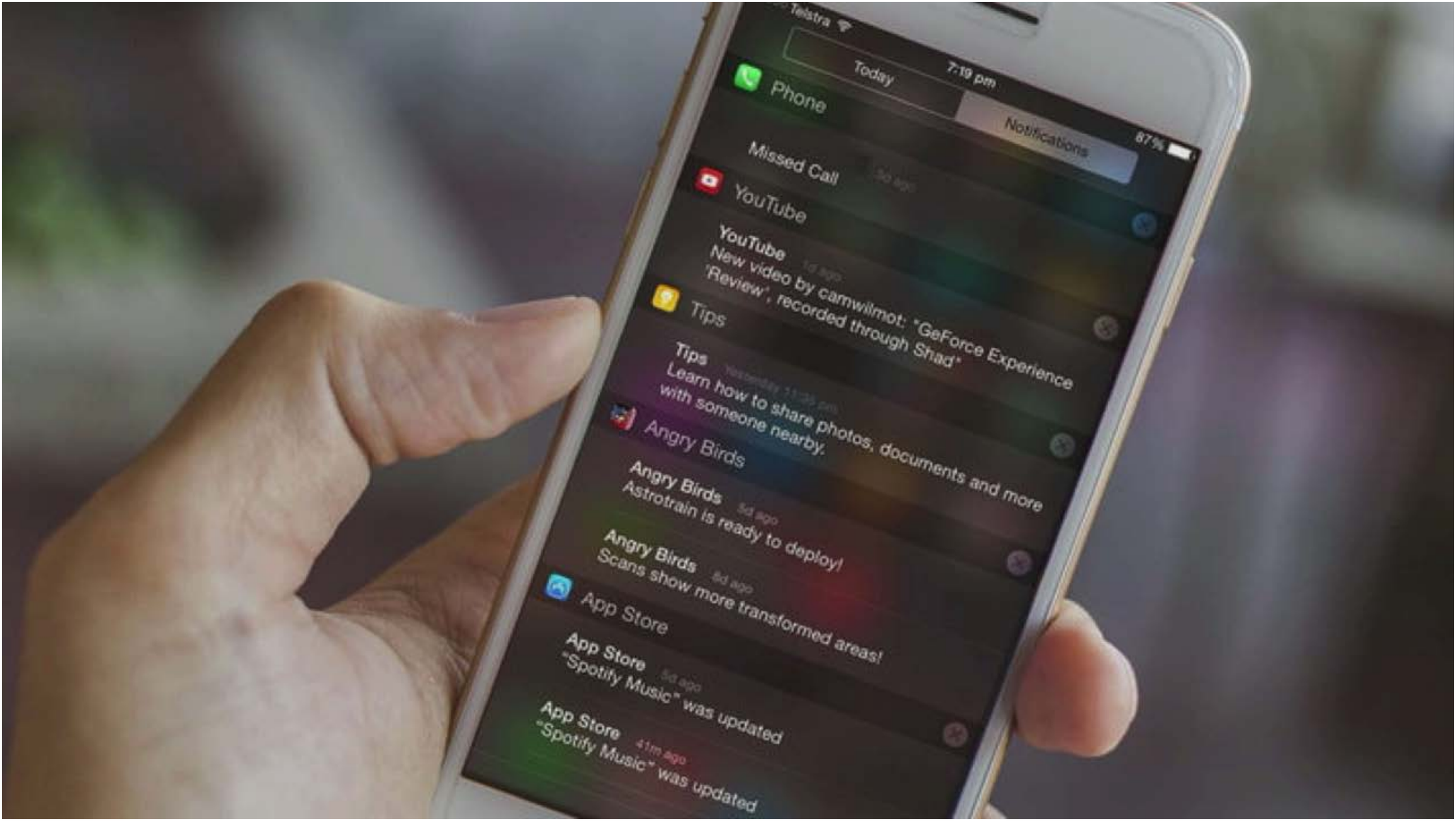
fluid interfaces

Principal Investigator: Pattie Maes


Telstra
Today
7:19 pm
Notifications
87%
Phone
Missed Call
YouTube
YouTube
New video by camwilmot: "GeForce Experience 'Review', recorded through Shad"
Tips
Tips
Learn how to share photos, documents and more with someone nearby.
Angry Birds
Angry Birds
Astrotrain is ready to deploy!
Angry Birds
Scans show more transformed areas!
App Store
App Store
"Spotify Music" was updated
App Store
"Spotify Music" was updated

we create systems
that sense a user’s internal and external state
and intervene to seamlessly enhance
our cognitive abilities

Decisions

Attention and Wellbeing

Memory

Dreams

Learning

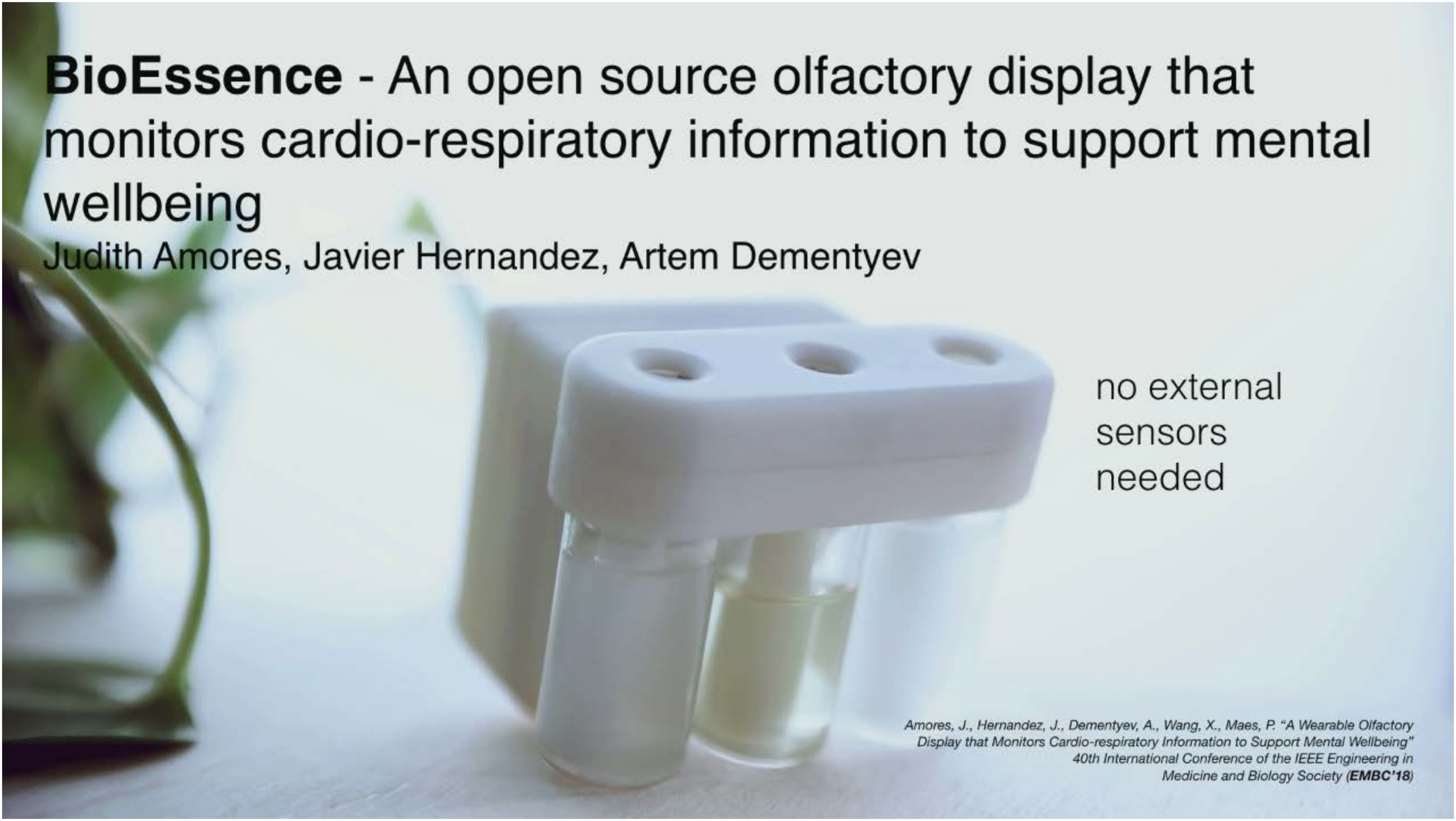
decisions


AlterEgo - Silent speech interface
Arnav Kapur, Sreyas Kapur

emotion regulation

BioEssence - An open source olfactory display that monitors cardio-respiratory information to support mental wellbeing

