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Christoph Guger

Physiological Measures and Brain-Computer Interface Control in VR

biomedical engineering program

Peach Summer School 2007

EEG and ECG measurement, Signal Analysis, Classification and Applications

Guger Technologies OEG

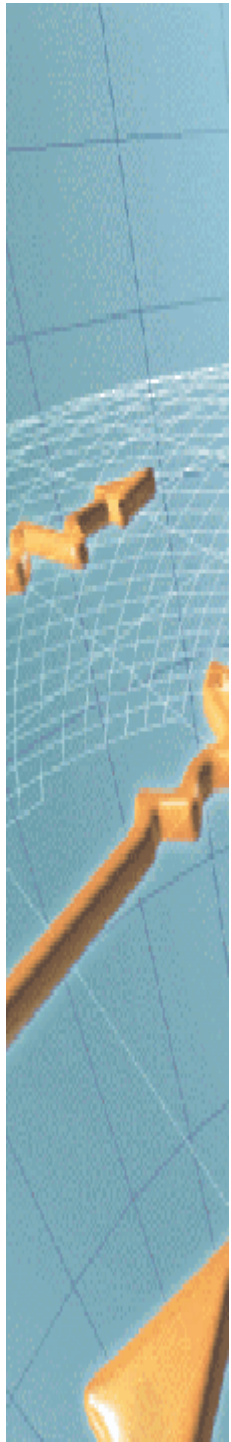
Herbersteinstrasse 60, 8020 Graz, Austria

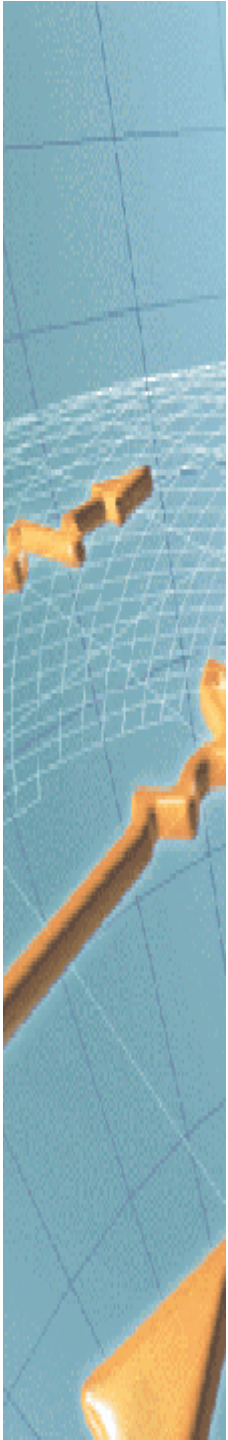
g.tec medical engineering GmbH.

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g.tec – “accelerate your biosignal research”



company description

- founded 1999 by Günter Edlinger and Guger Christoph
- private company, located in Graz and Schiedlberg (Linz), Austria
- inter-disciplinary team (biomedical- , telematics engineers, psychologists)
- export of products into >40 countries (all continents)
- customers: universities, university hospitals, R&D departments, industry

company fields:

- bio-engineering, medical electronics (bio-electricity)
- offers hard- and software products for biosignal research
(neural cells: EEG, ECoG; muscle cells: ECG, EMG; other tissue: EOG, ...)
- performs user specific adaptations and developments
- mainly based on flexible rapid prototyping environment under *MATLAB/Simulink*

PRESENCIA



EU IST project: PRESENCIA – Virtual Reality

Tracking subject responses in the VE by neuro-physiological measurements: building better VE, therapy applications for patients with anxiety psychosis, ...

- University College London (UCL), UK
Mel Slater, Doron Friedman, Angus Antely,
Vino Vinayagamoorthy
- University of Technology Graz, Austria
Robert Leeb, Gert Pfurtscheller
- Insituto de Neurociencias, UMH, Alicante, Spain
Mavi Sanchez
- g.tec medical engineering GmbH, Schiedlberg, Austria
- Guger Technologies OEG, Graz, Austria





Content



Experiment in a virtual bar in the CAVE of UCL

- Training and experimental phase with breaks in presence (BIP)

- Speaking avatar

- ECG analysis

- Social phobia in VR

Brain-Computer Interface

- Concept

- Orthotic control with BCI

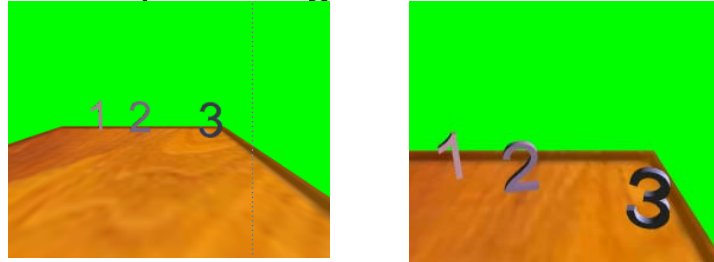
- Spelling device

- Navigation in VR

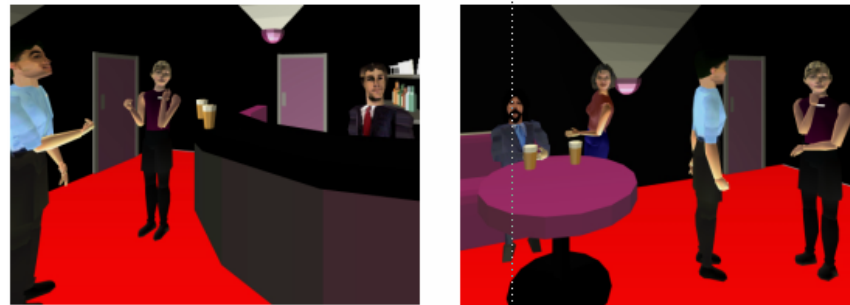
Experimentn in Virtual Bar

1) **baseline phase** – subjects standing in CAVE with no images displayed

2) **training phase** – simple navigation task to move around the VE



3) **experiment phase** – subjects were in the virtual bar with 5 virtual characters (1 barman, 2 couples)



virtual characters were speaking to participant (about 30 sentences)
experiment lasted 5 minutes

4 BIPS were introduced in form of a whiteout (2 seconds)

Subjects

31 subjects participated

Each participant filled out a social phobia questionnaire with 27 yes/no questions

1. I feel relaxed even in unfamiliar social situations

Yes No

2. I try to avoid situations which force me to be very sociable

Yes No

3. It's easy for me to relax when I am with strangers

Yes No

4. I have no particular desire to avoid people

Yes No

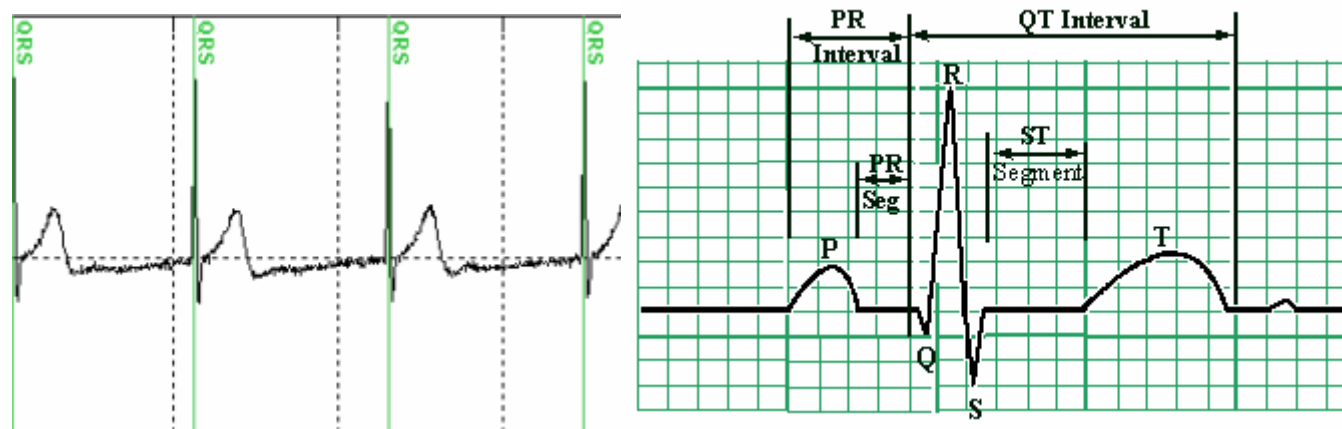
Median score: 6

Minimum score: 0

Maximum score: 23

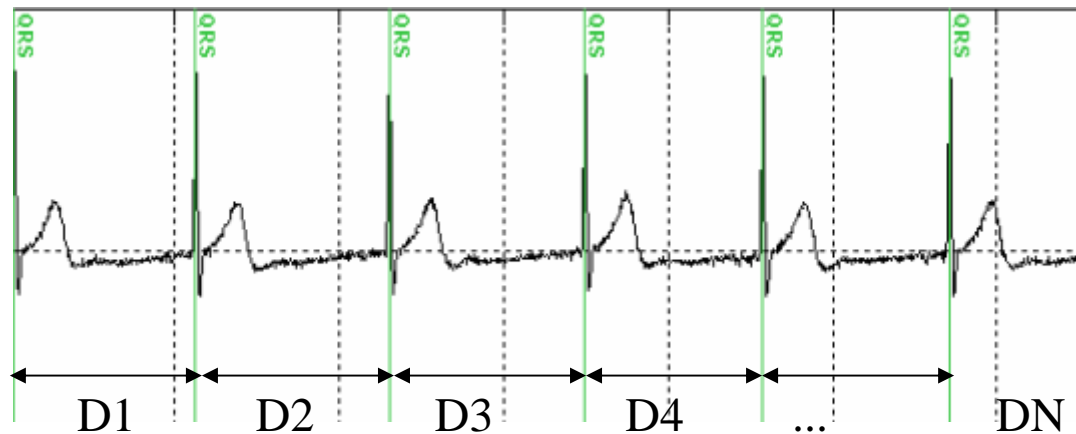
Data analysis

ECG was acquired as standard Einthoven I derivation at 256 Hz



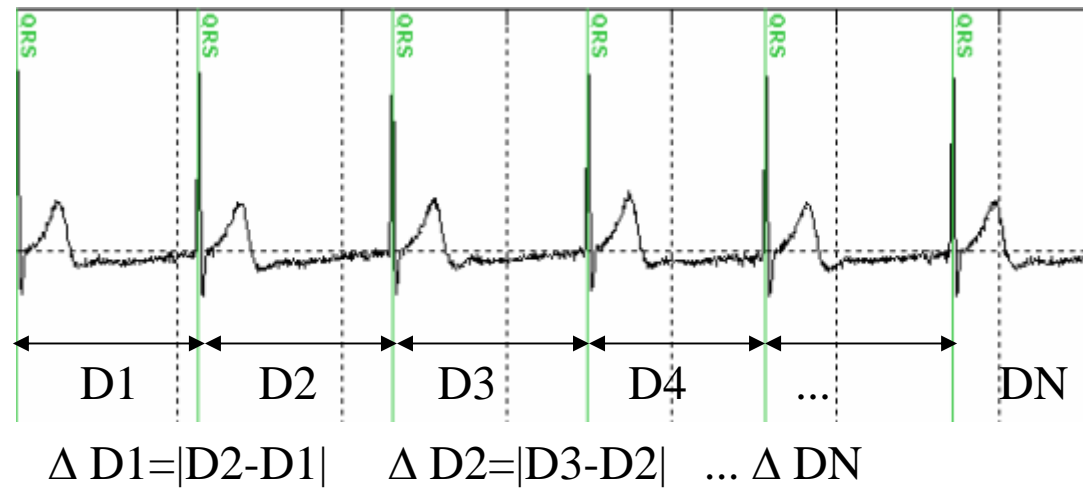
Find the QRS complexes (heart depolarisation) in the time series

Calculate the interval between 2 QRS complexes -> NN interval



How to calculate the heart rate variability (HRV)

RMSSD ... square root of the mean squared difference of successive NN intervals

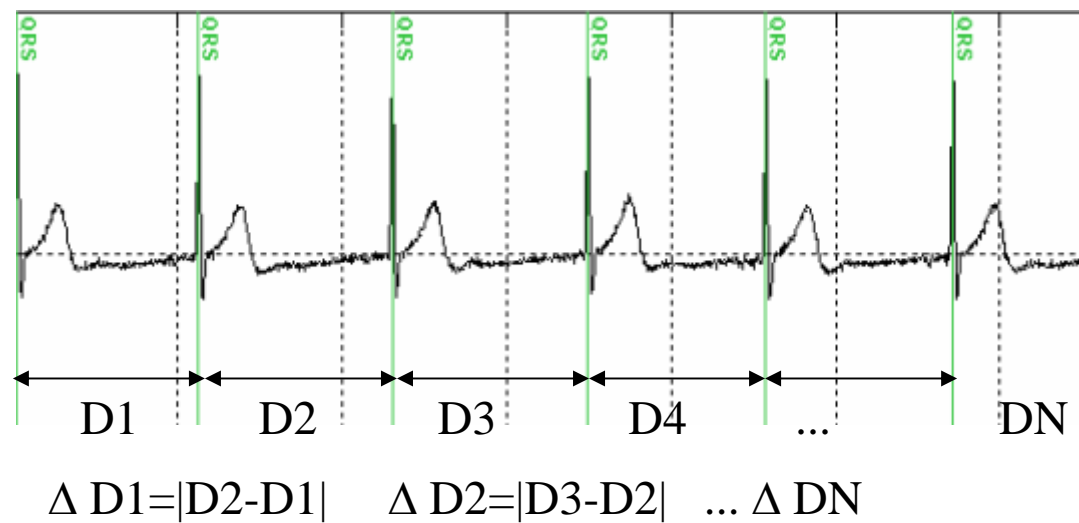


$$\text{RMSSD} = \text{SQRT} (\text{MEAN} ([\Delta D1^2, \Delta D2^2, \dots, \Delta DN^2]))$$

HRV time domain

NN50 ... number of successive NN intervals which differ by more than 50 ms

Segments must be equal !!



