Can machines live our lives?

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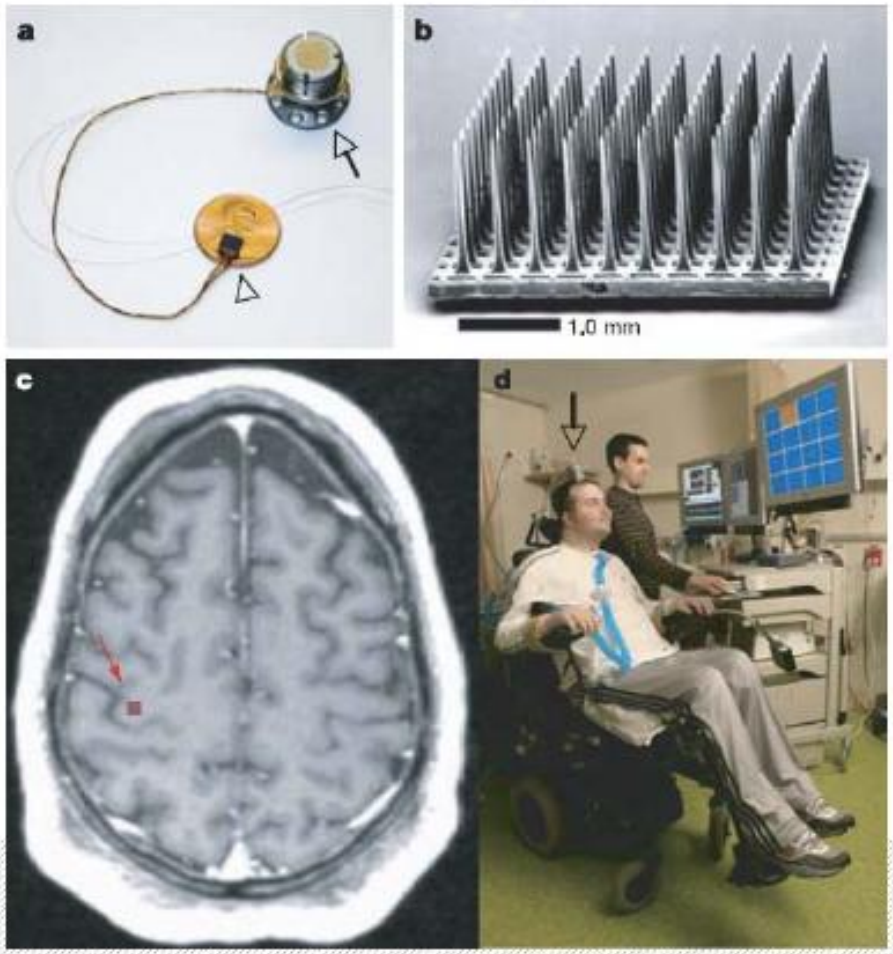
What is a BCI?