Judith Amores, Javier Hernandez, Artem Dementyev



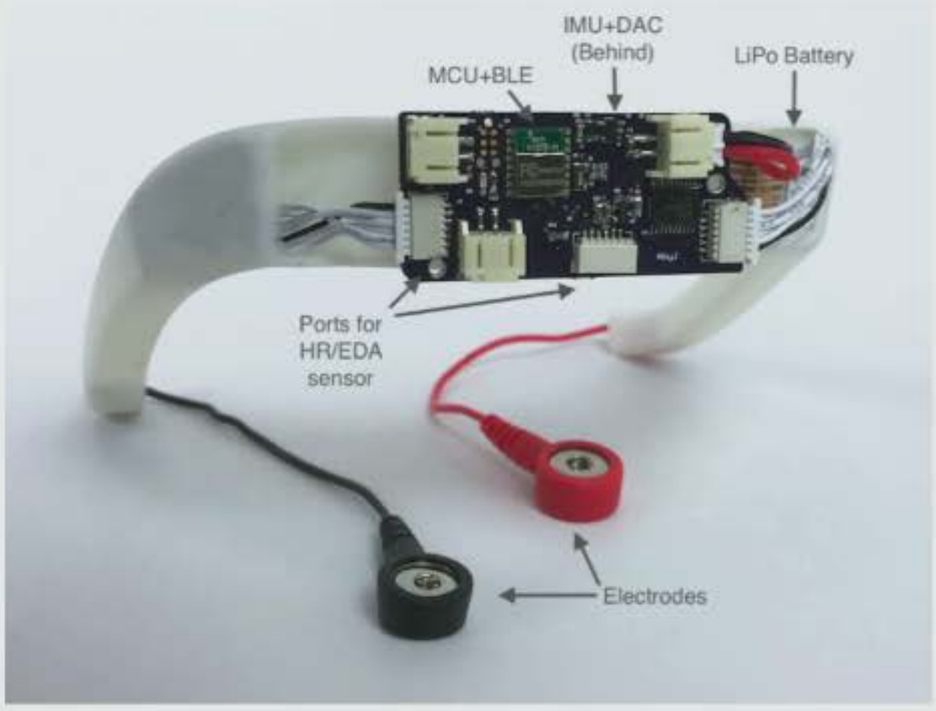
no external sensors needed

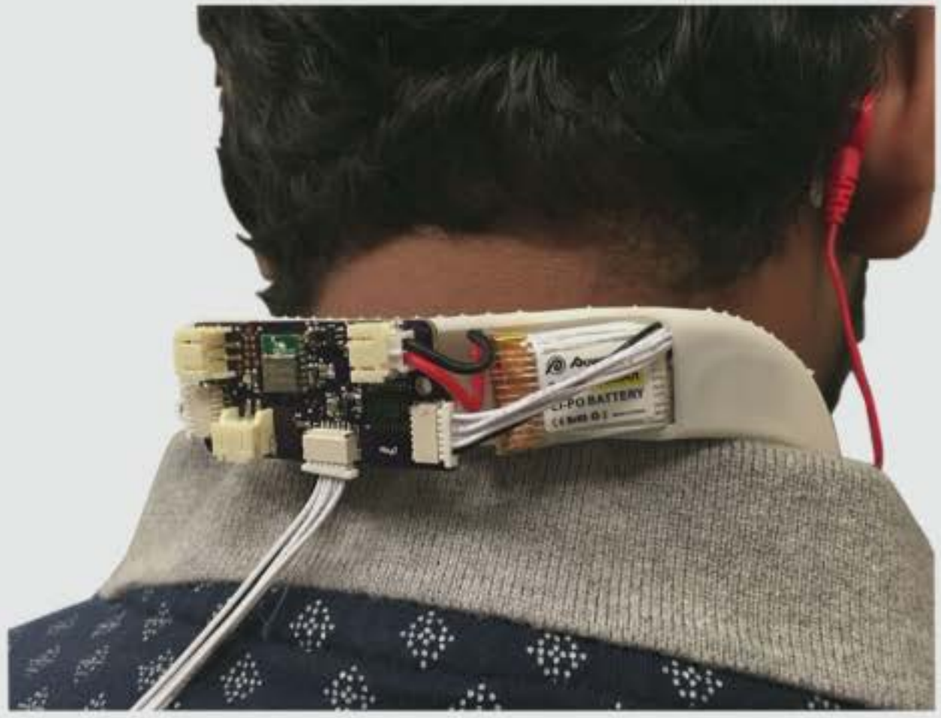
*Amores, J., Hernandez, J., Dementyev, A., Wang, X., Maes, P. "A Wearable Olfactory Display that Monitors Cardio-respiratory Information to Support Mental Wellbeing" 40th International Conference of the IEEE Engineering in Medicine and Biology Society (**EMBC'18**)*


PCB
Transformer
~24mm
~32mm
Relays
USB Port
~19mm
~28mm
Microcontroller
BLE
IMU
Battery
Body Movement (1)
Accelerometer Data (IMU)
Piezoelectric
Scent Release (6)
Scent Container
Cotton Filter
Hardware
Trigger Scent
5
2
BIO ESSENCE
Release Scent
Burst
Intensity, Frequency
0 seconds burst every 0 seconds
Heart Rate
If BPM over 40 release scent
Respiration
If Rf over 0 release scent
3
4
Accelerometer Data
Global Vitals
HR
Respiration
Quality Indexes
User Input (7)
Physiologic-based Rules
Software

MoveU - wearable vestibular stimulation device that electrically stimulates the vestibular system to induce sensations of motion

Abhinandan Jain, Misha Sra





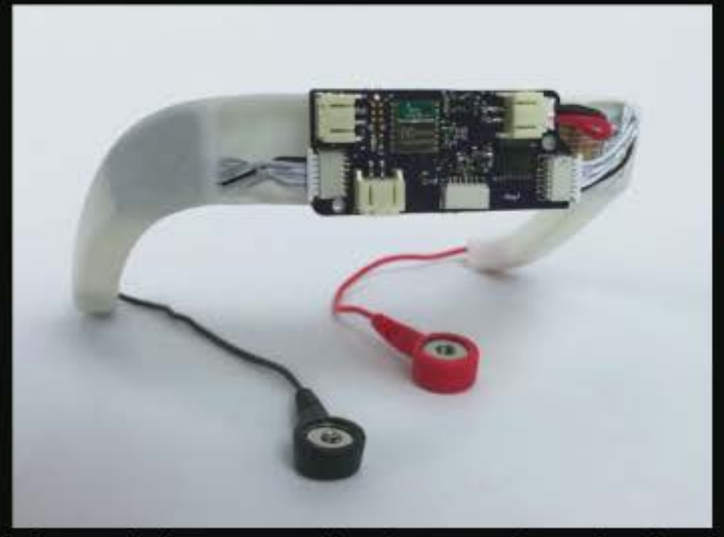
Wearable for stimulating the Vestibular System to alter the sense of balance and spatial orientation