$NN50 = NN50+1$ if $\Delta D_i > 50$ ms

pNN50 ... $NN50 / (\text{total number of NN intervals})$



Hear-rate variability

Variability of heart rate is influenced by autonomic nervous system activity

Several effects change the HRV:

Changes in 2-5 seconds intervals

Respiratory sinus arrhythmia (RSA) mediated by respiration
Controlled by parasympathetic system

Changes in 10 second rhythms

Blood pressure regulation

Changes with a period length above 20 seconds

Mediated by sympathetic system

Changes in minutes and hours range

Influenced by neurohumoral oscillations in the circulating blood
Circadian rhythms
Rapid eye movement phases during sleep

How to identify the frequency?

Spectral analysis detects periodic oscillations:

Absolute Measures

VLF – very low frequency band 0.003 – 0.04 Hz

LF – low frequency band 0.04 – 0.15 Hz

HF – high frequency band 0.15 – 0.4 Hz

Relative Measures

The normalization minimizes the effect of changes of total power on LF and HF

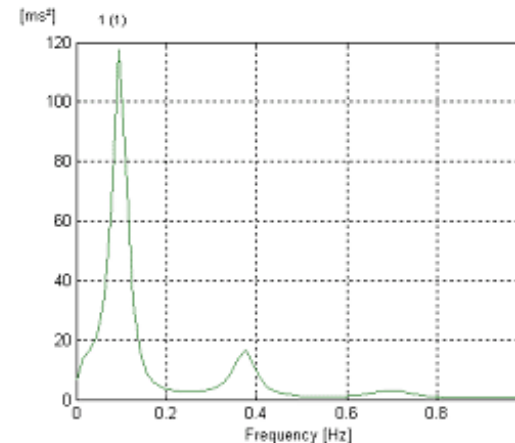
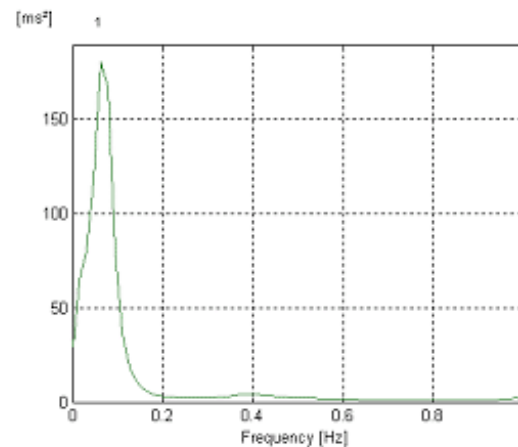
LFnorm – mediated by the sympathetic system

HFnorm – mediated by the parasympathetic system

HRV Comparison

Mean over all subjects. $p < 0.05$

Parameter	Training	Experimental
Mean HR [bpm]	93,41	88,33
RMSSD [ms]	22,5	27,1
PNN50 [%]	4,9	8,3
LF norm [n.u.]	74,5	64,9
HF norm [n.u.]	15,1	22,3

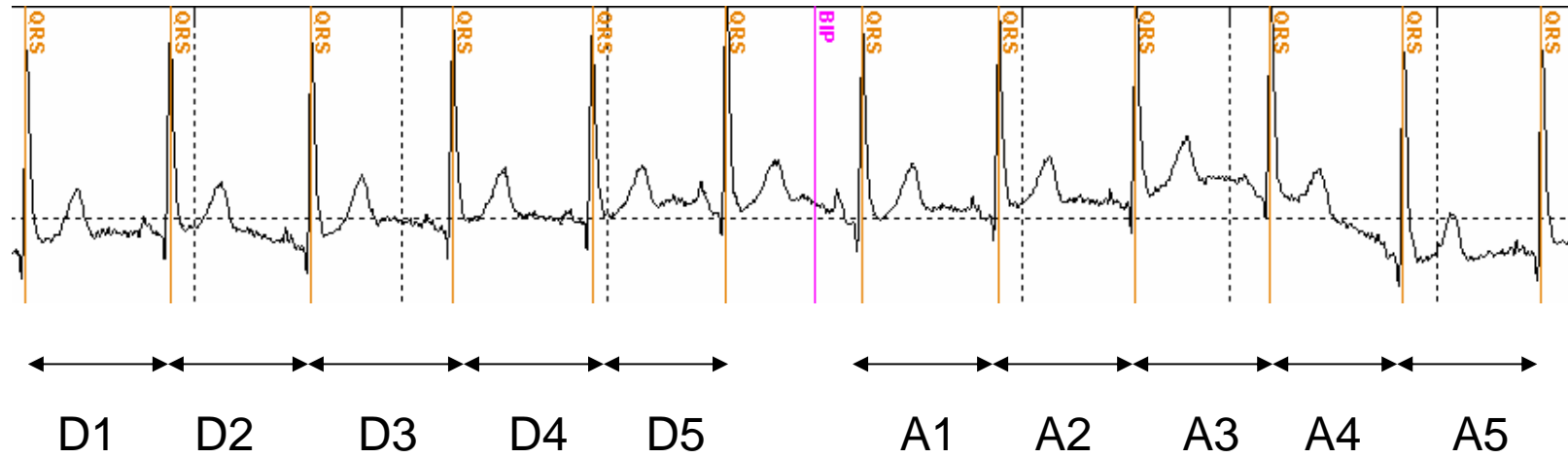


Parasympathetic activity is increased in the bar:

HFnorm ↑, LF/HF ↑

Bar: Heart-rate ↓ and HRV ↑

Event-related ECG



BIP

Mean heart rate calculated before the BIP and immediately afterwards

Averaged over 4 BIPS

Mean heart rate decreased for all subjects by 2.3 bpm because of BIP ($p < 0.01$)

Speaking avatar

Mean heart rate calculated before the speaking avatar and afterwards

Averaged over 30 sentences

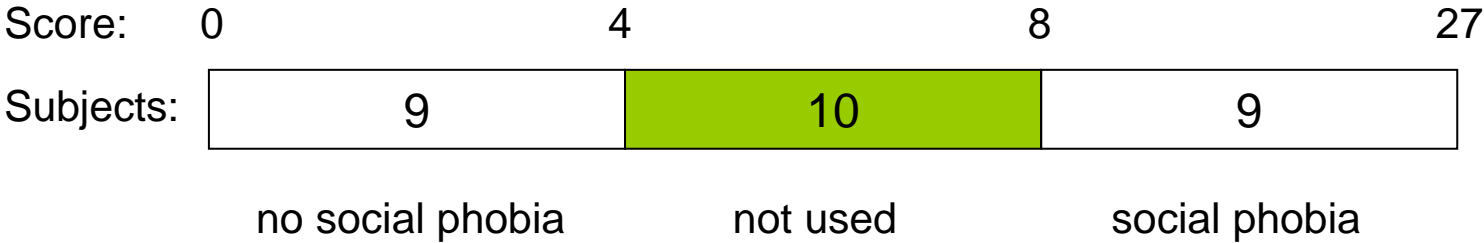
Mean heart rate increased for all subjects by 0.7 bpm because of speaking avatar ($p < 0.05$)



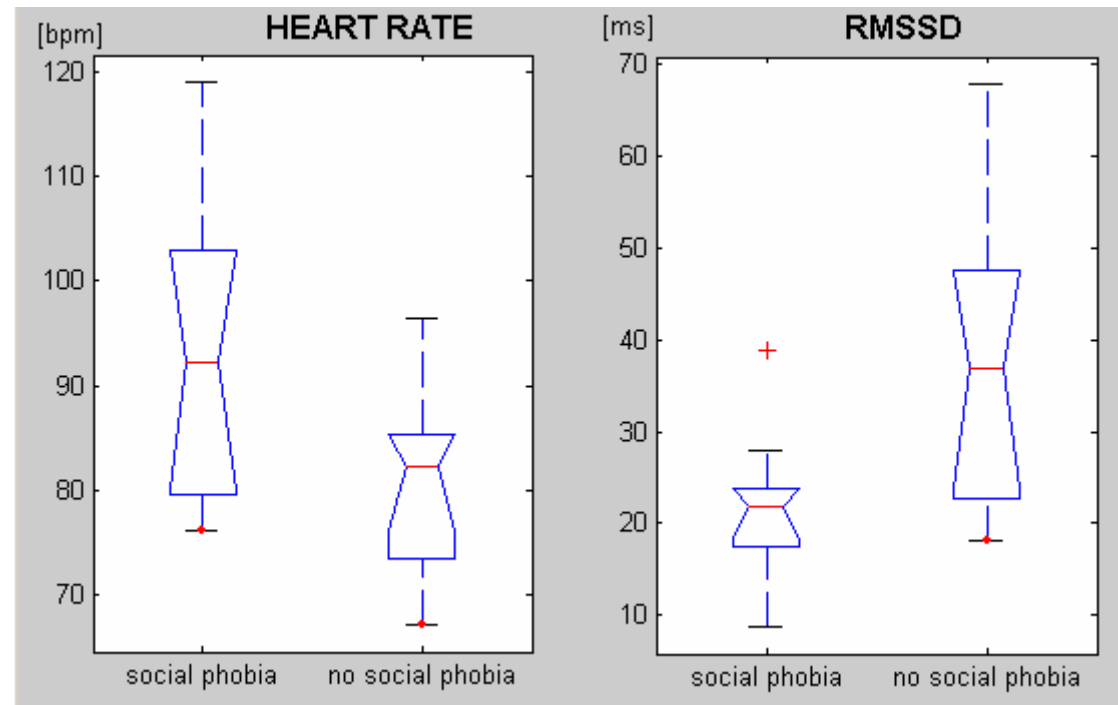
Social phobia classification



Comparison of social phobic and non-social phobic participants of the bar experiment



Social phobia classification



	Score > 8	Score ≤ 4	p-value of ANOVA
MeanHR [bpm]	92.8±14.6	83.7±13.9	0.048
RMSSD [ms]	21.6±8.3	35.8±15.5	0.022
PNN50 [ms]	4.8±5.5	12.2±11.8	0.039

Heart rate ↑ and HRV ↓ with social phobia ($p < 0.05$)
Social phobic participants are less relaxed in the bar

Discussion

BIPS: heart rate ↓ (2.3 bpm)

Speaking avatar: heart rate ↑ (0.7 bpm)

In the training phase the LF was increased and HF was decreased compared to the bar phase

This indicates mental stress

Several possibilities:

- Novelty of experience of being in the VE
- Unfamiliar equipment (goggles, 3D mouse)
- Conversely, the positive relaxing effect of being in the bar could have caused the changes in heart rate and HRV

Very interesting is the increased heart rate and lower HRV in the social phobic patients, which indicates higher mental stress in the bar

The Virtual Stanley Milgram Obedience Experiment

Milgram found that people administer lethal electric shocks in scientific experiments

Due to ethical controversy nowadays impossible to carry out such experiment

Participant is seated behind electric shock machine

Experimenter is seated to the participant's right

The virtual character (Learner) appears to be seen through a window

1 CUE word with 4 possible answers

The participant reads the 5 words and the Learner answers

Answer incorrect -> participant turned up a voltage dial on the shock machine and presses a button to administer the shock.