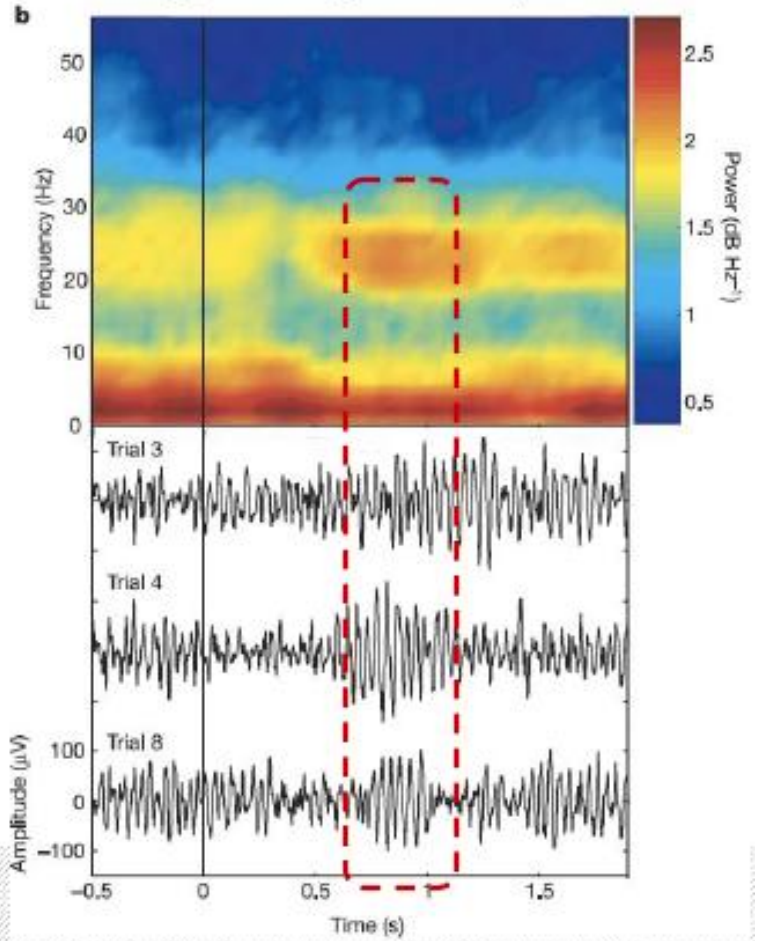
A brain-computer interface (BCI, or brain machine interface – BMI) is a system able to analyze and classify a brain signal in *real-time* (online) so that it can be used as a control function. BCI have been used to bypassing the motor system. Some applications are:

- Spelling (communication) devices
- Controlling classic and neural prostheses
- Neurorehabilitation & neurofeedback therapy
- (In the future:) Building a powerful cyborg - we are closer to this than teletransportantion.

This example shows what BCI could be used for.