Our goal: compact, wearable platforms

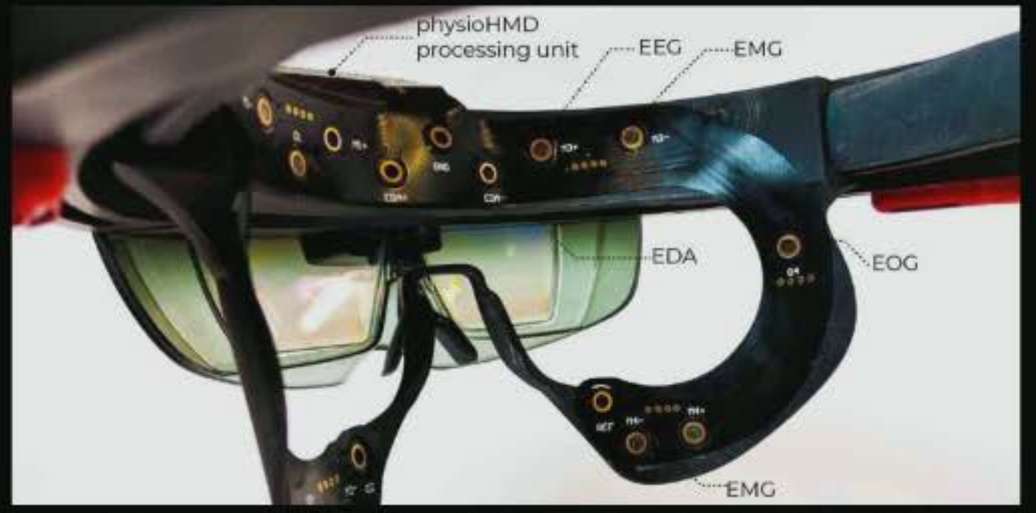
Masca -REM

Dormio - hypnagogia

BioEssence - Scent



MoveU - vestibular stimulation



Fascia - EEG, EOG, EDA, EMG, EEG

AttentivU - attention+

Brain-Computer Interfaces: towards Cognitive Augmentation 1.0

Nataliya KOSMYNA, Ph.D

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@nataliyakosmyna

mit media lab

fluid interfaces

Who am I?

- Master in AI, **2012**, Université Joseph Fourier, Grenoble, France
- Ph.D in Computer Science, specialization – Brain-Computer Interfaces, **2015**, Université Grenoble-Alpes, France
- Post-doc Inria Rennes, Hybrid team, Brain-Computer Interfaces, France, **2015-2017**
- Post-doc MIT Media Lab, Fluid Interfaces Group - cognitive augmentation, Cambridge, US, **since 2017 - ongoing**

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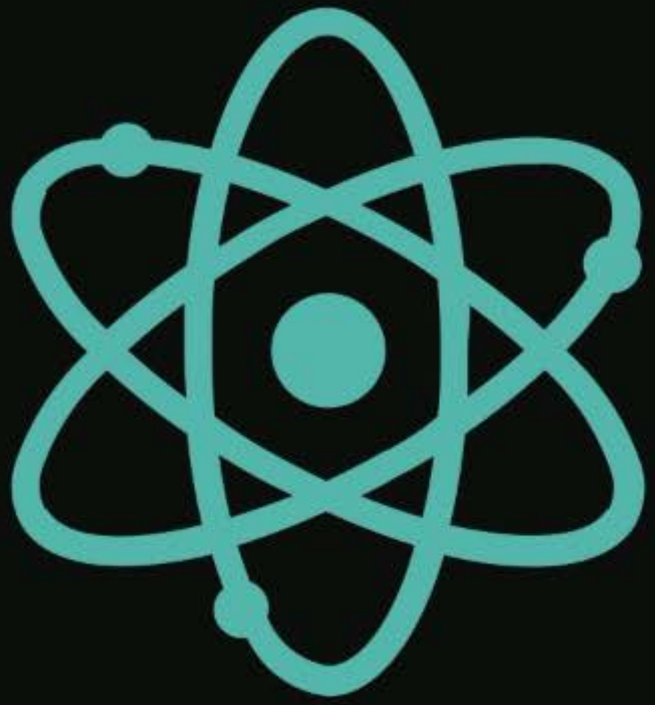

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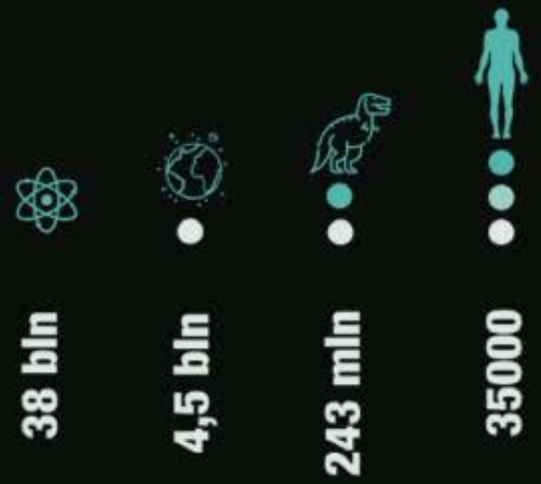
Evolution continued...



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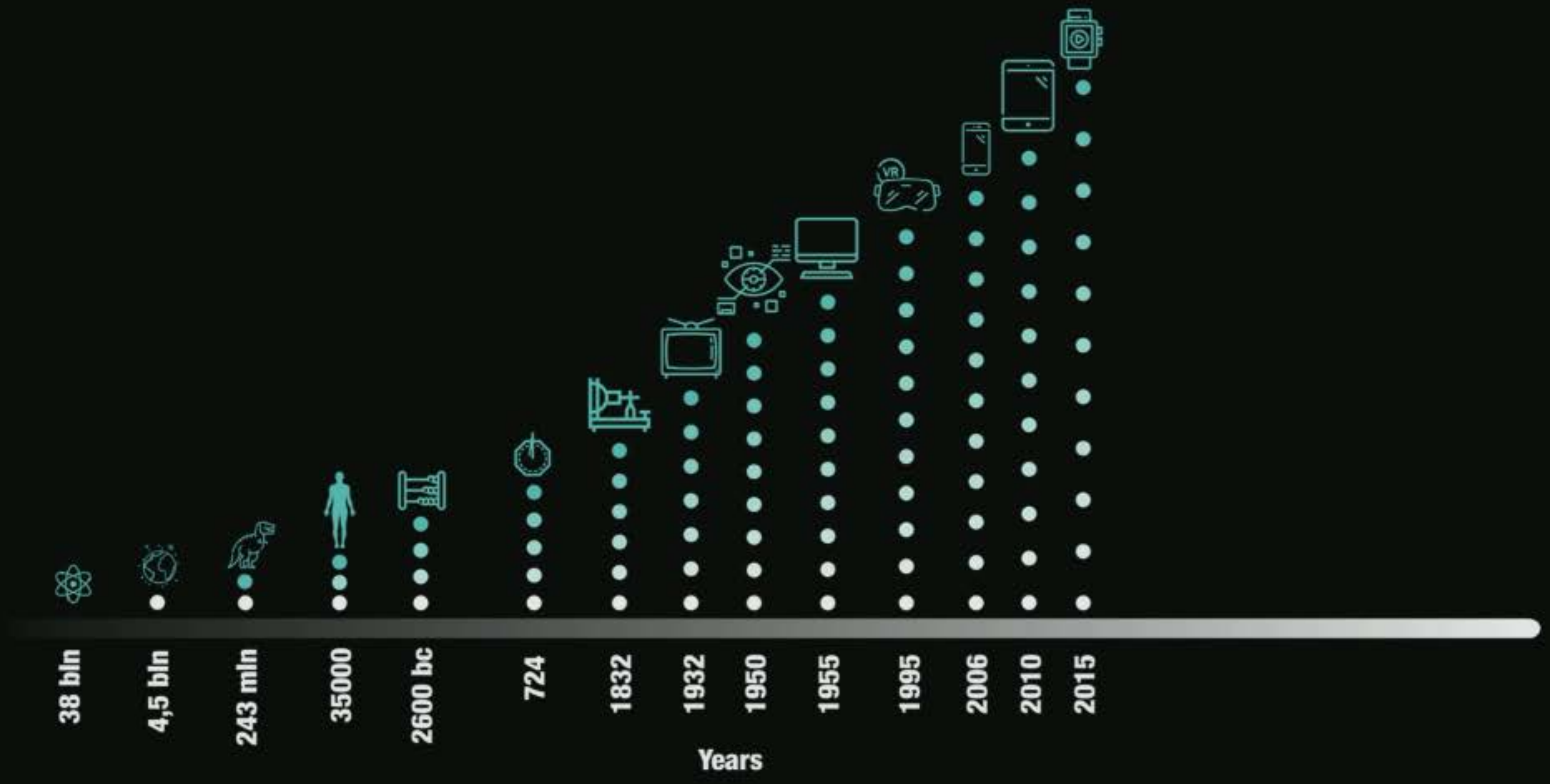