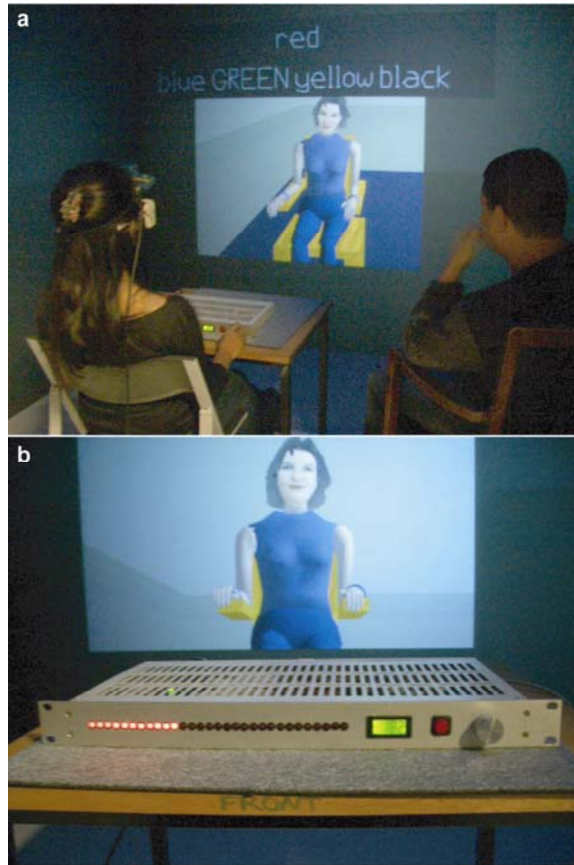


Figure 1. Slater et al.



Results

Early Withdrawal (17 gave 20 shocks, 3 gave 19 shocks and less by 3 persons)

Skin conductance level increases

Heart-rate increased

Heart-rate variability decreased

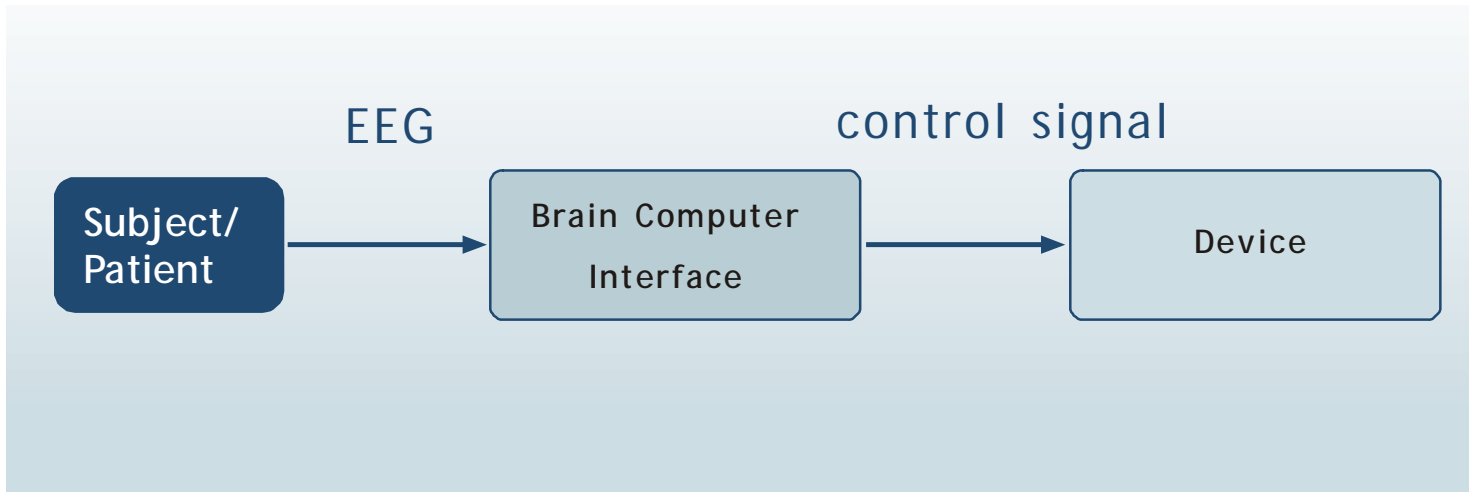
Reaction time increased

Many said that they were surprised by their own responses
All said that it had produced negative feelings – which was a direct feeling or mediated through a ‘what if it were real?’ feeling.

Tested that the participants respond to extreme social situations as if they were real

Open Access at PLOS One 2006

Brain-Computer-Interface (BCI) in VR

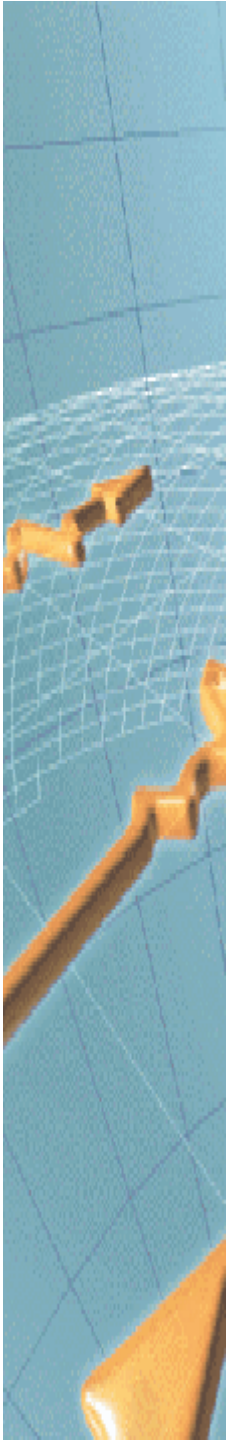


“A system for **controlling a device** e.g. computer, wheelchair or a neuroprosthesis by human intention which does not depend on the brain’s normal output pathways of peripheral nerves and muscles” [Wolpaw et al., 2002].

HCI – Human Computer Interface

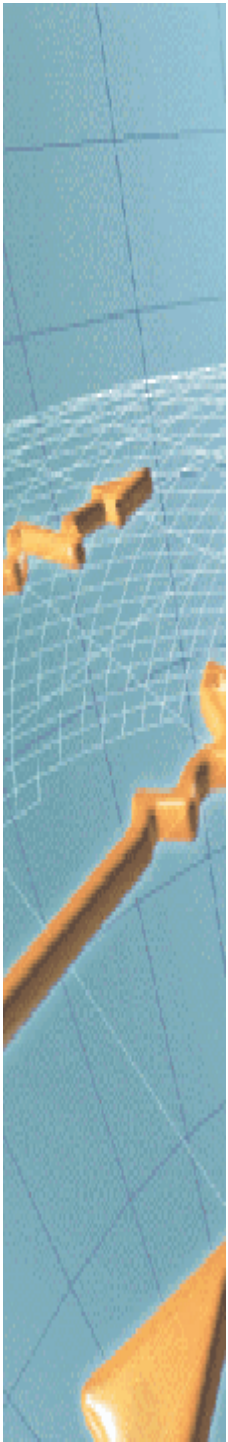
DBI – Direct Brain Interface (University of Michigan)

TTD – Thought Translation Device (University of Tübingen)



Applications of a BCI in patients

- patients with **amyotrophic lateral sclerosis (ALS)**
- **locked-In Syndrome (LIS)** to communicate
- patients with **amputations** to control a robotic limb
- patients with **spinal cord lesions** to control a FES device or a wheelchair
- gaming
- composing music
- walking through VE



Excursus: Measuring brain activity

Electroencephalogram (EEG)

small electrodes (#1 - #256) attached to the surface of the scalp
place electrodes at certain predefined positions according to the
“international 10/20 system”

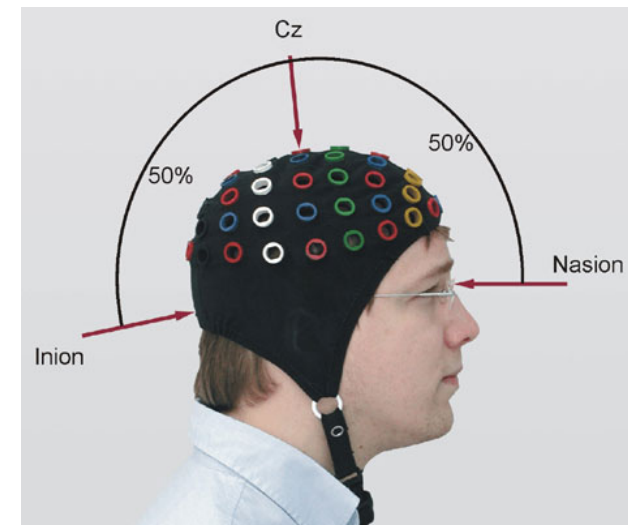


EEG amplitudes: **5 – 100 μ V**

EEG frequencies: **1 – 40 Hz**

**EEG: non-stationary time signal
varies greatly between subjects
low signal-to-noise ratio**

- spatio-temporal patterns
- non-invasive



Excursus: Measuring brain activity

Electro-corticogram (ECoG)

4 mm diameter

~ 100 electrodes

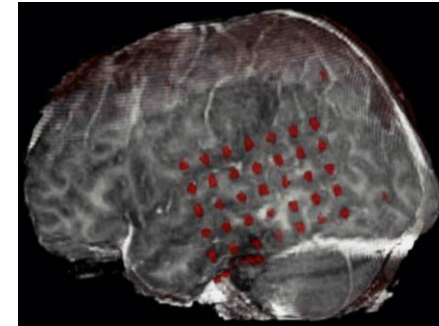
EEG amplitudes: **0.5 mV**

EEG frequencies: **1 – 100 Hz**

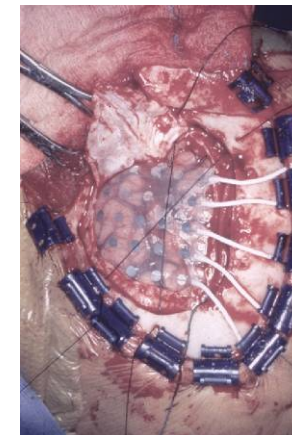
- resolution considerably better than EEG
- provides opportunity for multi-channel control
- more direct correlation to activity

invasive

limited study opportunities

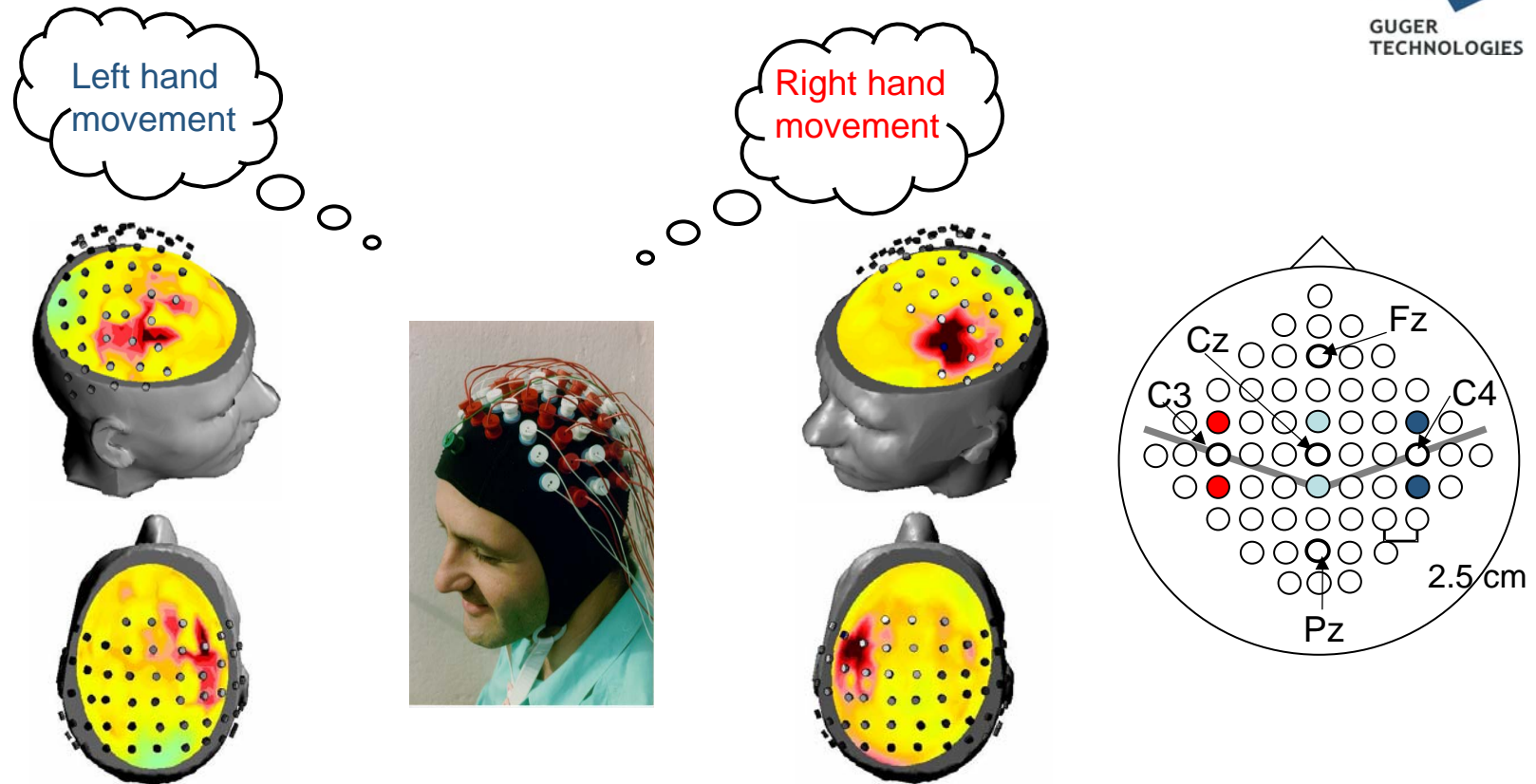


modified from University of Michigan



modified from University of Michigan

Physiological Background

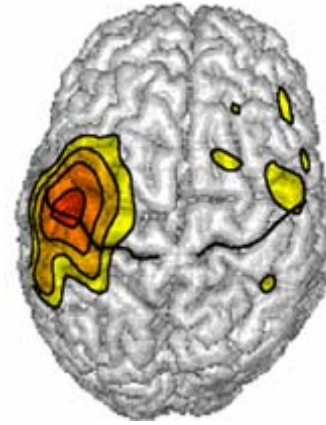


Imagination of hand movement causes an ERD which is used to classify the side of movement. The desynchronization occurs in motor and related areas of the brain. Therefore, for analyzing and classifying ERD-patterns the electrodes must be placed close to sensorimotor areas.