BCI in its most extreme form





Approaches to BCI

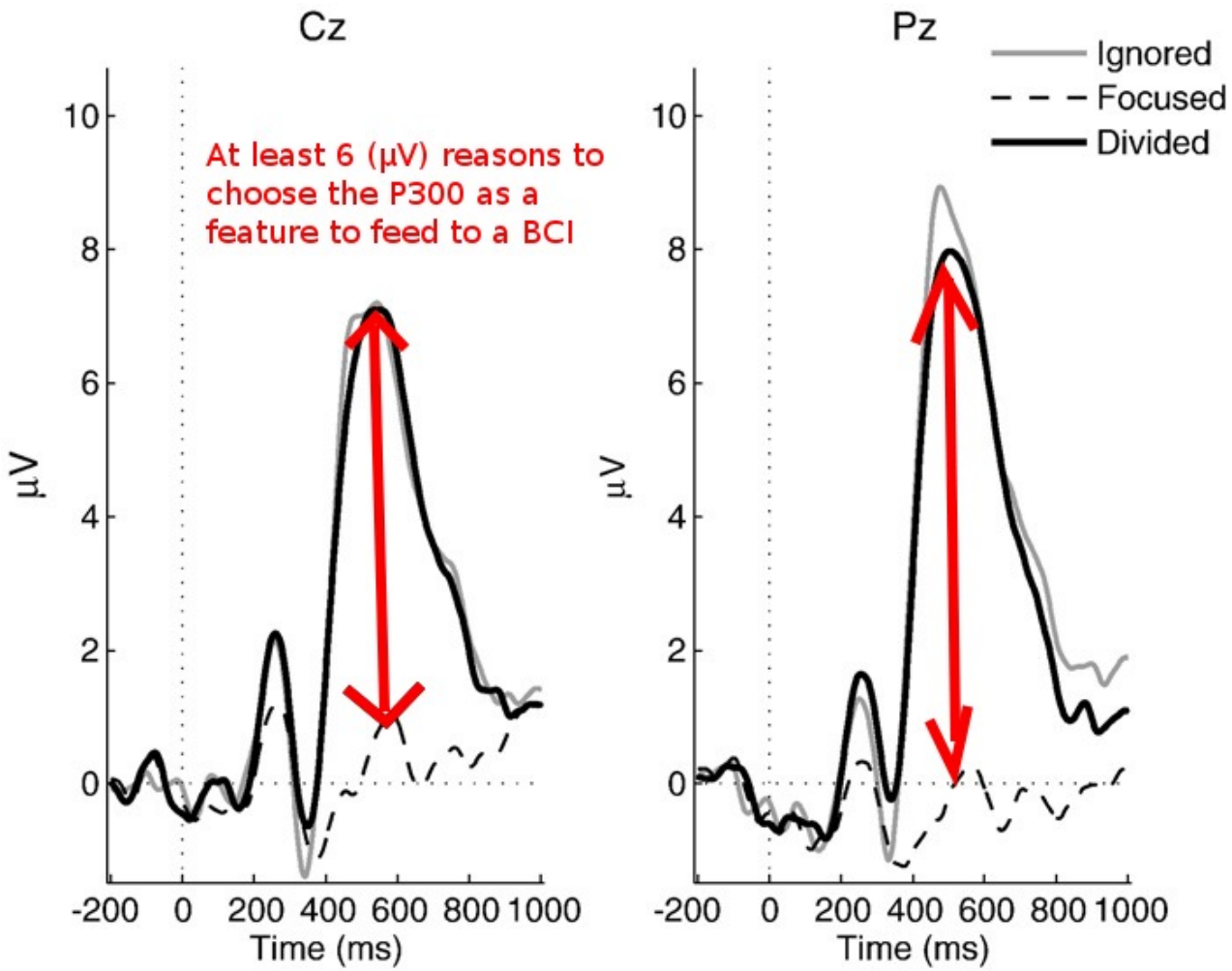
User thinks something, the machine interprets the thought.
A BCI does a real-time (moment-by-moment) classification of the user's brain signal to determine the user's brain state.
There are **2** main approaches

- **Wadsworth**: The user learns to use the machine - the user evokes a specific response depending on what he desires the machine to do. – one size fit all.
- Berlin (**BBCI**): Let the machine do the learning - user states are fed to the machine which finds features to discriminate among them. – each person is unique.

The P300 speller

The first BCI systems (1970s-80s) were 'spellers'.
P300 spellers aim to identify the letter the user is 'thinking'.
P300 spellers categorize the presence or absence of the P300 components of the event-related brain potentials (ERP). It's a binary procedure.
The P300 or P3 reflects the (human) categorization of an infrequent target item.
The P300 or P3 is the biggest and most studied ERP waveform.
The P300 is very reliable and everybody can evoke it (e.g. The P300 indexes that comatoes patients are going to wake up).

Why the P300?


Cz
Pz
Ignored
Focused
Divided
At least 6 (μV) reasons to choose the P300 as a feature to feed to a BCI
μV
10
8
6
4
2
0
-200
0
200
400
600
800
1000
Time (ms)

How does a P300 speller work?

Each row and column of the matrix is intensified in a random sequence.
The user focuses attention on one of the 36 character cells of the matrix.
The row and column intensifications that intersect at the attended cell represent the target stimulus (oddball), which occurs with a probability of 1/6.
With proper P300 feature selection and classification, the attended character can be identified and communicated.

The Matrix

Example of a user interfacing with a P300 speller.

Types of BCIs

- **Active BCI**. An active BCI is a BCI which derives its outputs from brain activity which is directly and consciously controlled by the user, independent of external events, for controlling an application. (BBCI & Wadsworth)
- **Reactive BCI**. A reactive BCI is a BCI which derives its outputs from brain activity arising in reaction to external stimulation, which is indirectly modulated by the user for controling an application. (P300 speller & SSVEP BCI)
- **Passive BCI**. A passive BCI is a BCI which derives its outputs from brain activity arising withouth purpose of voluntary control, for enriching a human-machine interaction with implicit information on the actual user state. (user state BCI)

How does classification work?

