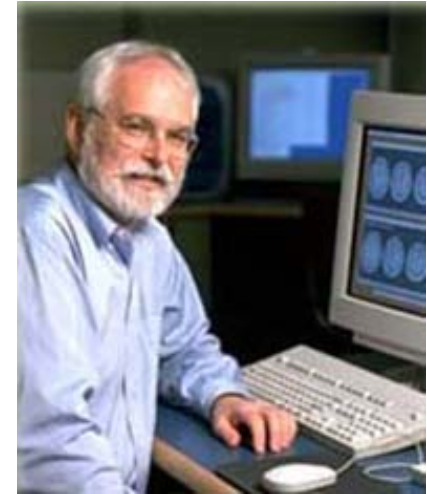


BRAIN GATE SYSTEM

BrainGate System is a BCI designed for human use. It is the result of research and development at premier academic institutions such as Brown University, the Massachusetts Institute of Technology, Emory University, and the University of Utah. The program led by John Donoghue funded by the Cyberkinetics Inc.

Currently, the system consists of a „*sensor*” (a device implanted in the brain that records signals directly related to imagined limb movement); a „*decoder*” (a set of computers and embedded software that turns the brain signals into a useful command for an external device); and, the „*external device*” – which could be a standard computer desktop or other communication device, a powered wheelchair, a prosthetic or robotic limb.

http://www.brown.edu/Administration/News_Bureau/2006-07/06-002.html



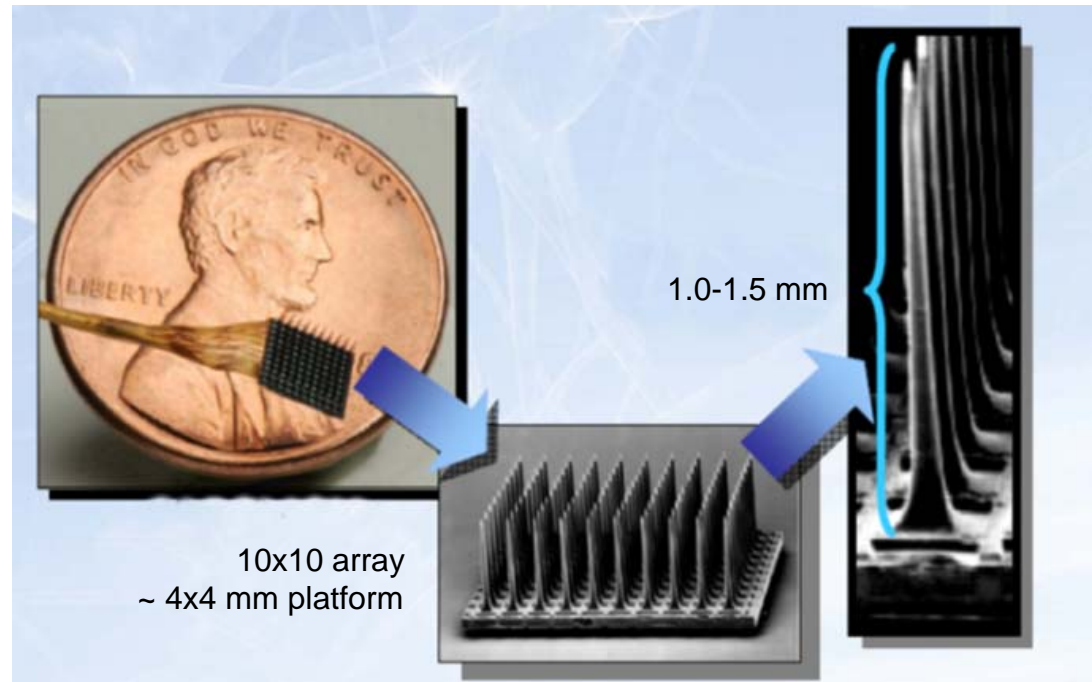
JOHN DONOGHUE

Henry Merritt Wriston Professor
Dept. of Neuroscience
Brown University
Providence, RI

<http://www.braingate.com>

<http://donoghue.neuro.brown.edu/>

BRAIN GATE SENSOR – UTAH ELECTRODE ARRAY



The BrainGate sensor, resting on a US penny. It is a 100-electrode Si sensor array developed at the Utah University. The electrodes are 1.0-1.5 mm long, insulated with Parylene. If inserted into the neocortex, the uninsulated, Pt coated tips reach the fifth large pyramidal cell layer. <http://www.cyberkineticsinc.com> <http://www.braingate.com/> www.BrainGate2.com

BRAIN GATE SYSTEM



The first participant in the BrainGate trial (MN). He is sitting in a wheelchair, mechanically ventilated through a tracheostomy. The grey box (arrow) connected to the percutaneous pedestal contains amplifier and signal conditioning hardware. He is looking at the monitor, directing the neural cursor towards the orange square in this 16-target 'grid' task.