Mental strategies



Left hand

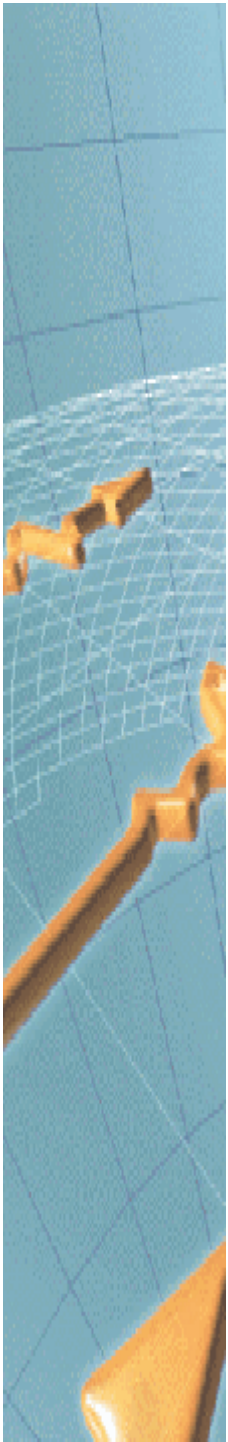


Right hand

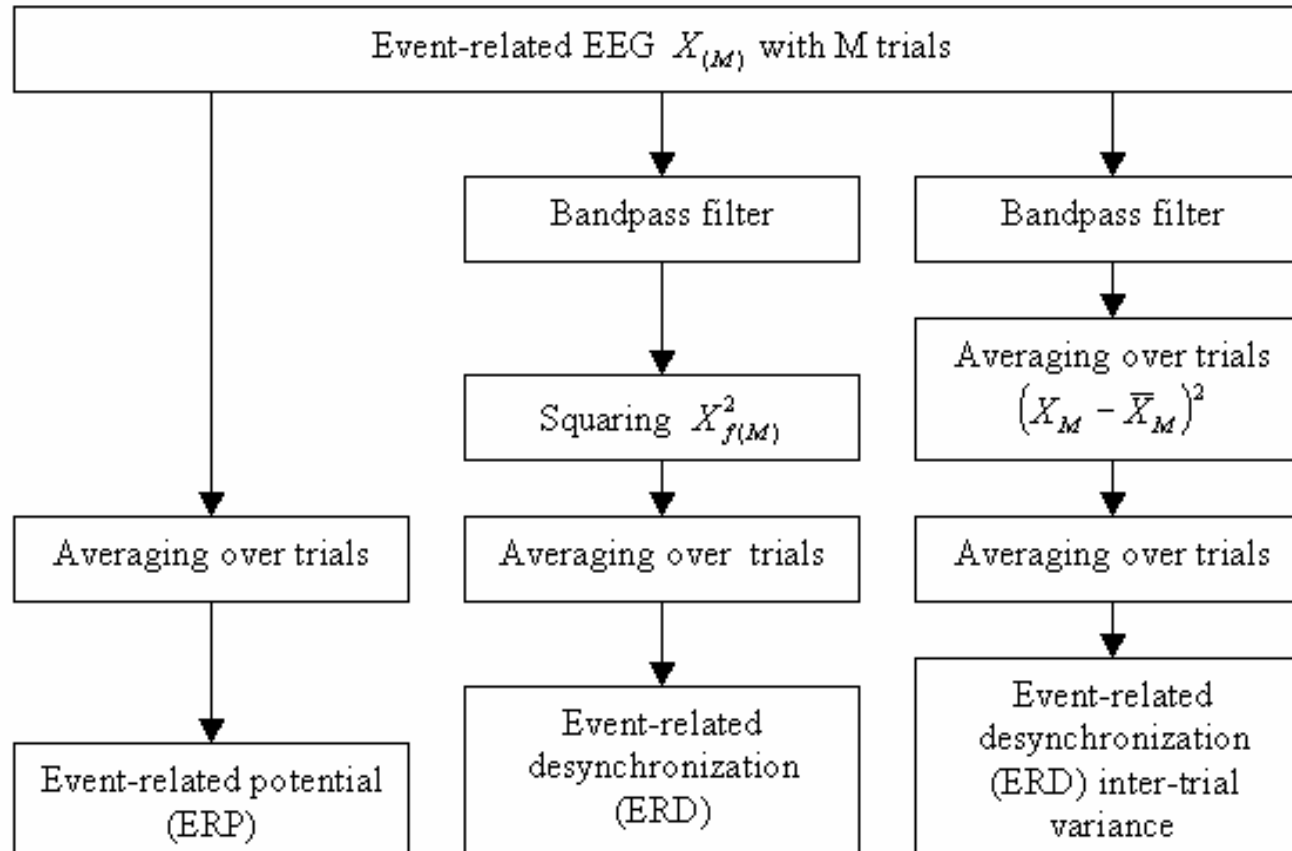


Foot

motor imagery



Event-related-desynchronisation/synchronization



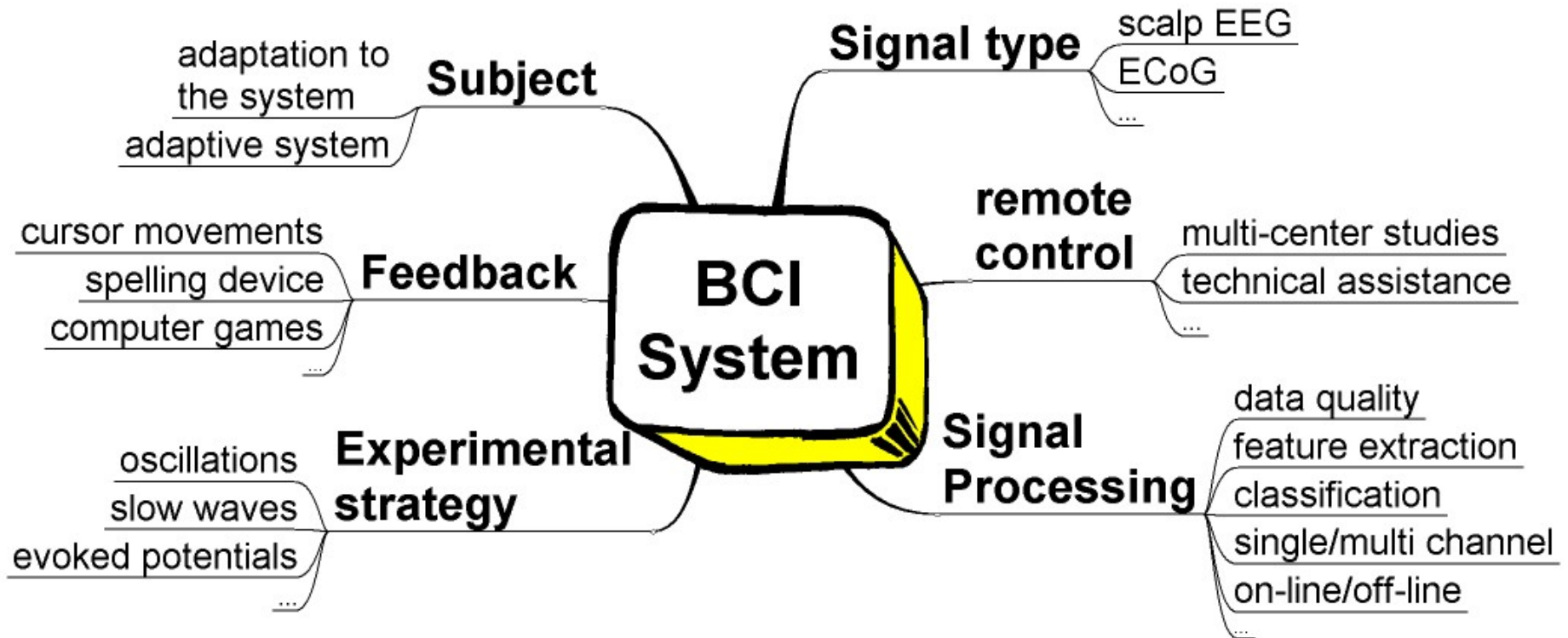


Influencing components

adaptation
to subject



technical issues



Steps in BCI development

Step 1: Selection of parameter estimation and classification algorithms

Step 2: Implementation of the algorithms

Step 3: Off-line simulation

Step 4: Connection to the real world

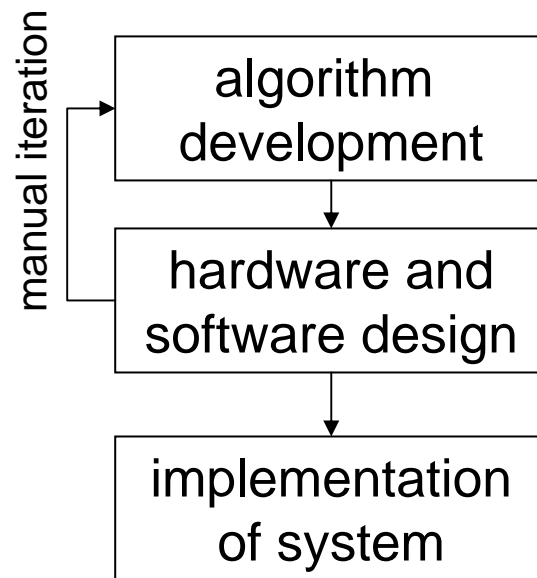
Step 5: Real-time code generation

Step 6: Real-time tests

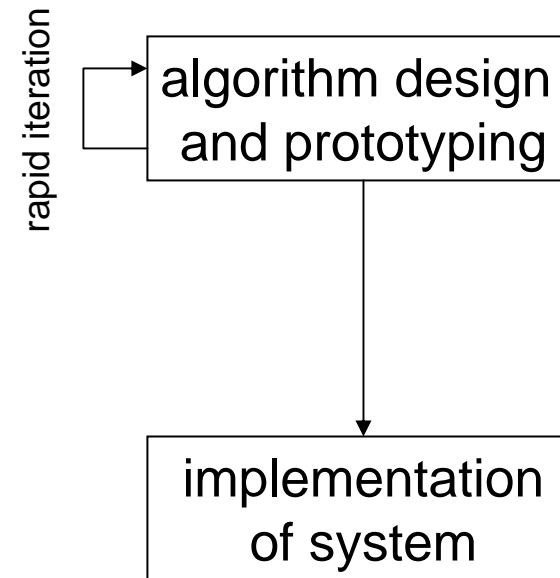


Why Rapid Prototyping?