The machine learning task of classification is to find a rule, which assigns an observation to one of several classes.
Rule $\rightarrow$ the statistics underlying a certain signal are learned and used to predict new incoming information.
Classification is a difficult problem, it requires dimensionality reduction.
Example for a common EEG-based BCI:
1 s of recording @ sampling frequency of 1000 Hz
128 electrodes
10^5 dimensions $\leftarrow$ without including all other sources of noise...
How can it be done?

Types of classifiers

A classifier finds features to discriminate among different classes.
Basically it is an efficient algorithm.
A crucial aspect of a classifier is the use of class information to determine which features discriminate the classes.

Unsupervised

Does NOT use class information (the factors of interests must be identified manually- e.g., PCA, ICA, various form of factor analysis)

Supervised

Uses class information (the factors of interests are determined by the classifier - e.g., CSP)

ICA and CSP

ICA (independent component analysis) and CSP (common spatial pattern) are the most popular types of unsupervised and supervised algorythms.

ICA or blind source separation

Linearly decomposes the EEG signal into components whose activities are temporally maximally independent between one another. However, it is the experimenter that (tries to) determines what component corresponds to which mental state.

CSP

The experimenter feeds the class information to the algorithm, which aims to solve the problem of finding the features that maximally distinguish between the two classes.

A practical example

Assume that a machine is to distinguish male and females individuals given a database containing information about all human beings.
Assume that, among other information, the database contains physical attributes (e.g. eye color, hair color, weight, height, size of the nose, size of the feet, etc.).
Assume that information about the person's sex is missing.
The machine has no idea

1. of what a person is, or what male and female are.
2. that there is one physical attribute allowing the distinction between ladies from gentlemen.

Determining which physical properties in the database allow discriminating men from women is a **dimensionality reduction problem**.

Unsupervised algorythm

In the **unsupervised** approach the machine try to find a way to separate the database into two classes.
basically it corresponds to order to the machine: "these are human beings". Make two classes of them.
Determining that the algorythm distinguishes men from women correctly is difficult.
Especially because unsupervised algorythms will return two classes, but the discriminative feature(s) might be 'wrong' (e.g., body size, or body size and height, or hair colour).
Classification based on 'wrong' features will lead to erroneous discrimination (e.g. a small man might be classified as a woman).

The supervised approach

In the **supervised** approach the categories are defined before starting the discrimination process.
It corresponds to order to the machine: Given these 20 men and these 20 women find a way to distinguish between them.
The algorythm finds the features that allow the maximal distinction between those two groups and then apply those features to the database for testing.
Classifiers do not need to consider all the information in the data base. In fact, it could be that the classifier finds the only necessary detail to determine if a person is a man or a woman.
If it succeeds, the classifier has reduced all the dimensions into one feature.

Classification does not always work. . .

IMPORTANT

- If database info does not allow classification, algorythms might not converge
- It might be that the feature used for classification is another than the expected one.

BCI procedure

Classifiers performance is evaluated through a **cross-validation** procedure.
From the complete data set 80-90% is used for classification, 20-10% for validation.
Classification: Features are extracted from the dataset (training set).
Validation: Test the discriminative power of the previously extracted features on a new data set (validation set).
Generalization Error: How effectively the classifier can distinguish among various classes (also called expected risk).

P300-based spellers

First BCI.
Uses the oddball paradigm to evoke a P300: The desired letter presented among the others is the oddball.
The BCI recognizes the letter the user is thinking when it recognizes the presence of a P300.

. . . does it work in practice?

P300 spellers might not be very effective because some of the characteristic of the features (P300) that have to be extracted might not be optimal.
For example, only **one** target at the time can be selected, this requires long periods of focussed attention on the target letter (at least 6 * ISI + 6 * ISI = 12 * ISI flashes $\sim 2 \div 2.5$ s).