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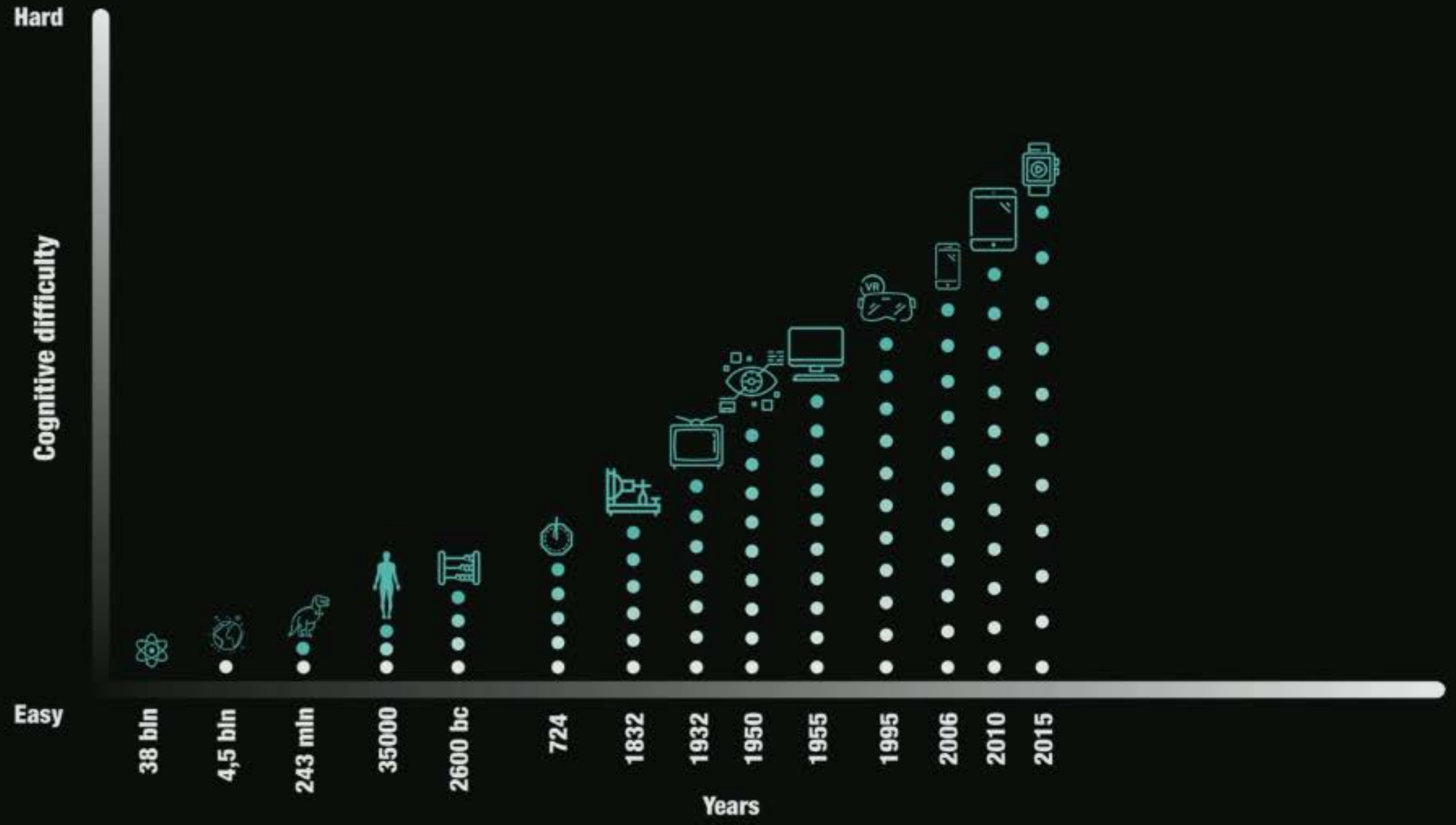

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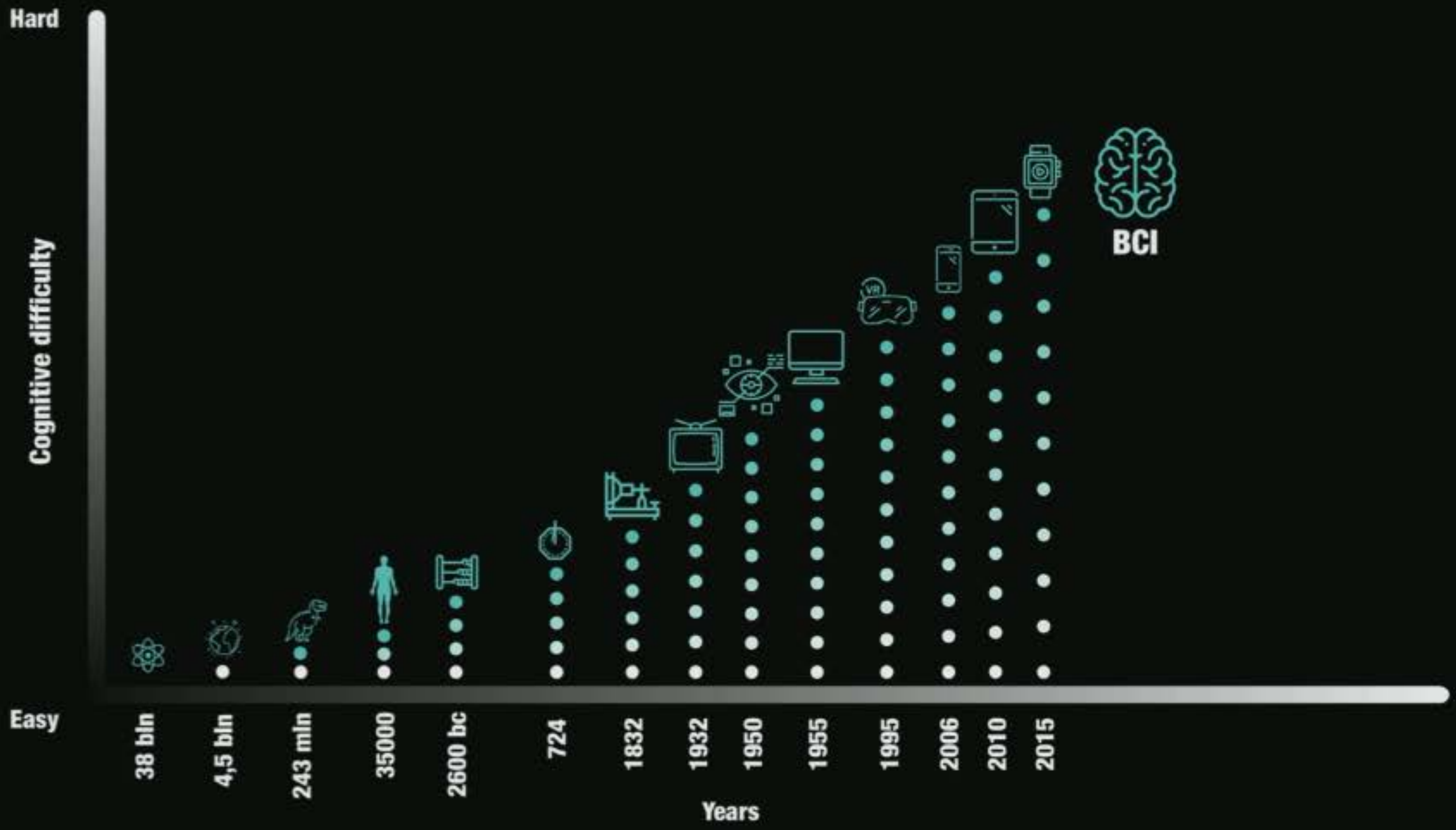