traditional approach



rapid prototyping process

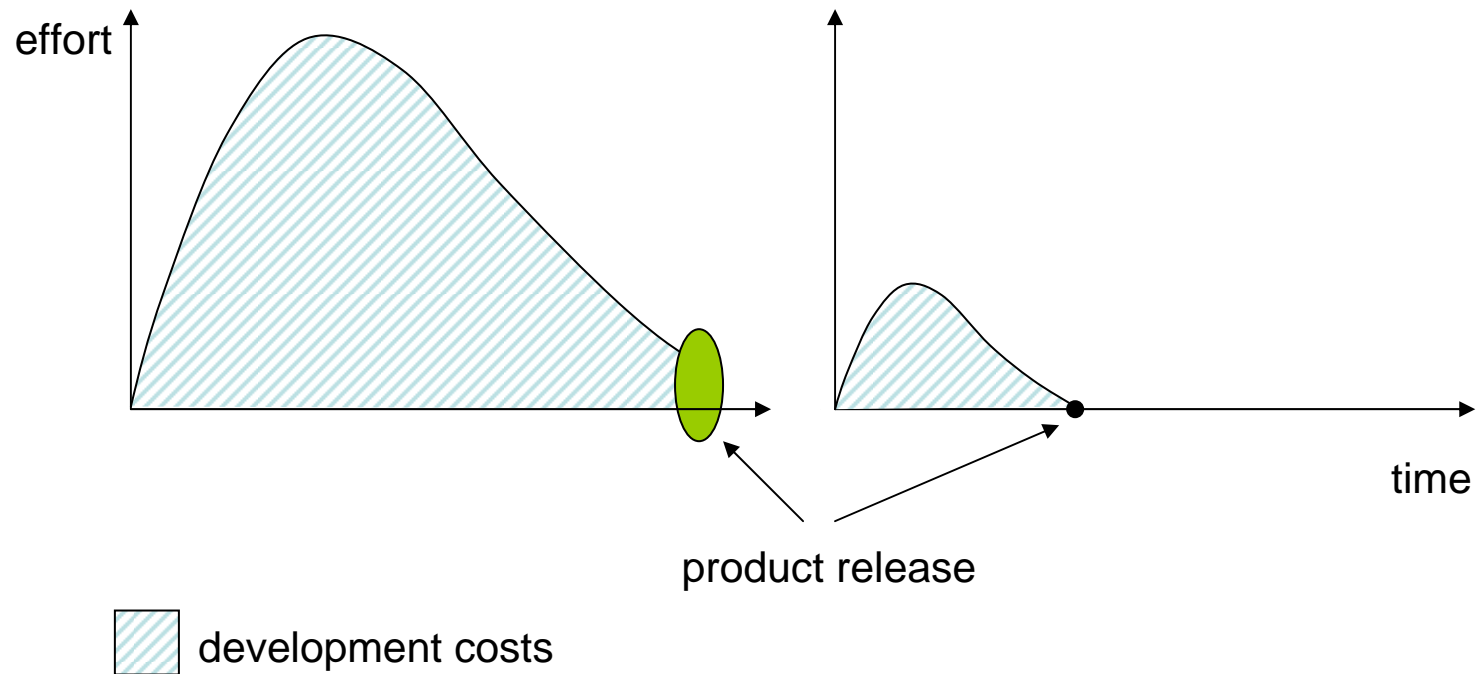




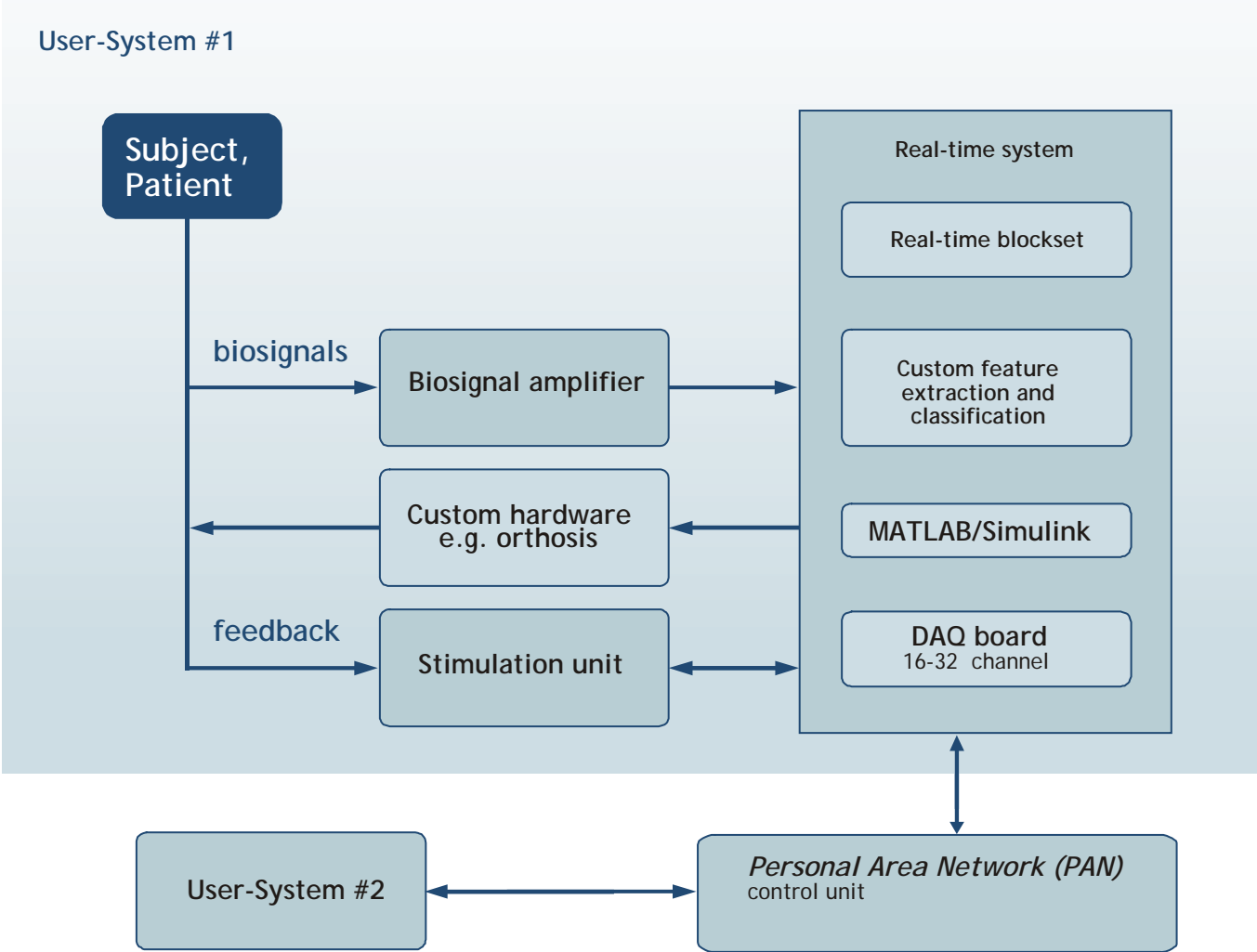
Why Rapid Prototyping?

traditional approach

rapid prototyping process



MATLAB and Simulink environment



Selection of parameter estimation algorithms

(I) Non adaptive estimation:

Band power (optimal frequency bands)

KALCHER et al. 1993

AR parameters

PFURTSCHELLER et al. 1997

WOLPAW 1997 ✓

Hjorth parameters

GUGER 1997, OBERMAIER et al. 1999

Common Spatial Patterns (CSP)

MÜLLER - GERKING et al. 1999,

RAMOSER 2000

GUGER 2000

(II) Adaptive estimation

AAR parameters (RLS algorithm)

SCHLÖGL

Selection of classification algorithms

(I) Neural networks (≥ 2 classes)

LVQ, DSLVQ

FLOTZINGER et al. 1994

PREGENZER and PFURTSCHHELLER 1999

(II) Linear discriminant (2 classes) ✓

signed distance function

PFURTSCHHELLER et al. 1998

LUGGER et al. 1998

(III) Hidden Markov Models (≥ 2 classes)

OBERMAIER et al. 2001

(IV) Support-Vector Machines

MÜLLER

Hardware Development

EEG, ECoG, EMG, EOG, ECG amplifiers
1-128 channels

A. USB based biosignal amplifier

- 16 integrated 24 Bit ADCs
- Floating point DSP
 - re-referencing
 - oversampling (~20000 times)
 - bandpass and notch filtering



B. Mobile device

- 2-4 AA batteries
- 1 integrated 16 Bit ADC
- serial/USB interface
- 1 week operation time
- TCP/IP remote control



C. Stand-alone device

- analog output
- combine it to DAQ board (e.g. NI)
 - resolution
 - sampling frequency
- PCI or PCMCIA board



Software Programming Environment

A. C++ Application Program Interface

- allows to integrate amplifier

B. MATLAB API

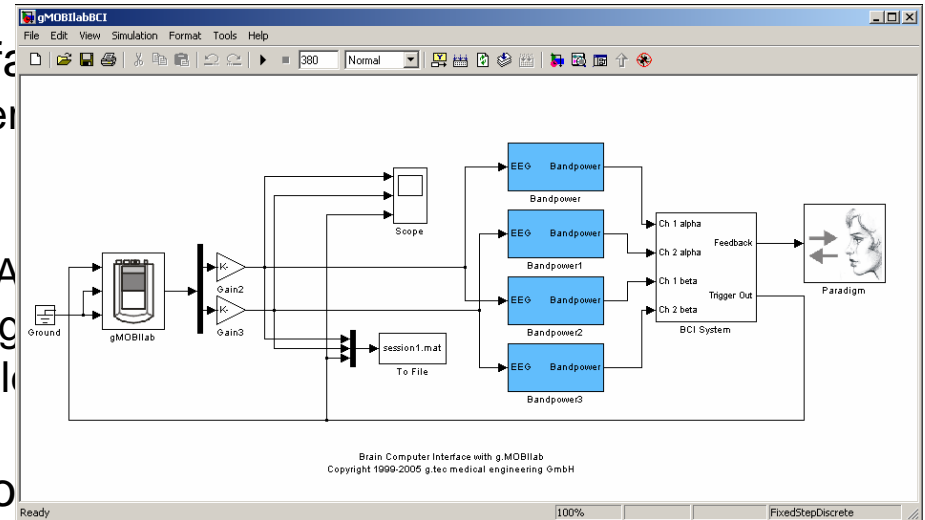
- integrate amplifiers into MA
- access to all toolboxes (Sig
- access to user written M-file

C. Simulink Highspeed on-line Pro

- amplifier device driver block under Simulink
- copy the block into Simulink model and connect the signal processing (S-functions) and paradigm blocks (MATLAB code)
- just exchange the amplifier device driver and work with the same signal processing blocks

All three options give full access to hardware

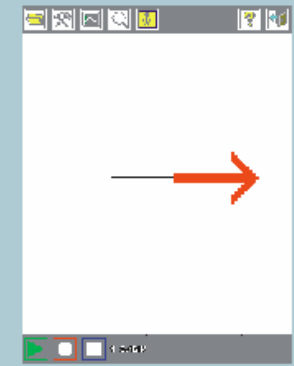
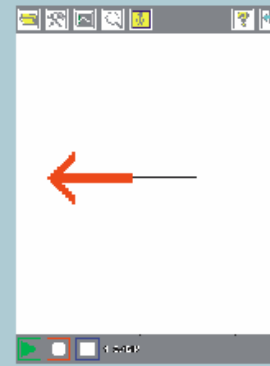
- bandpass, notch settings
- sampling frequency
- impedance check
- data buffer
- ...



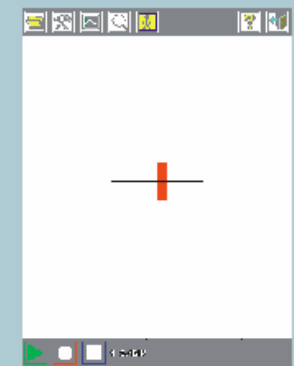
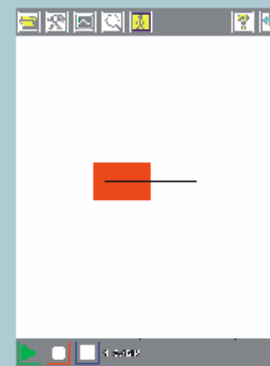
Training BCI Control