Can another method select the characters allowing:

- Better signal to noise ratio.
- To switch faster from one object to another.

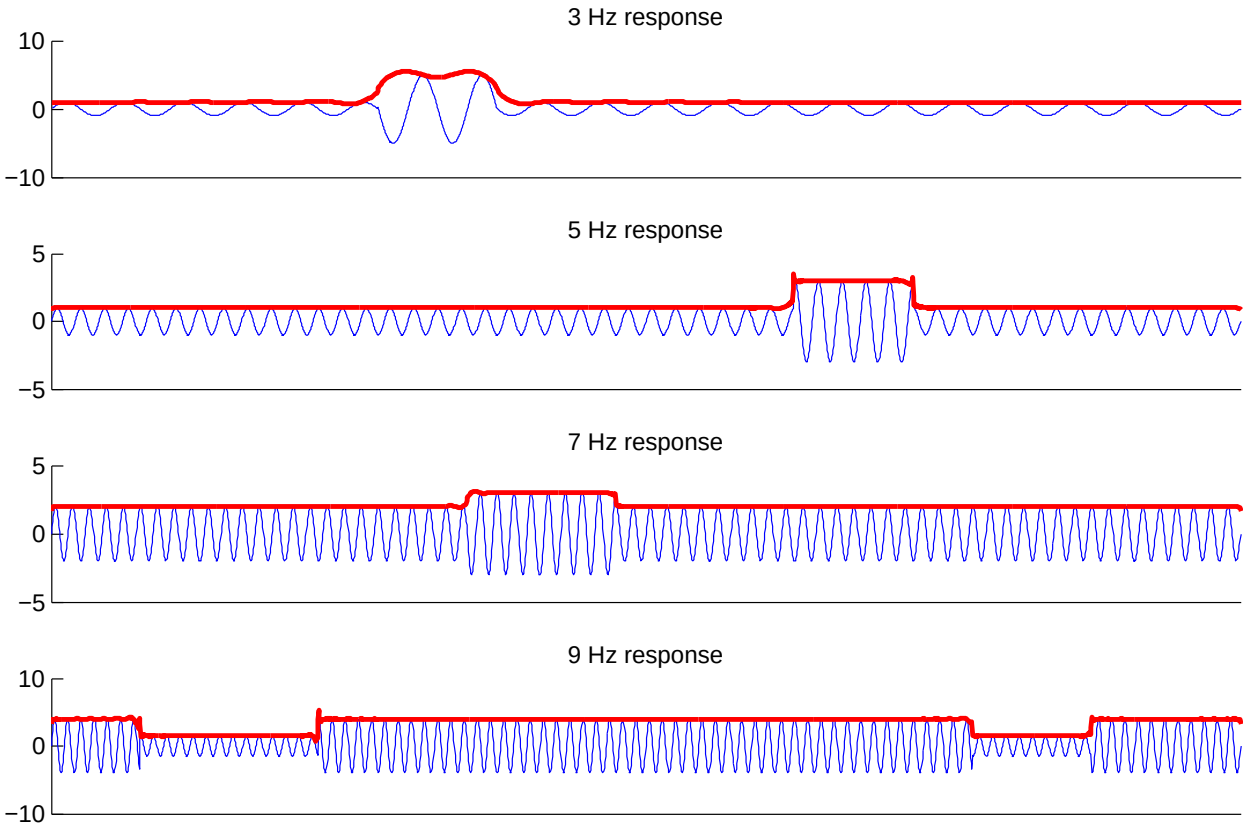
Steady State Evoked Potentials

Steady state evoked potentials are physiological responses evoked by series of sensorial stimulations.
This is an example of two streams of stimuli that can evoke SSVEP.
The amplitude of the SSEP depends on the amount of attention deployed on the stimulus generating the oscillation:

- **attended** stimuli or locations generate an **increase** in SSEP amplitude.
- **unattended** stimuli or locations generate a **reduction** in SSEP amplitude.