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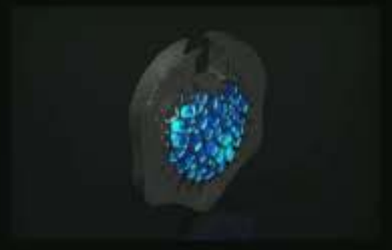





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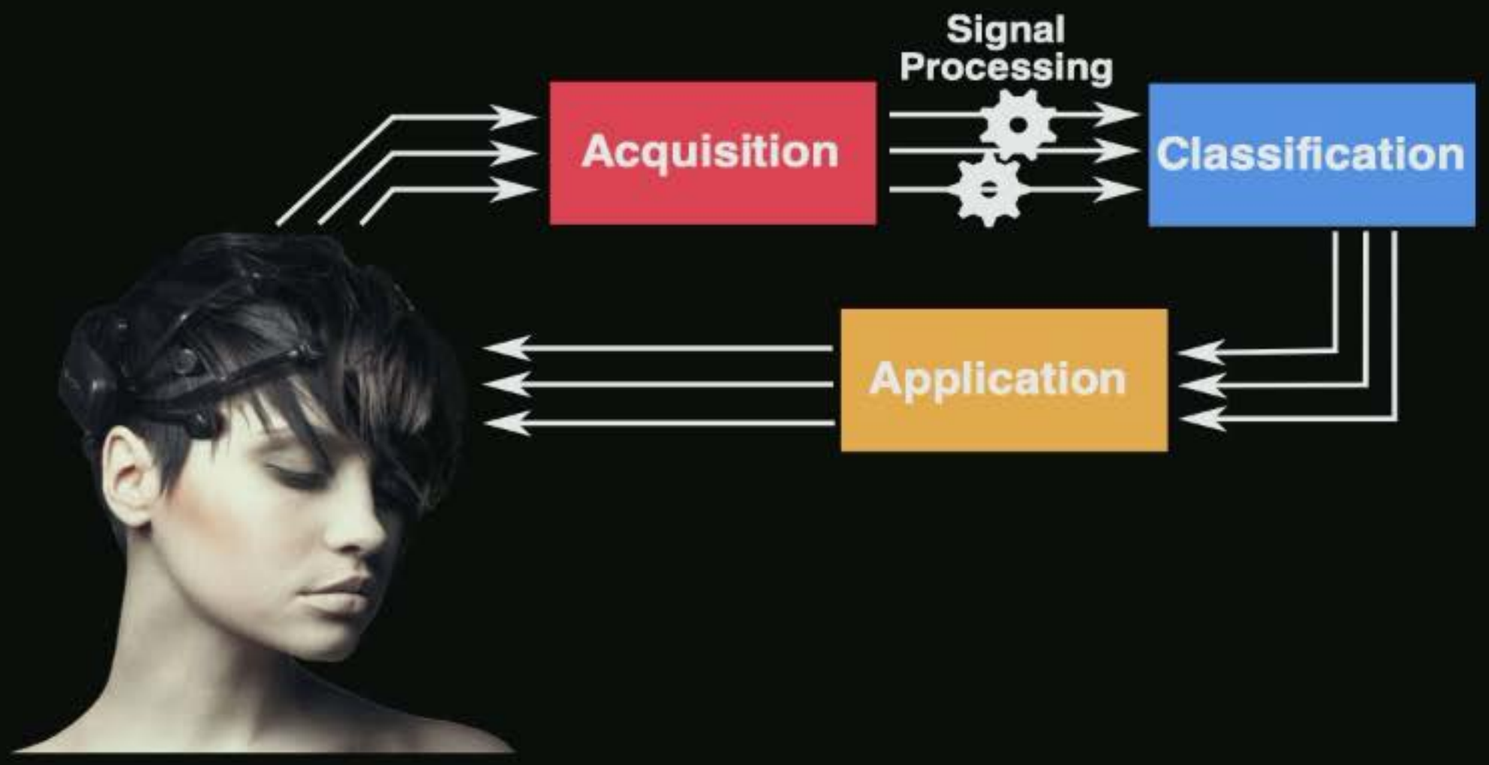
How does it actually work?



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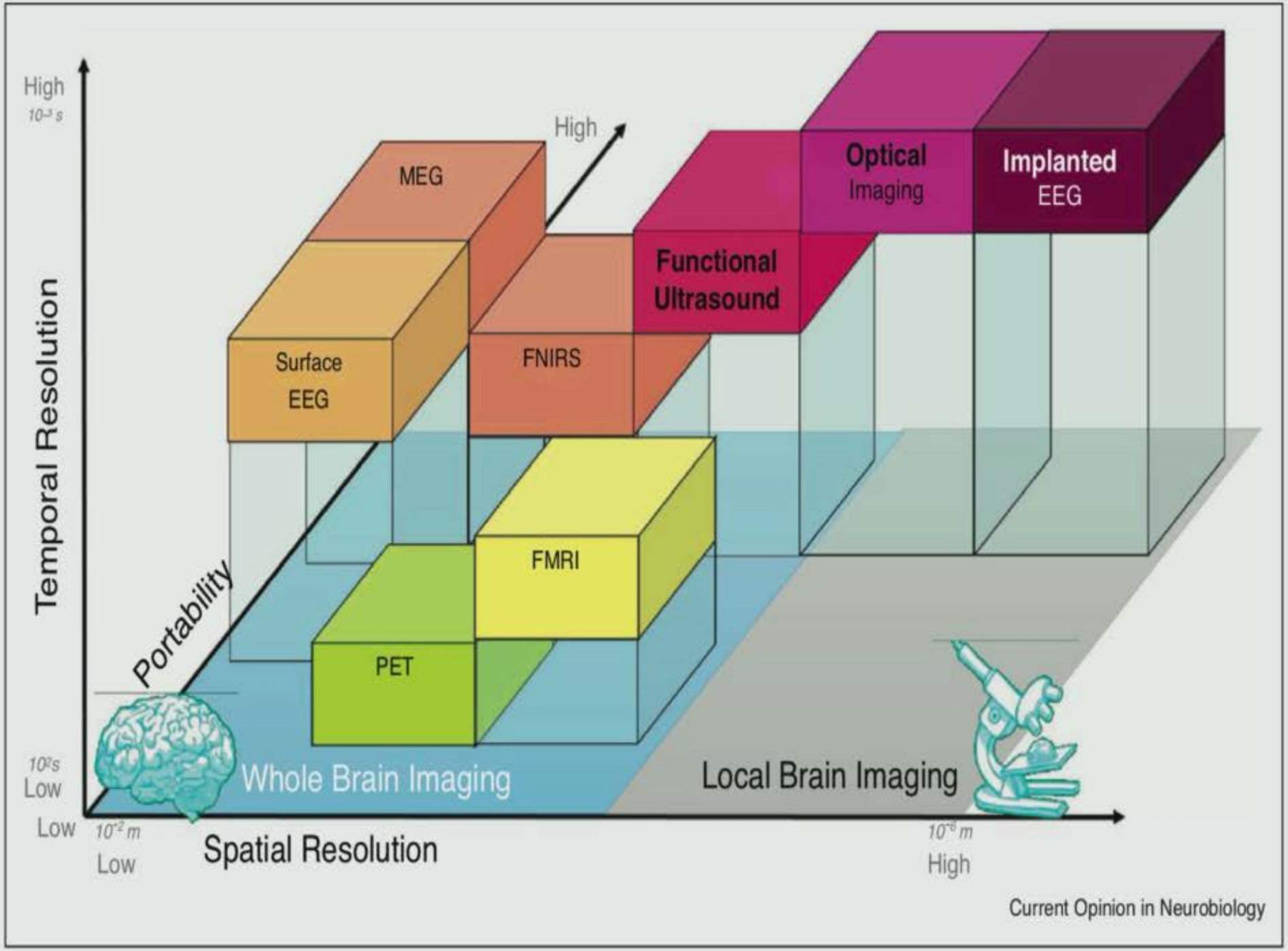
QUENC
CHAMP MAGNÉTIQUE