Training phase



Feedback / BCI application phase

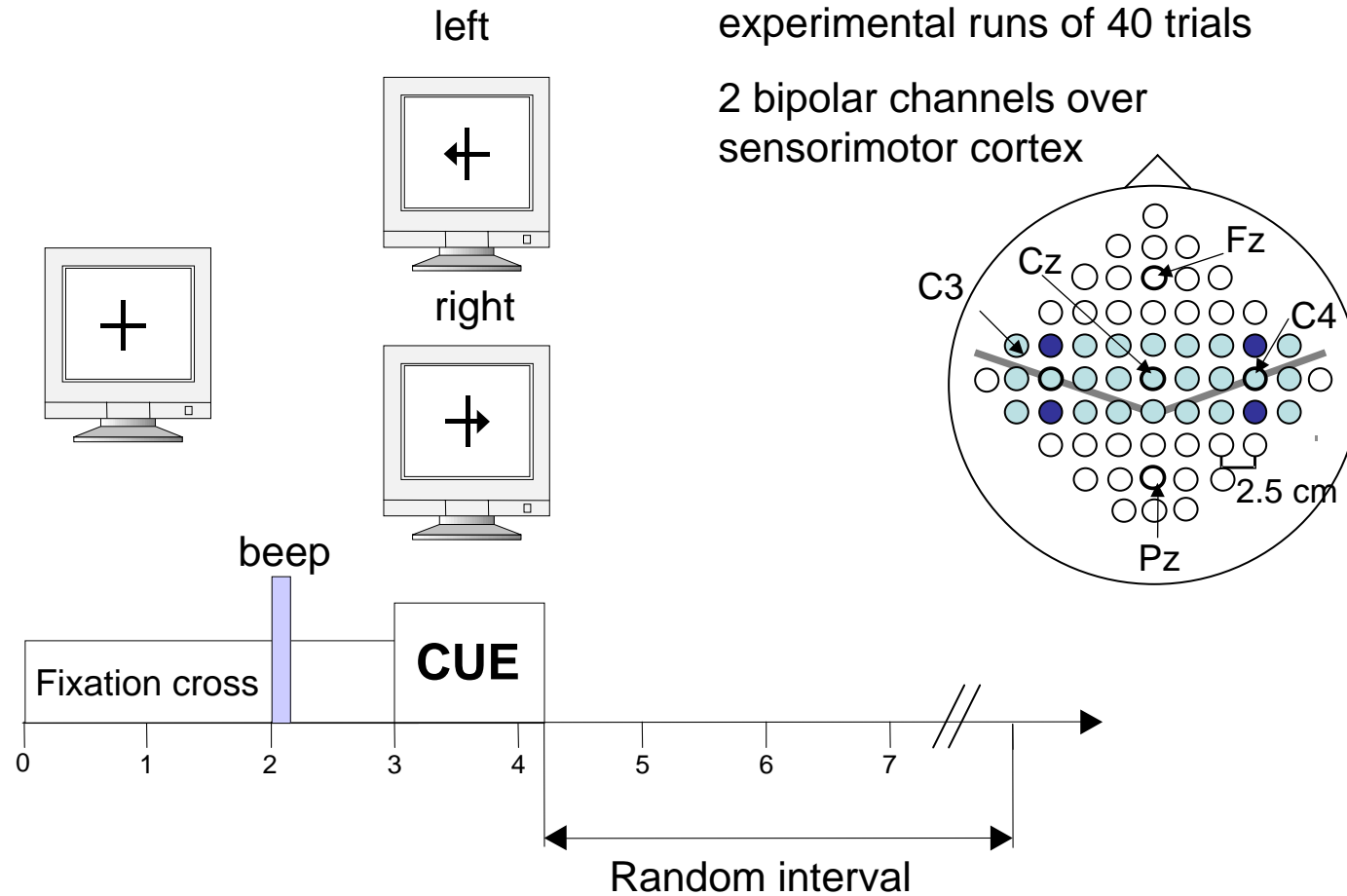




Off-line simulation - Paradigm

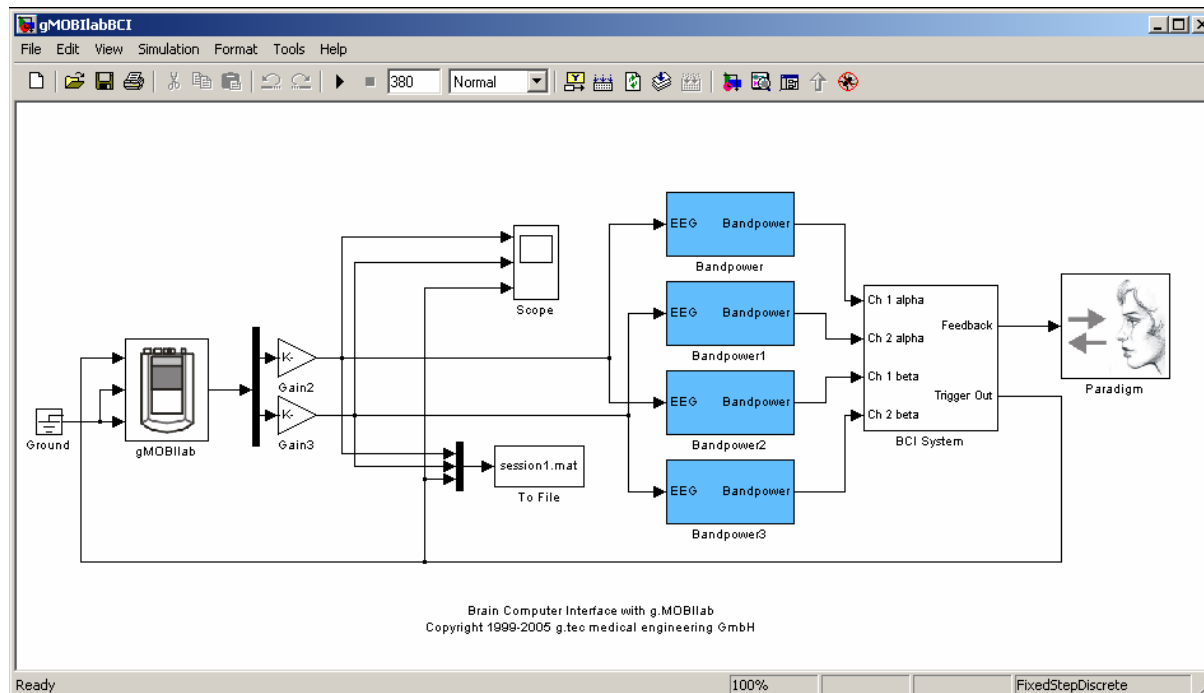
Each session was divided into 4 experimental runs of 40 trials

2 bipolar channels over sensorimotor cortex



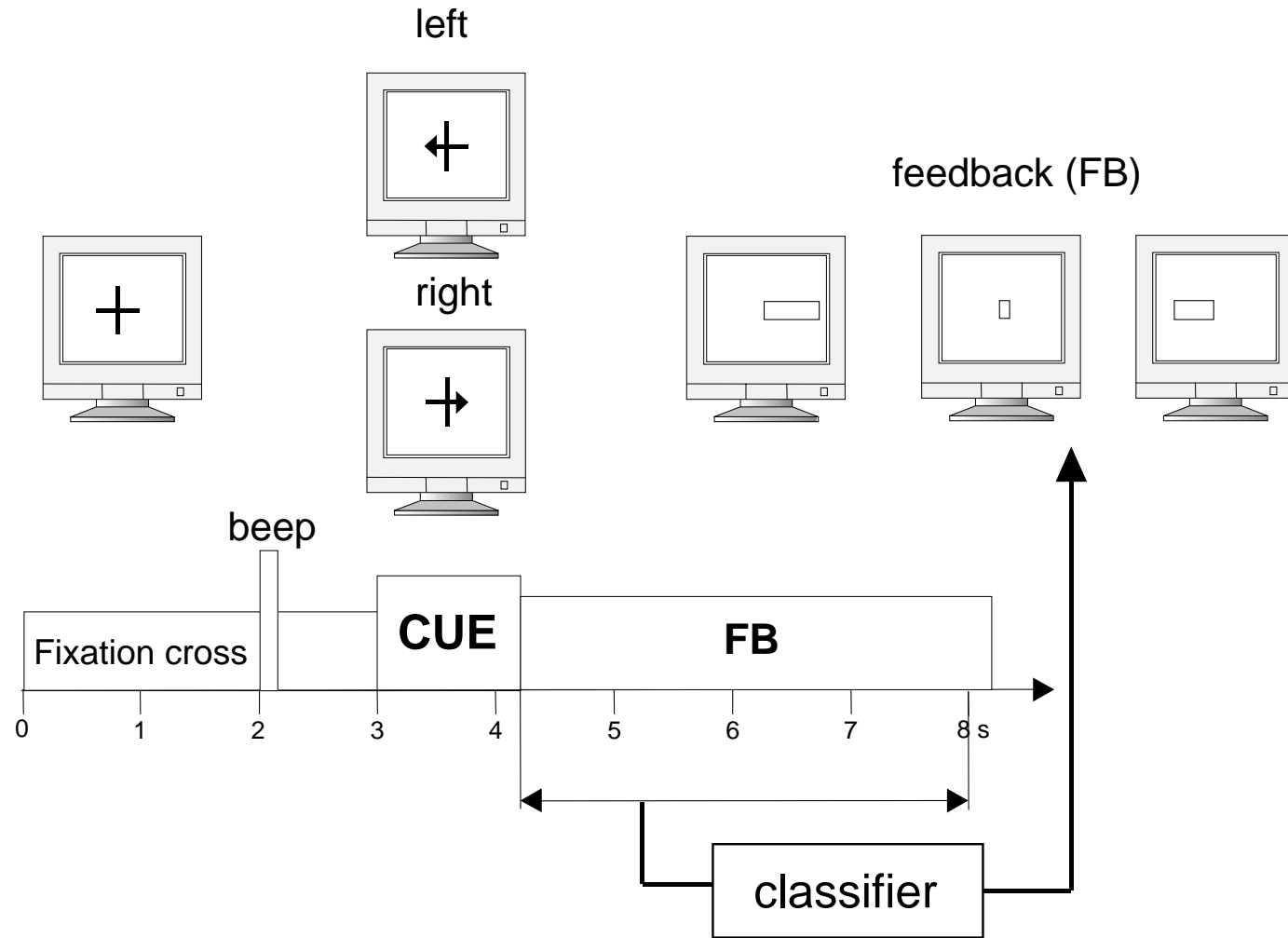
g.USBamp Simulink Highspeed on-line Processing

- amplifier device driver block reads data into Simulink in real-time
- blocks for signal visualization and data storage
- feature extraction with bandpower algorithm implemented as S-function in C
- on-line linear discriminant analysis
- paradigm implemented as S-function with MATLAB code

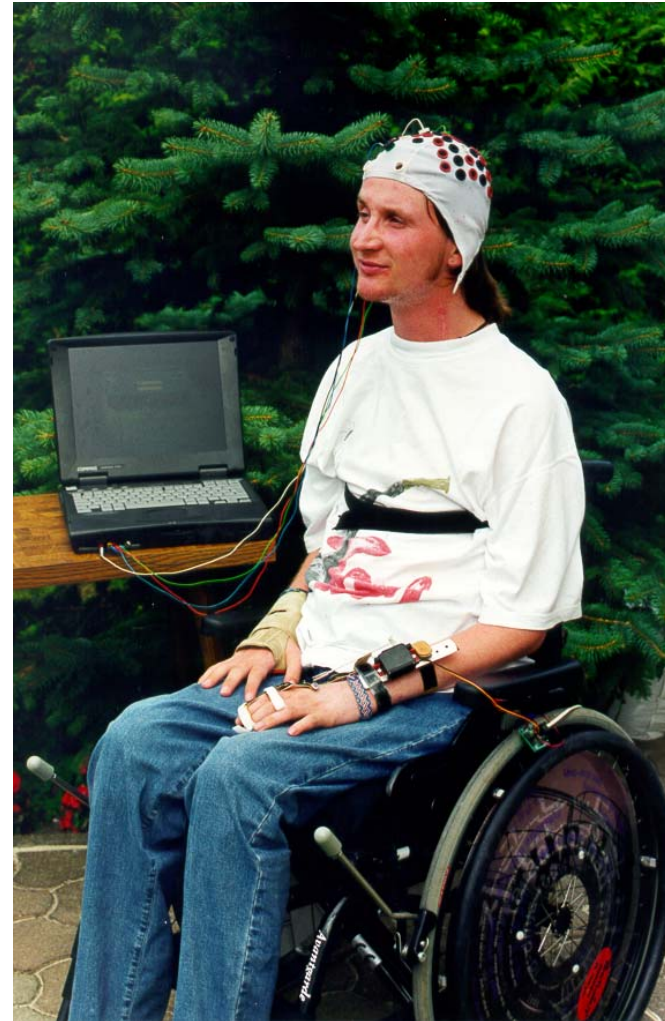


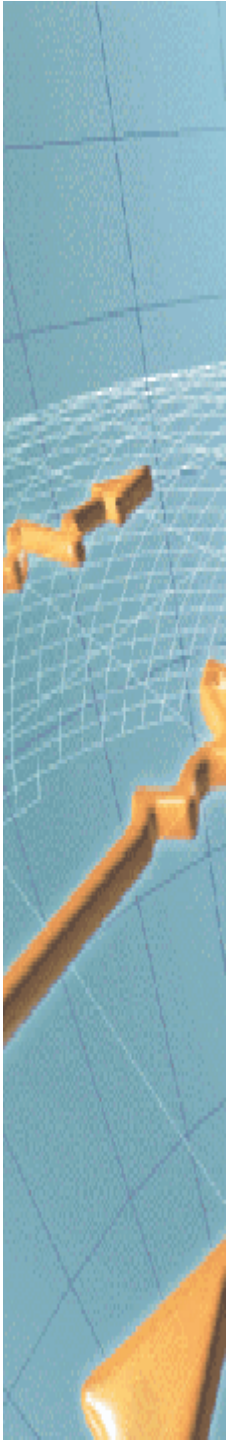


Connection to real world – Imagination with continuous feedback



Patient Tom (C4/C5 lesion)