SSEP works in many modalities: Visual, Auditory, Tactile, but BCI has mostly been developed using the visual modality.

Frequency modulation of SSVEP



Why SSVisualEP BCI?

SSVEP gives 3 main advantages over traditional EEG/ERP techniques:

1. Independent from the intrinsic characteristic of the stimuli
2. Related to attention requests (i.e. focused attention increases the amplitude of the SSEP)
3. Each object or location is tagged with a distinct frequency providing a unique response for each stimulus or location)

SSVEP based speller and navigation

Spelling can be implemented also with SSVEP, using chekerboards flickering at different frequencies.
Similarly, SSVEP has been used for navigation in an environment or map... This movie shows an example of a SSVEP-based navigation system.
Such an application might seem very abstract, but is it actually far from reality?
Early SSEP research was performed using goggles or positioning LEDs on the border of the screens or boards where the stimuli were projected.
...however,

SSVEP And P300 BCI

Disadvantages

- Force participants to perform a visual task which might be unnatural (gaze at blinking objects).
- Auxiliary visual stimuli or goggles are necessary to evoke the response. Also, the flashes might be fastidious (some photosensitive individual might not be happy to have seizures all day long).

BCI must be possible in a simpler way, for example classifying brain activity using another type of signal which...

- Must be present in the EEG
- Allows maximum distinction between features

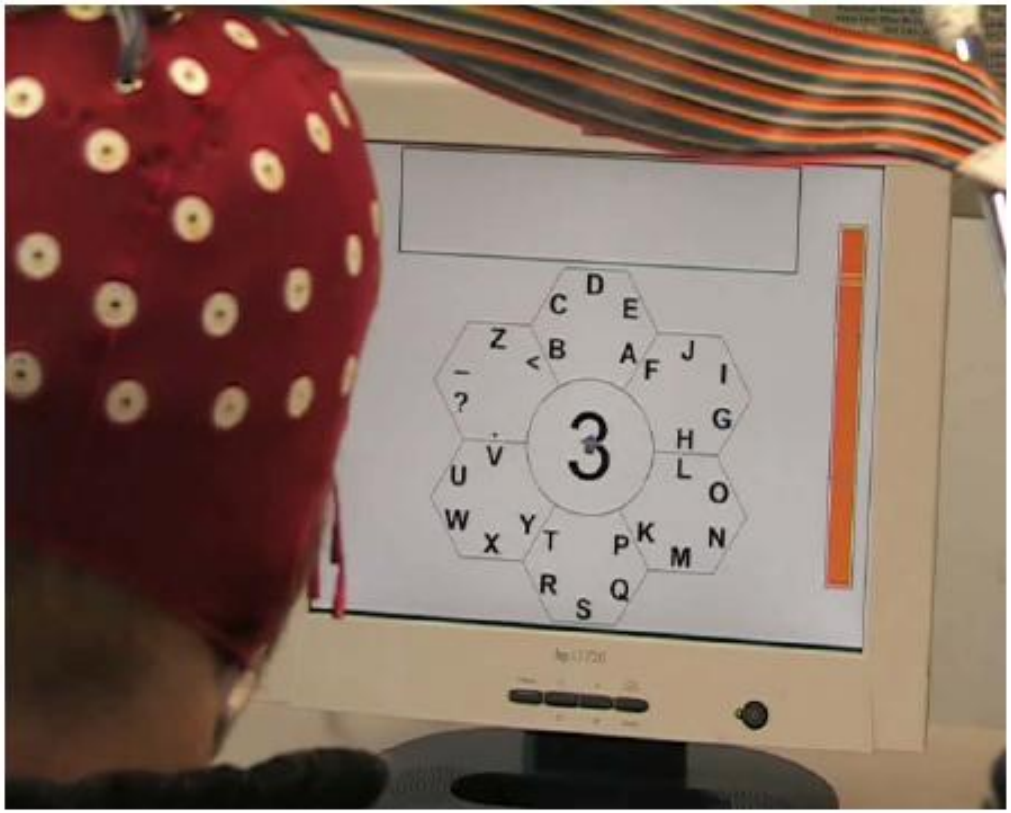
BCI according to the Wadsworth Center

Approach similar to the P300 speller, but uses β and μ rhythms instead.
β and μ are movement related EEG rhythms.
Participants need to learn to modulate the amplitude of the rhythms to 'manouver' a cursor in one or two dimensions.
This BCI is active, rather than reactive.
This is a typical one-size-fit-all BCI approach.

Background

Also ERD/ERS BCI are set on movement-related activity.
The μ rhythm (8-14 Hz posterior central, 20 Hz pre-central) is usually suppressed or attenuated (ERD) when participants imagine a movement.
This movie clip shows a paraplegic moving in a virtual environment in which he has to greet avatars. This is done using only 1 electrode.
Movement-related BCI classify a relatively robust signal because the activity is lateralized, scalp information can be used to interpret movement intentions.

The BBCI HEX-O speller



It is the fastest spelling BCI.
The user imagines left or right hand/foot movements and the cursor moves accordingly.
Cleverly designed interface speeds up the identification process.
It's a close loop system, user receives feedback from the machine.