MAGNETOM
CHAMP MA

Current MEG scanner based on SQUID sensors

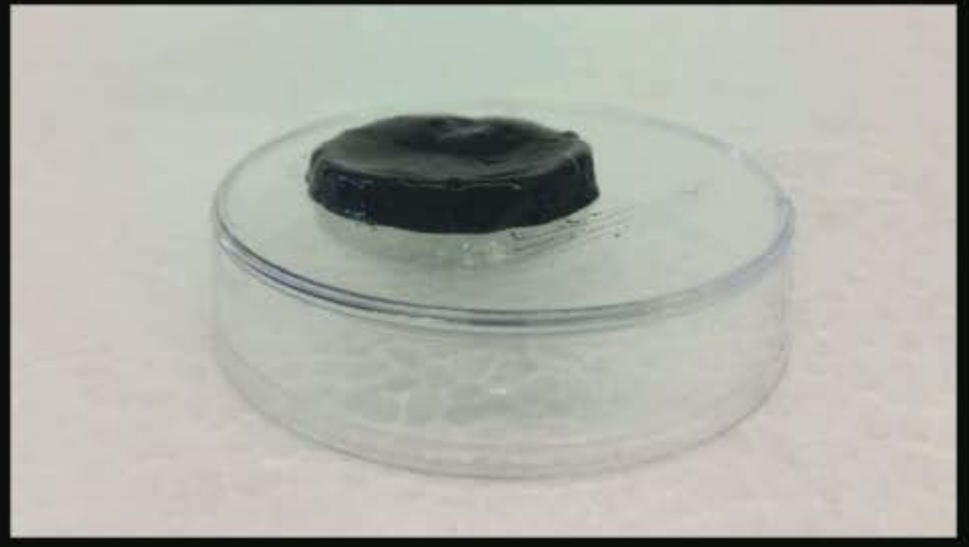
New MEG scanner with OPM sensors

Boto et al. (2018) *Nature*


High
10⁻³ s
Temporal Resolution
High
MEG
Surface
EEG
FNIRS
Functional
Ultrasound
Optical
Imaging
Implanted
EEG
FMRI
PET
Portability
10²s
Low
Low
10⁻² m
Low
Whole Brain Imaging
Local Brain Imaging
Spatial Resolution
10⁻⁶ m
High
Current Opinion in Neurobiology

EEG!

What do we use to measure it?



Why should you care?

Faceplate	Comfort	Signal Gain(dB)	Shelf Life(months)
Facepad	4.5	NA	NA
Gold Plated	3.1	0	>12
Ag/AgCl	4.1	-1	<6
Hydrogel	4.4	+7	<1

Table 2: Comparison of Comfort, Signal Quality and Shelf life of different electrodes

What do you measure?

- Event Related De/Synchronization (ERD/ERS)
- Event-Related Potentials (ERPs)
- Steady State Evoked Potentials (SSEP)

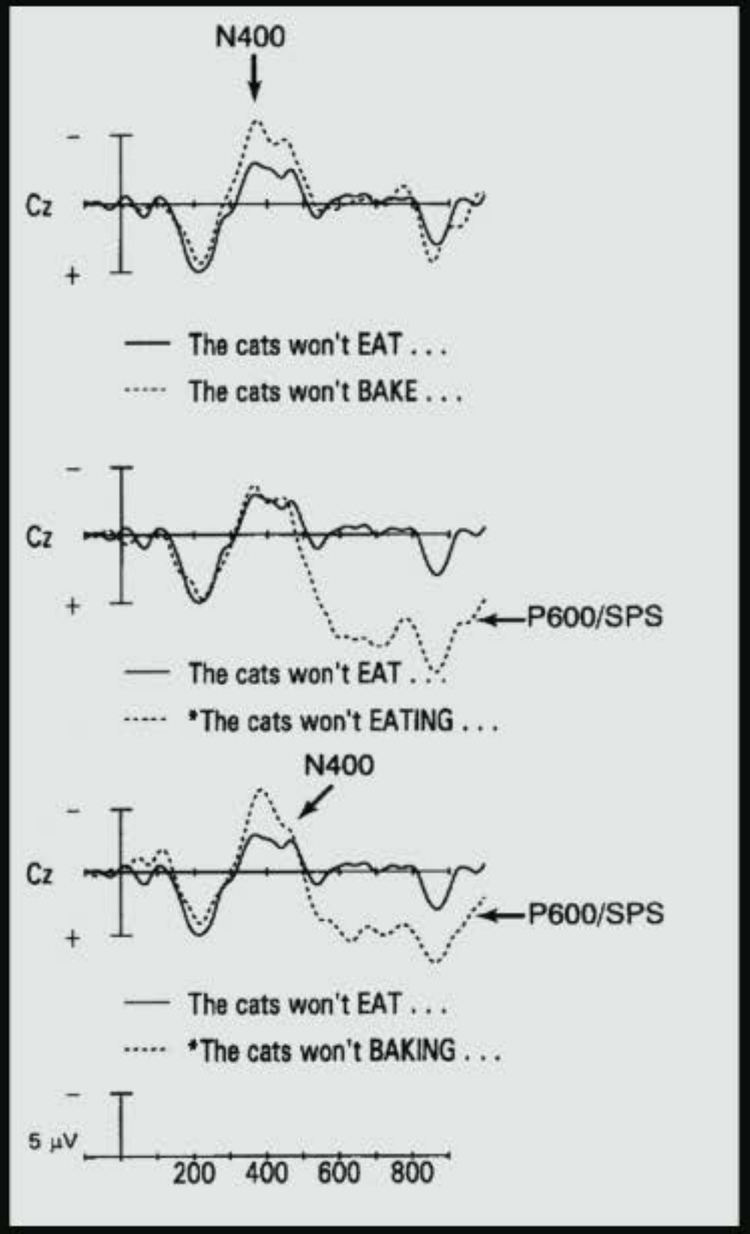
ERPs

Presenting a stimulus to the subject—like a light flash or tone pip - the EEG breaks up into a series of *much larger* peaks and troughs.

This series of waves is the ERP, related to the stimulus event, whatever it was. The number of peaks and troughs depends on the complexity of the stimulus (names of people – 5-8).

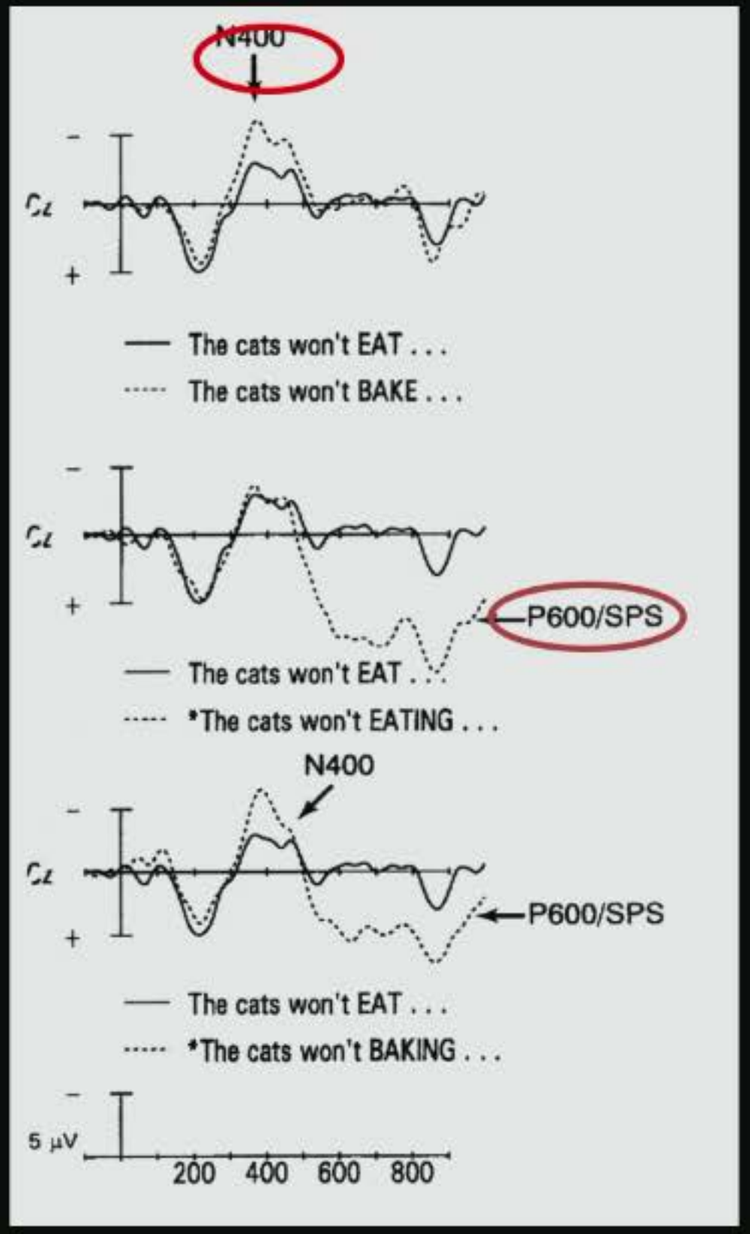
Names of ERPs: N or P + number (200, 400, etc).