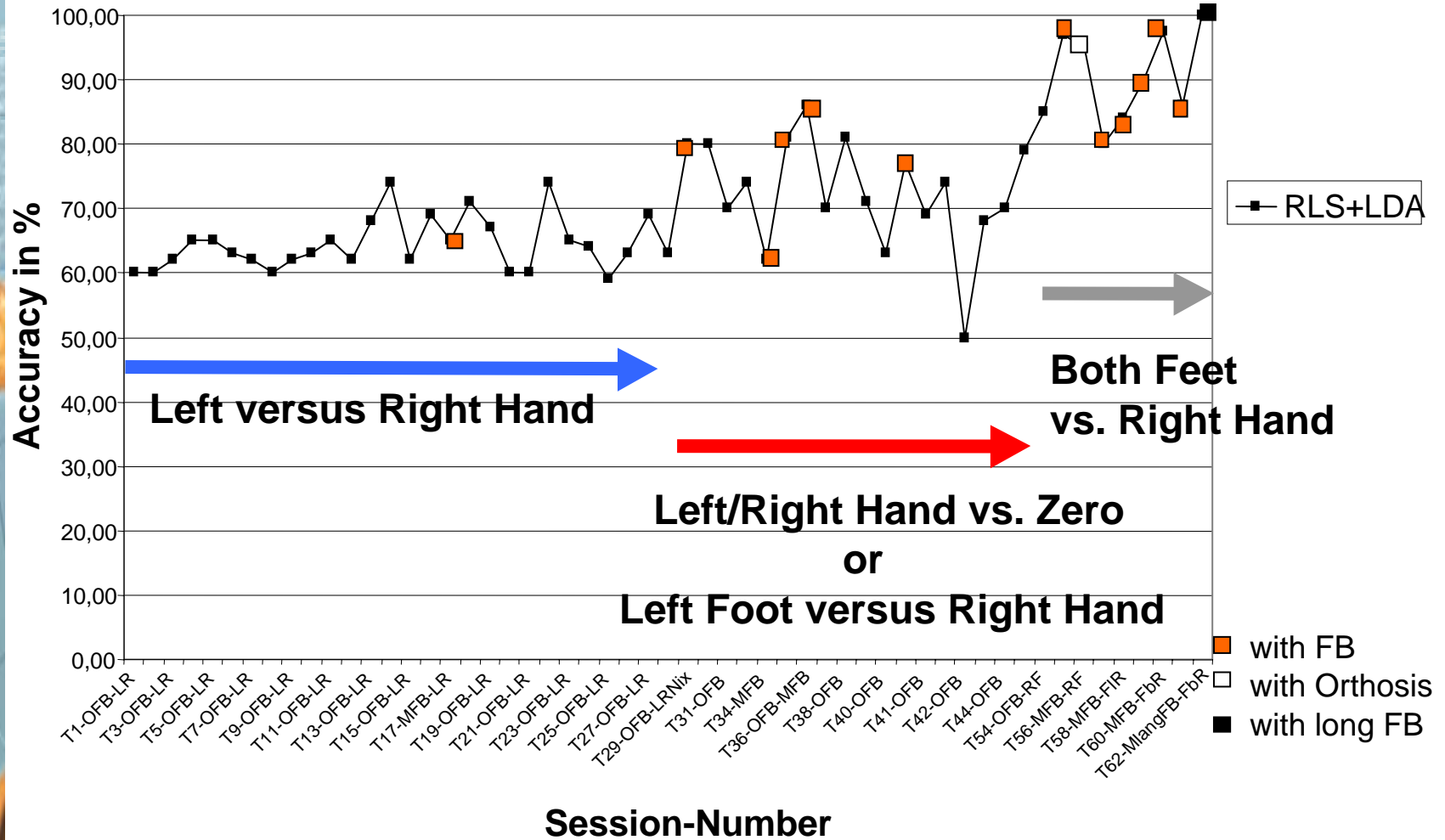


Video: Control of orthosis

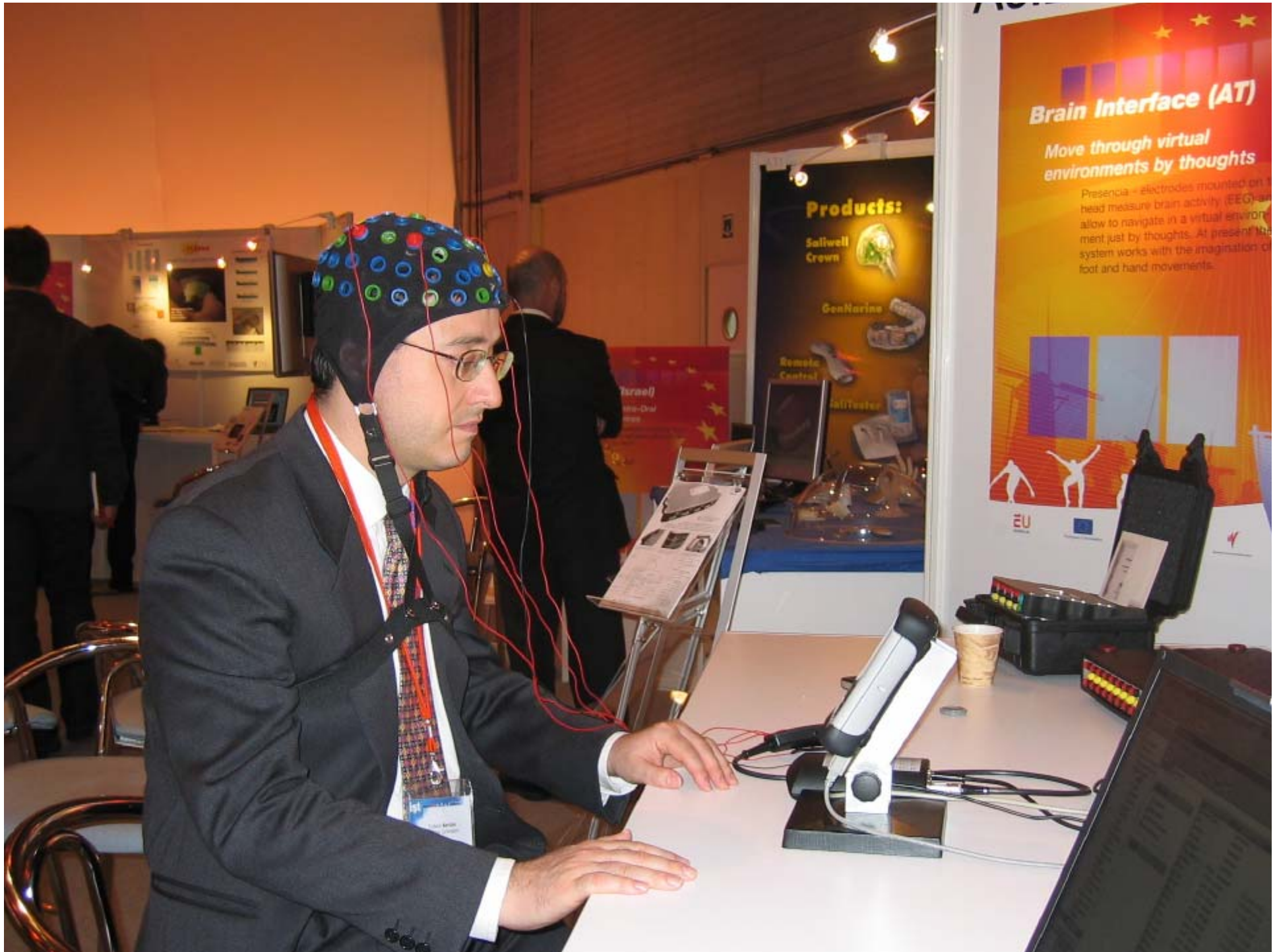


Training Results

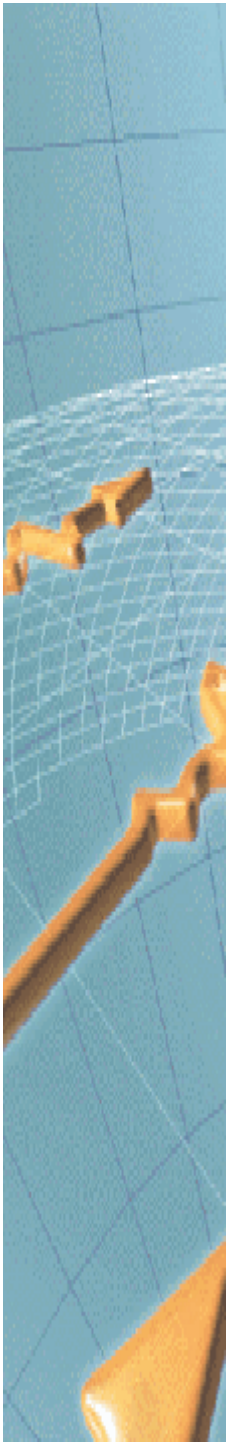
Classification Results, T.S., Age: 22, Mai - September, T1-T62







Playing Pong





How many people can control a BCI?

- BCI system at exhibition about bio-technology in Graz (6 months duration)
- data of all 99 subjects (first 2 month)
- 1 run without feedback
- next run with feedback
- 2 bipolar derivations analyzed with adaptive autoregressive parameters or bandpower of predefined frequency bands

Classification Accuracy in %	RLS Percentage of Runs (N=76)	BP Percentage of Runs (N=117)	RLS+BP Percentage of Runs (N=193)
90-100	6.6	6.0	6.2
80-89	10.5	14.5	13.0
70-79	30.3	33.3	32.1
60-69	40.8	42.7	42.0
50-59	11.8	3.4	6.7
	100	100	100



Summarizing Rapid Prototyping

- **technical issues**

- comparison of different parameter estimation and classification algorithms
- off-line and on-line comparison supported!
- update algorithms very quickly
- very flexible system
- system maintenance via remote control
- supports different paradigms

- **subject issues**

- subject can adapt to the classifier
- subject knows that the system is learning the new patterns
- different feedback strategies depending on subject
- high accuracy after a few sessions

P300 Spelling Device

BCI P300 Matrix Speller

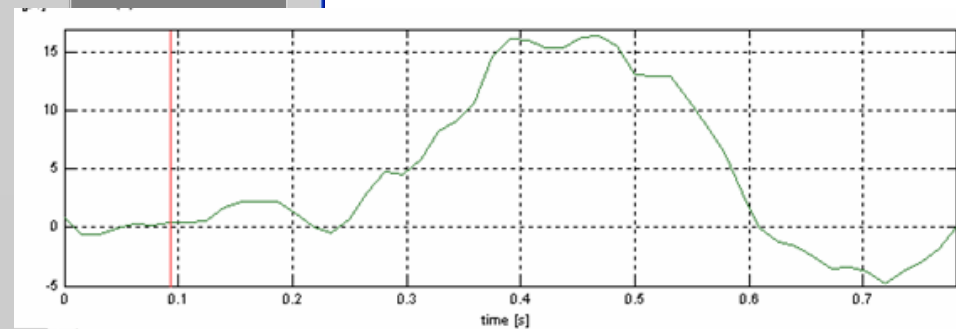
Correct: 3 Wrong: 0 Accuracy: 100% 😊

BCI
BCI

A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X
Y	Z	1	2	3	4
5	6	7	8	9	.