Based on CSP, it is a supervised algorythm!

BCI illiteracy

Many BCI based on the similar approach than the BBCI, are subject to "BCI illiteracy" (Kubler & Muller, 2007): Some participants cannot learn how to use the machine!

What's good of BCIs

ERD/ERS or CSP like classifiers are good because:

- Do not require additional visual stimuli
- Mental processes/strategies are used for the BCI
- Can be asynchronous (do not require a system trigger)

P300/SSVEP based BCI are good because:

- Allow a large number of commands
- Are very reliable
- Require short or no training
- Higher resistance to contamination by artifacts

But which one is the best?

A comparison of spellers performances

	P300	MI	SSVEP
Letters x Minute	Approx. 2	Approx. 2	Approx. 5
Participants reaching 80-100% accuracy	90%	20%	90%
Accuracy for 90% of the participants	80%	59%	85%

. . . and what if we could combine them to get the best of all?

Hybrid BCI

Hybrid BCI combines two types of signal to improve classification.
Providing a BCI with two types of (brain) signal (see, e.g. Brunner et al., 2010) can:

- Improve accuracy and speed
- Reduce the number of illiterates

They do however create dual-task interferences and switching costs.
Dual-task interferences are difficulties due to doing two tasks simultaneously.
In a dual-task situation wwitching costs are the difficulty of inhibiting one task when the other has to be executed.

So...What do you think of BCI?

Is it worthwhile the investment?
Would you use it?
For what?
Are Avatar or surrogates real (im)possibilities...?
Name a situation in which you think BCI would be handy?
Name a situation in which you think BCI would be handy for an unimpaired human being?

Implications for BCI

The types of BCI presented above are all active or reactive.
Re\active BCI require the user's constant attention!
What has been achieved is NOT exceptional:

- In **medical** research BCI is an extremely expensive, elittarian solution.
  . . . a 3-years old can type 2 letters per minute . . .
- In **applied** research BIC is a very fancy, very **useless** tool, because it does not augment human cognition/abilities!
  . . . the brand new Volkswagen Passat has a series of controls for driver performance and assistance, none of which based on the user physiological responses.

Is all this research an extreme blow?

fMRI based BCI

. . . some research groups think that BCI would greatly benefit if classification would be based on fMRI. Classification could be improved because of the somatotopic organization of the brain. Therefore BCI should be based on fMRI rather than EEG.

Advantages

- MRI allows fine analysis of WHERE things happens in the brain.
- Some argue that 'predictive' timing could even be better than with EEG.