Example: ERPs Related to Language



(Zhang et al., 2018)

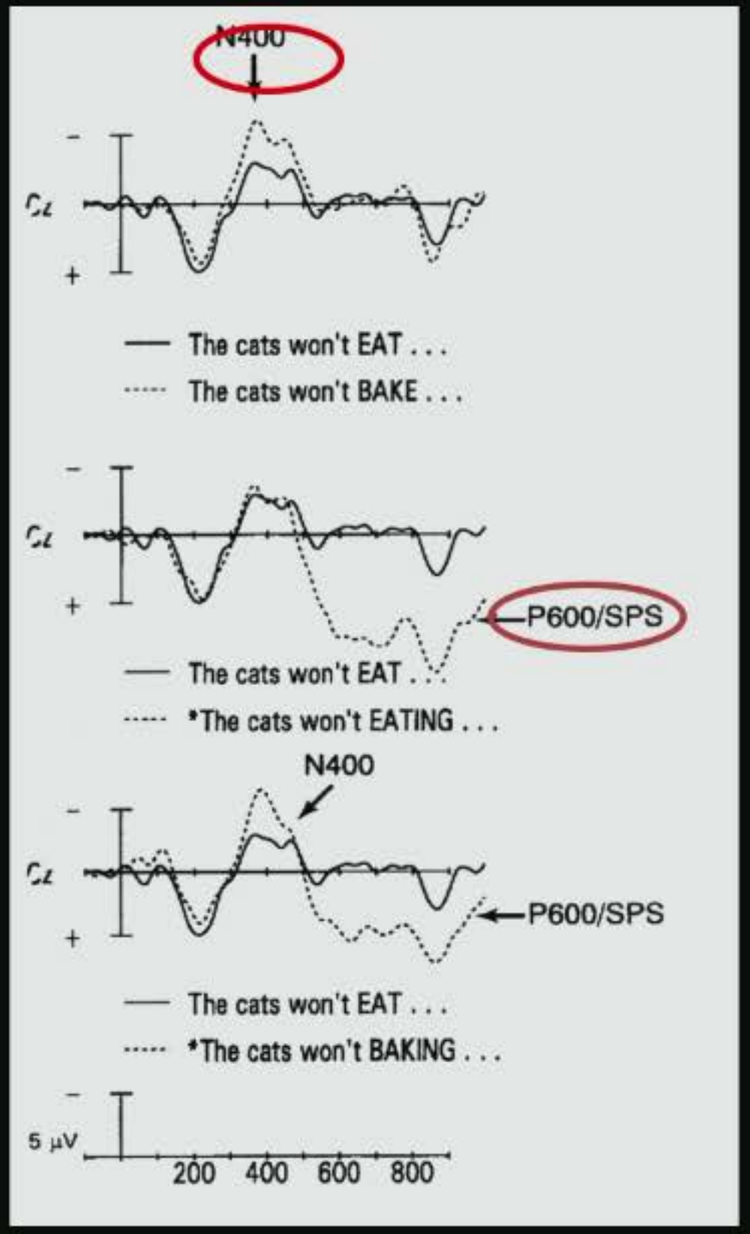
Example: ERPs Related to Language



N400 = ERP "component" related to meaning
- Bigger when word's meaning doesn't fit context
- Bigger for unfamiliar words
- May reflect amount of work required to integrate with context

(Zhang et al., 2018)

Example: ERPs Related to Language



N400 = ERP "component" related to meaning
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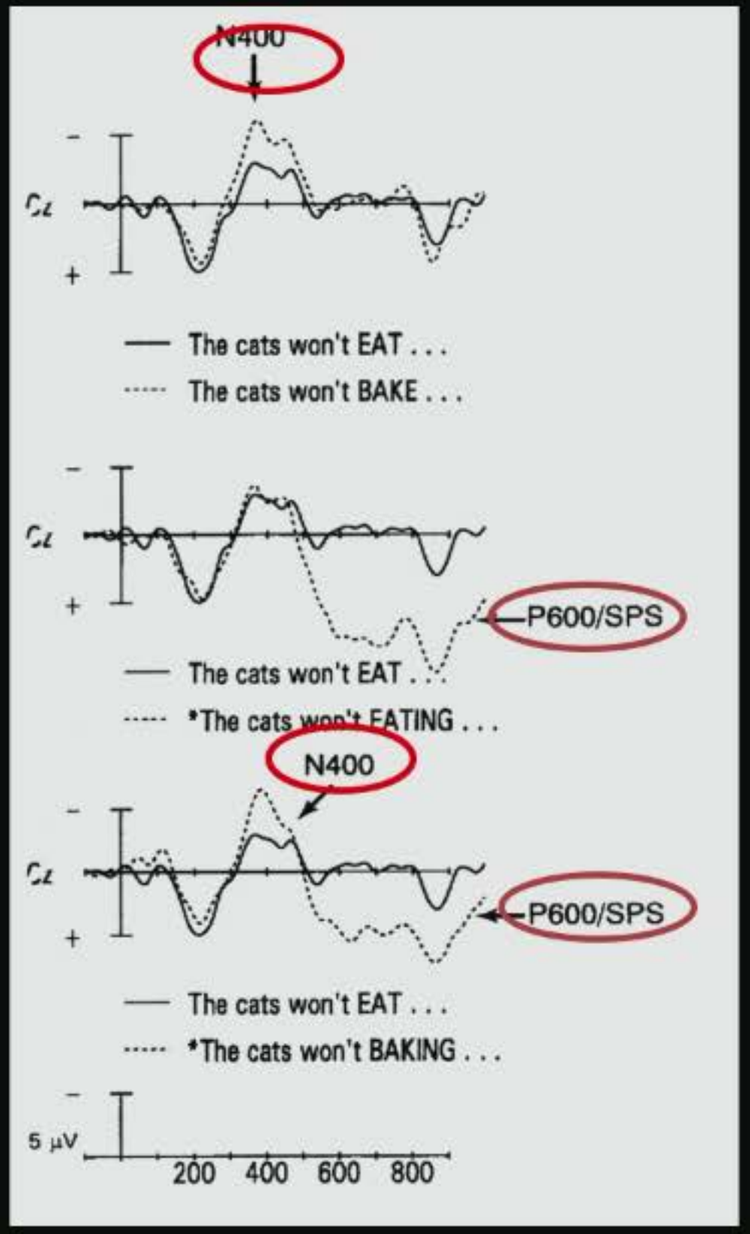
P600 = ERP "component" related to form
- Bigger when word not of expected type for a position in a sentence
- May be a type of P300
- Sometimes called Syntactic Positive Shift (SPS)