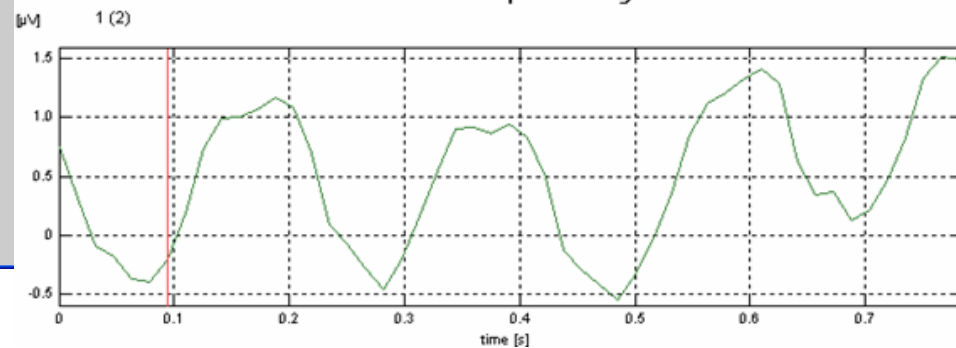
New Run

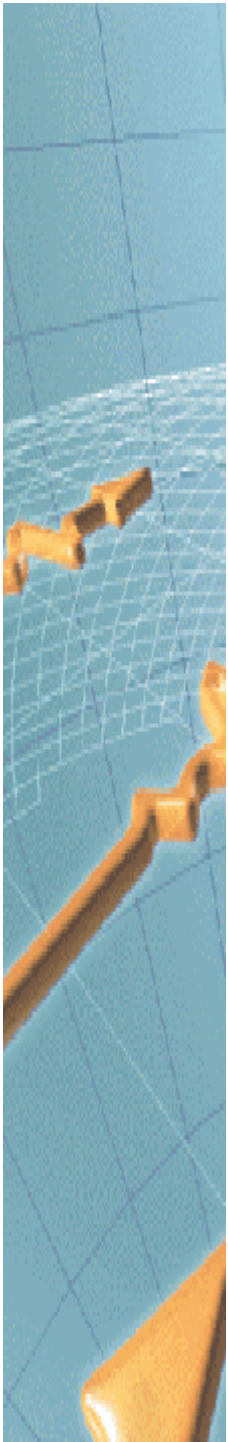
Show Debugging Information



fit

Simple average



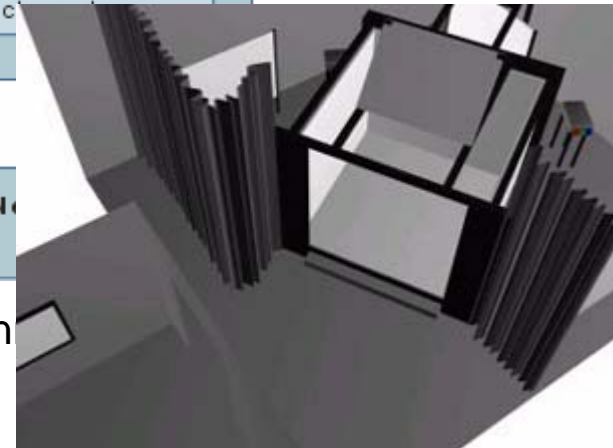
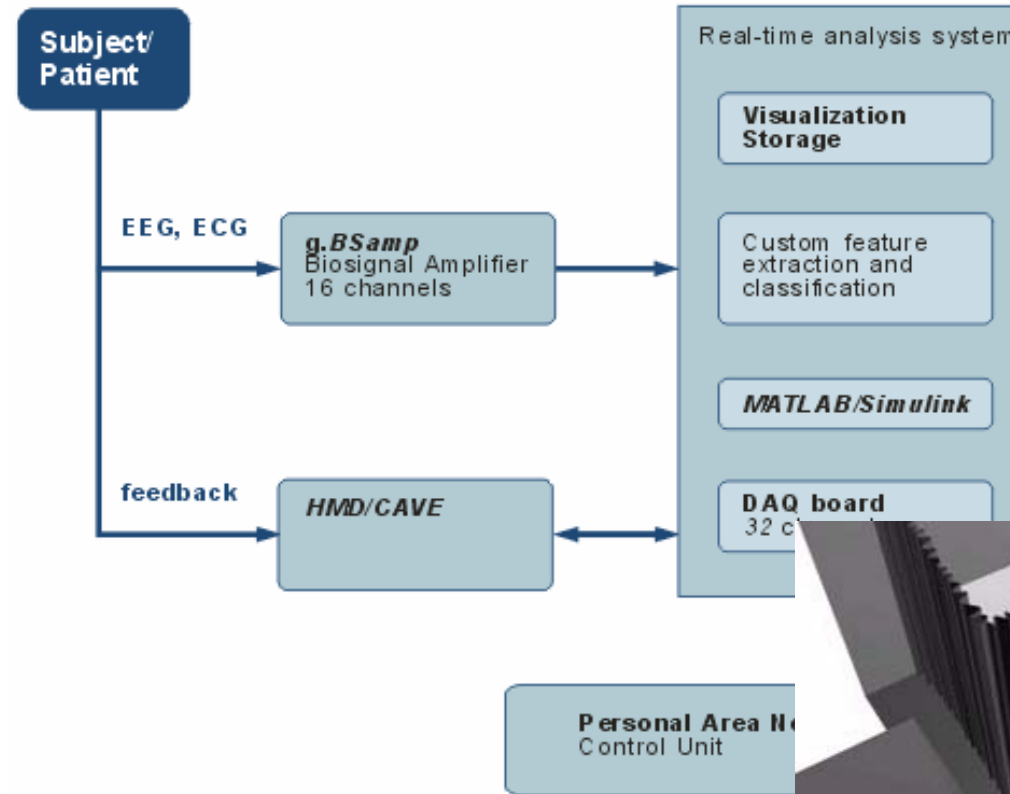


P300 Spelling Device

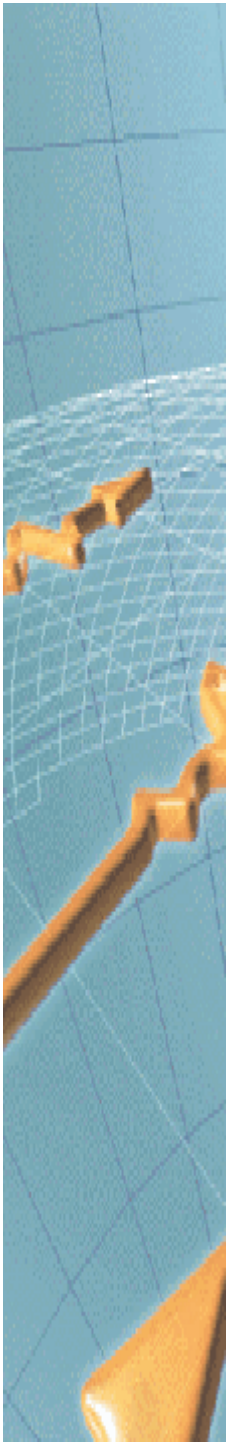


Biosignal Analysis and Recording System in VE

USER-System



- The recording system has to work in noisy environment
- CAVE system: creates a 3D Virtual World
TRIMENSION ReaCTor
3 back projected screens (3m x 2.2m)
1 floor screen projected by ceiling mounted projector
- 3D effect with shutter glasses

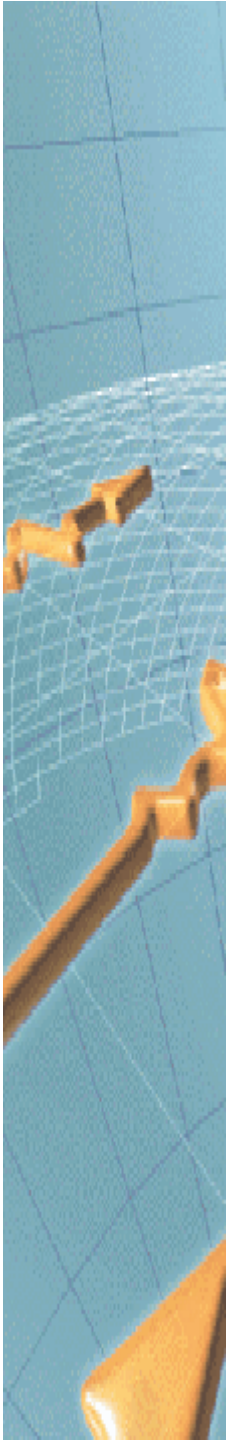


Navigation in Virtual Street with Avatars

Task to explore the virtual world as far as possible

		subject imagined	
		foot movement	right hand movement
cue class	foot movement	forward	stop
	right hand movement	backward	stop

→ achieved mileage as performance measurement

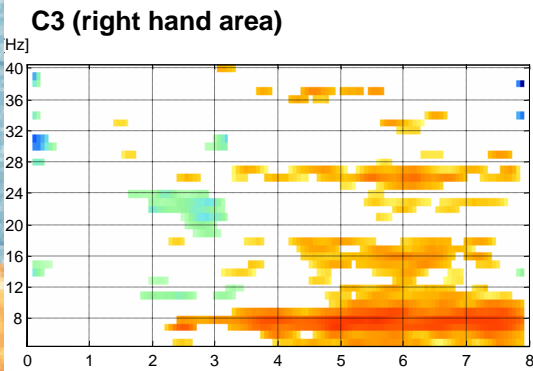


Movie: "Walking through a Virtual City by Thought"

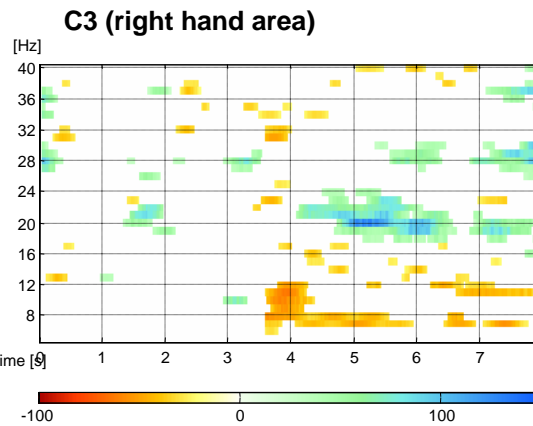


Brain Plasticity

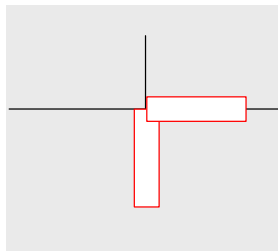
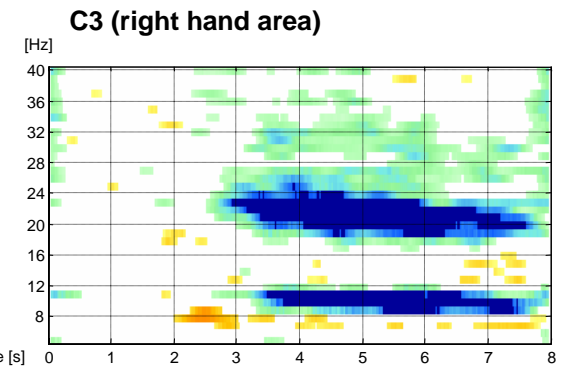
BCI training



HMD feedback



CAVE feedback

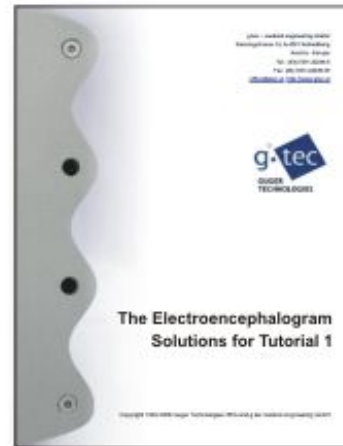
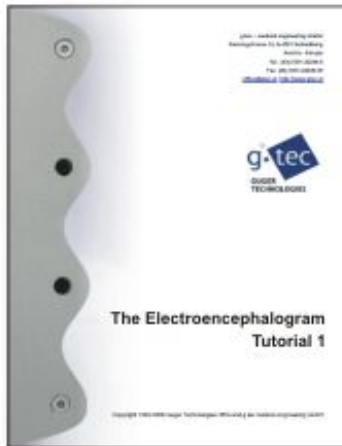


G.Pfurtscheller, R.Leeb, C.Keinrath, D.Friedman, C.Neuper, C.Guger & M.Slater

Walking from thought

Cognitive Brain Research, 2006

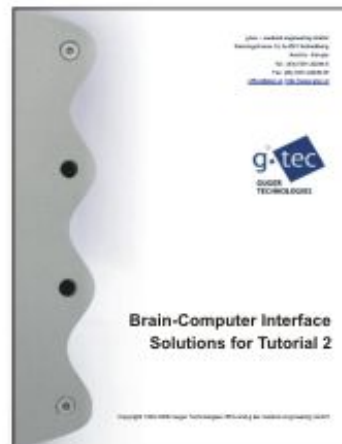
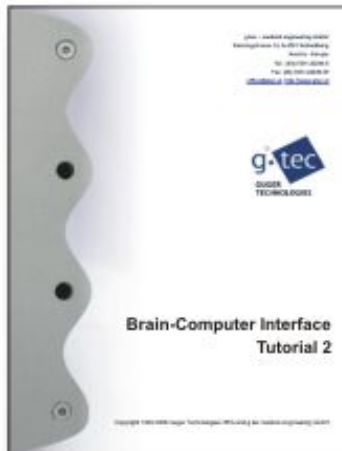
Biomedical Engineering Lectures



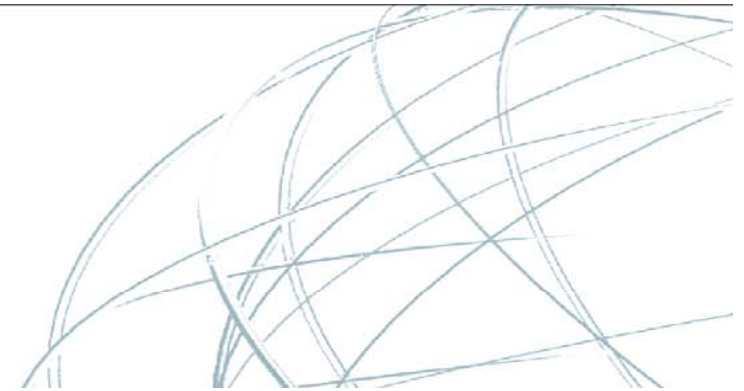
Average time to perform the lecture: 450 min

Pages of lecture: 47

Pages of solutions for lecture: 24



<http://www.presenccia.org>



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