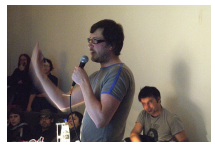
Drawbacks

- Extremely Expensive
- fMRI equipment is not "portable"

Mariko Mori - Ufo Wave

State-of-the-art BCI system used for art.

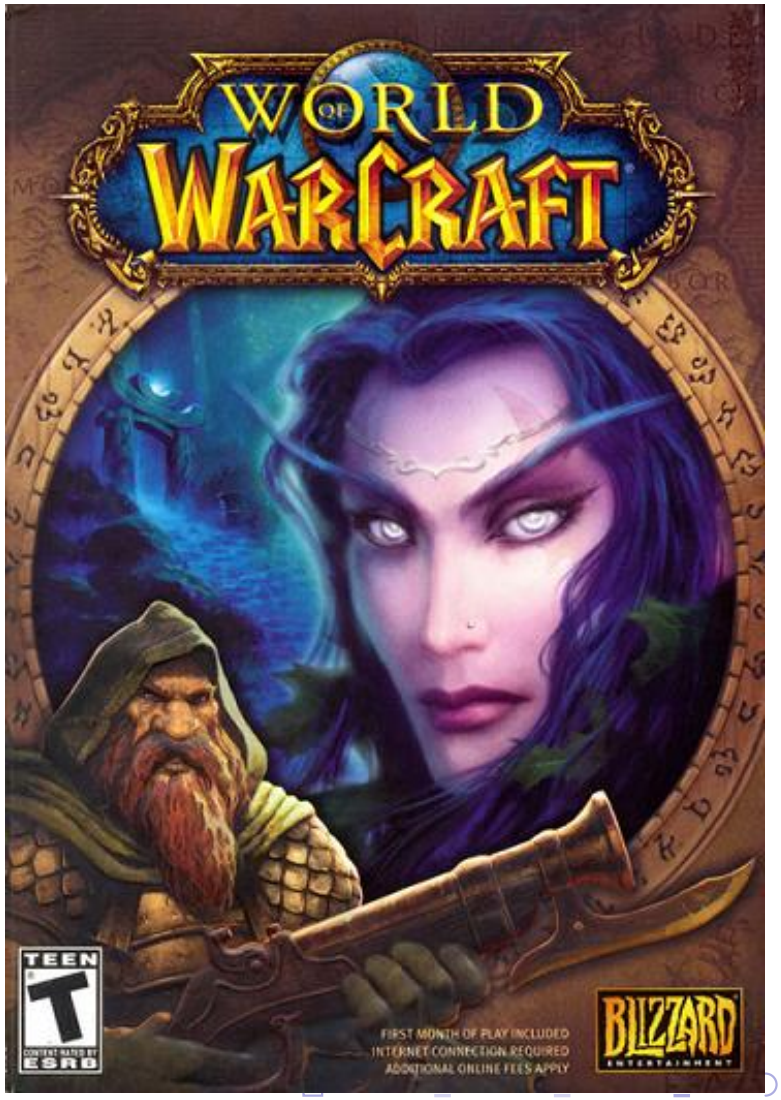
Christoph De Boeck - Steel Sky



Christoph De Boeck

BCI for gaming lovers!

Anton Nijholt's group included BCI in games.
In the game World of Warcraft the alpha rhythm is used to change the response of the character the player is using.



Deep Brain Stimulation

Deep Brain Stimulation (DBS) is a surgical treatment involving the implantation of medical device which acts as a **brain pacemaker**.
The device is similar to a television antenna which sends electrical impulses to specific parts of the brain.
DBS has been used to treat Parkinson desease, depression, obsessive compulsive disorder, . . .

The underlying principles and mechanisms of DBS are still not clear, therefore . . . nobody can predict the long term consequences.

That's all folks

If you interested in the presentation, you would like to read more about this topic, you have questions, or anything else, you can contact me at :

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Thank you for the attention!!