At left the MRI slice of his brain with the motor cortex (arrow). The small square represent the place of the electrode array.

http://www.braingate.com/meet_the_patients.html

<http://www.nature.com/nature/journal/v442/n7099/supinfo/nature04970.html>

Matthew Nagel (1979 – 2007) was the first patient of the BrainGate project. He suffered a spinal cord injury in 2001 (C4 tetraplegic) and the BrainGate electrode array was implanted into his motor cortex in 2004. The implant was removed after one year.

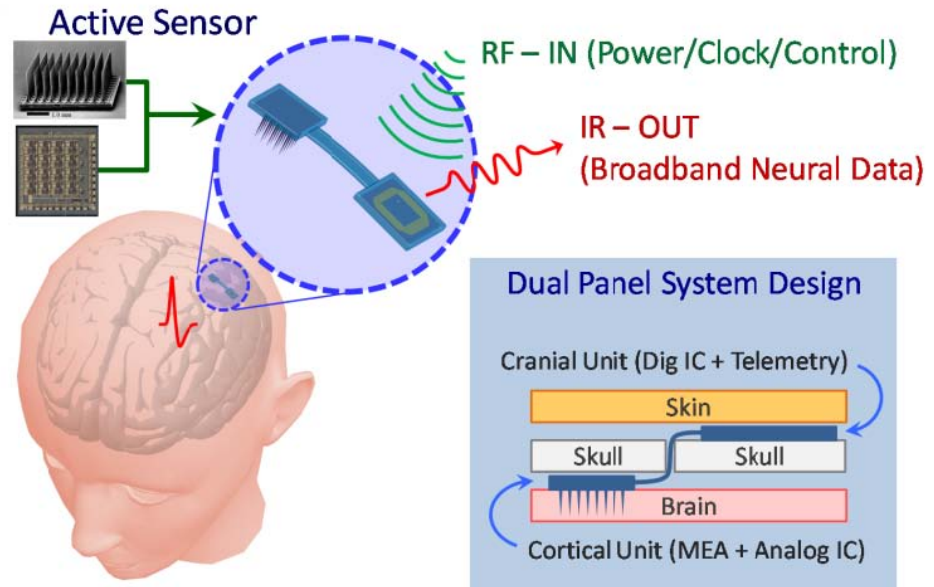
The system decoded the activity of a population of his cortical neurons. This way he could control computer cursor, he could open and close a prosthetic hand, and perform rudimentary actions with a multi-jointed robotic arm.

This proves that using these neural signals paralyzed humans can directly and successfully control external devices.

BRAIN GATE SYSTEM



Source: Wikimedia Common



Source: Nanophotonics and Neuroengineering Laboratory, Brown Univ.

Left: The present BrainGate System uses percutaneous connector between the lead of the electrode array and the preamplifier. This may be a source of infection.
Right: In the next generation of the System the brain electrical signals will be transmitted by telemetry.

<http://nurmikko.engin.brown.edu/?q=node/1>

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LINKS

<http://motorlab.neurobio.pitt.edu/>

<http://vis.caltech.edu/>

<http://www.mp.uni-tuebingen.de/mp/index.php?id=137>

<http://bci.tugraz.at/>

<http://www.nicolelislab.net/>

<http://www.neuralsignals.com/>

<http://www.npr.org/2011/05/12/135598390/mind-reading-technology-turns-thought-into-action>

<http://www.braingate.com>

<http://www.cyberkineticsinc.com/index.htm>

<http://news.brown.edu/pressreleases/2011/03/braingate>

<http://www.bciresearch.org/html/media/video-flash-hq.html>

<http://www.nyas.org/Publications/Ebriefings/Detail.aspx?cid=1914df78-19ec-440e-8d0d-19a8bf81140c>

http://videlectures.net/bbci09_berlin/

http://future-bnci.org/index.php?option=com_content&view=article&id=133:cognitive-science-160-introduction-to-bci-systems-brendan-allison&catid=50:bci-class&Itemid=61

www.bbc.de

REVIEW QUESTIONS:

- Which are the essential components of a BCI?
- List the brain electrical signals used in noninvasive BCIs.
- List the brain electrical signals used in invasive BCIs.
- Describe the Thought Translation Device.
- How does the patient learn to use slow cortical potentials in BCI?
- Describe the Language support program of the TTD
- What are the characteristics of the ERD/ERS?
- What is the principle of the P300 BCI?
- Which electrical signal is used in the Wadsworth BCI system?
- What are the characteristics of the visual steady state evoked potential?
- What is the neurotropic electrode?
- What kind of electrode is used in the Brain Gate System?