(Zhang et al., 2018)

Example: ERPs Related to Language



N400 = ERP "component" related to meaning
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P600 = ERP "component" related to form
- Bigger when word not of expected type for a position in a sentence
- May be a type of P300
- Sometimes called Syntactic Positive Shift (SPS)

(Zhang et al., 2018)

Motor ERPs and ErrP

There are also ERPs seen over motor areas which *precede* actual movements

ErrPs exploit error related negativity

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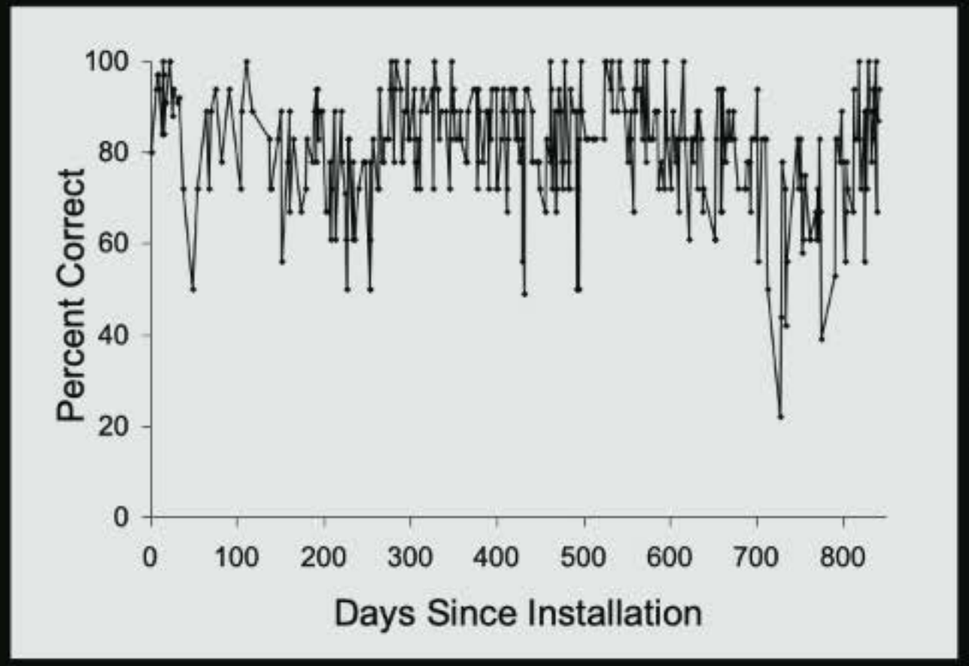
Can people use it long-term?



Subject: Re:
From:
Date:
To: Jonathan R. Wolpaw
Cc:

No problem.

I couldn't run my lab without BCI. I do molecular neuroscience research and my grant pays three people.

I'm writing this with my EEG courtesy of the Wadsworth Center Brain-Computer Interface Research Program (www.wadsworth.org)

New York State Department of Health | Wadsworth Center

Does the BCI improve their lives?

Late-stage PALS used a BCI for:

Does the BCI improve their lives?

Late-stage PALS used a BCI for:

Used it at work and home: conducted ALS research at U Penn, supervised 3 employees, and used environmental control at home (*>5 years*).

Used the BCI to communicate with her husband and caregivers for several hours, several times/week (*>3 years*).

To her caregiver: “Don’t let the dog pee on the rug.”

To the researcher: “Speak louder.”

To her husband: “It hurts when you rub my eyes at night.”

Does the BCI improve their lives?

Late-stage PALS used a BCI for:

Used it at work and home: conducted ALS research at U Penn, supervised 3 employees, and used environmental control at home (*>5 years*).

Used the BCI to communicate with her husband and caregivers for several hours, several times/week (*>3 years*).

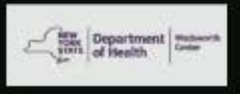
To her caregiver: "Don't let the dog pee on the rug."

To the researcher: "Speak louder."

To her husband: "It hurts when you rub my eyes at night."

Asked for personal care, made appointments and organized the his social and house (*>18 months*).

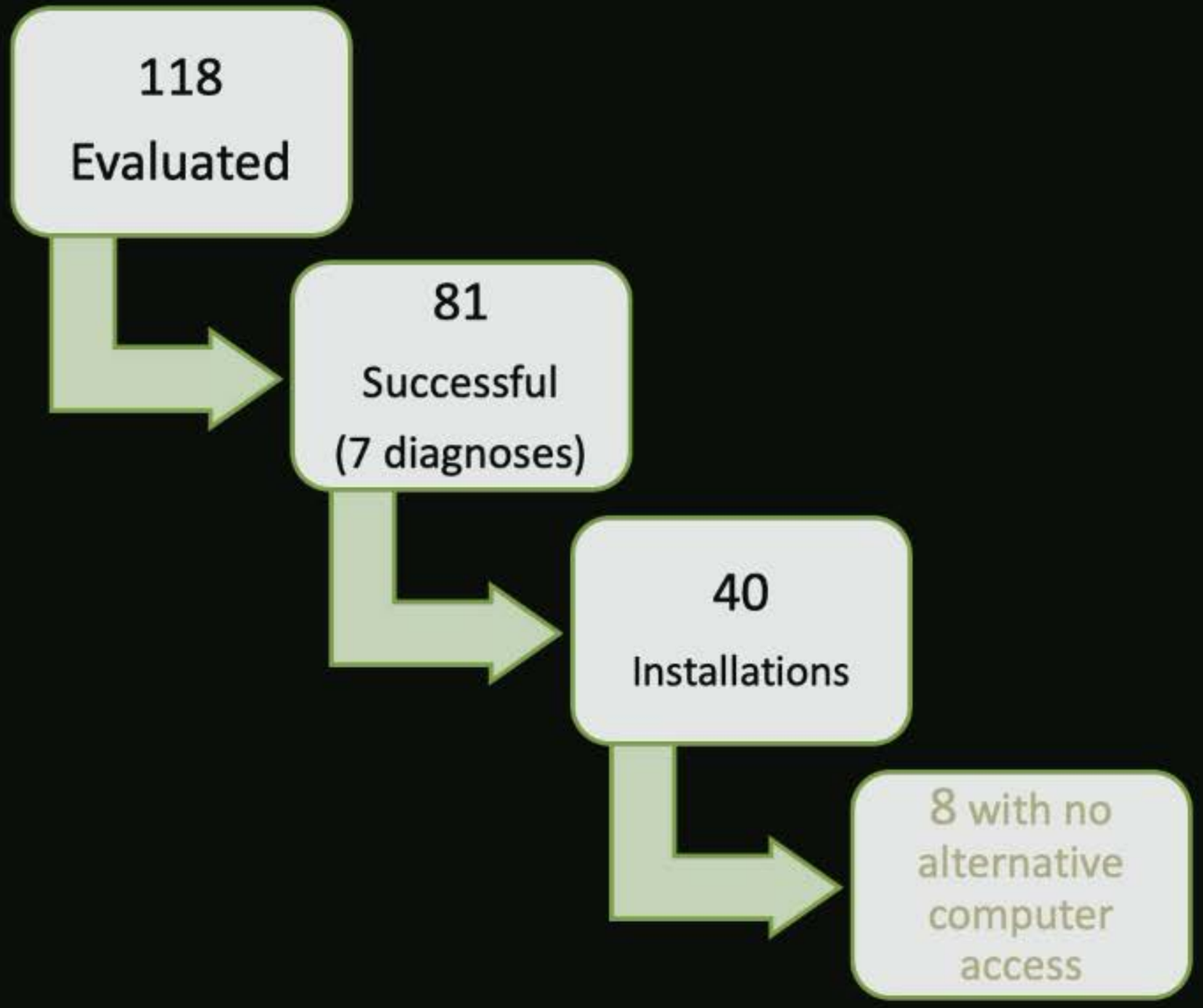
Asked to have his power of attorney changed and obtained a divorce (*>2 years*).



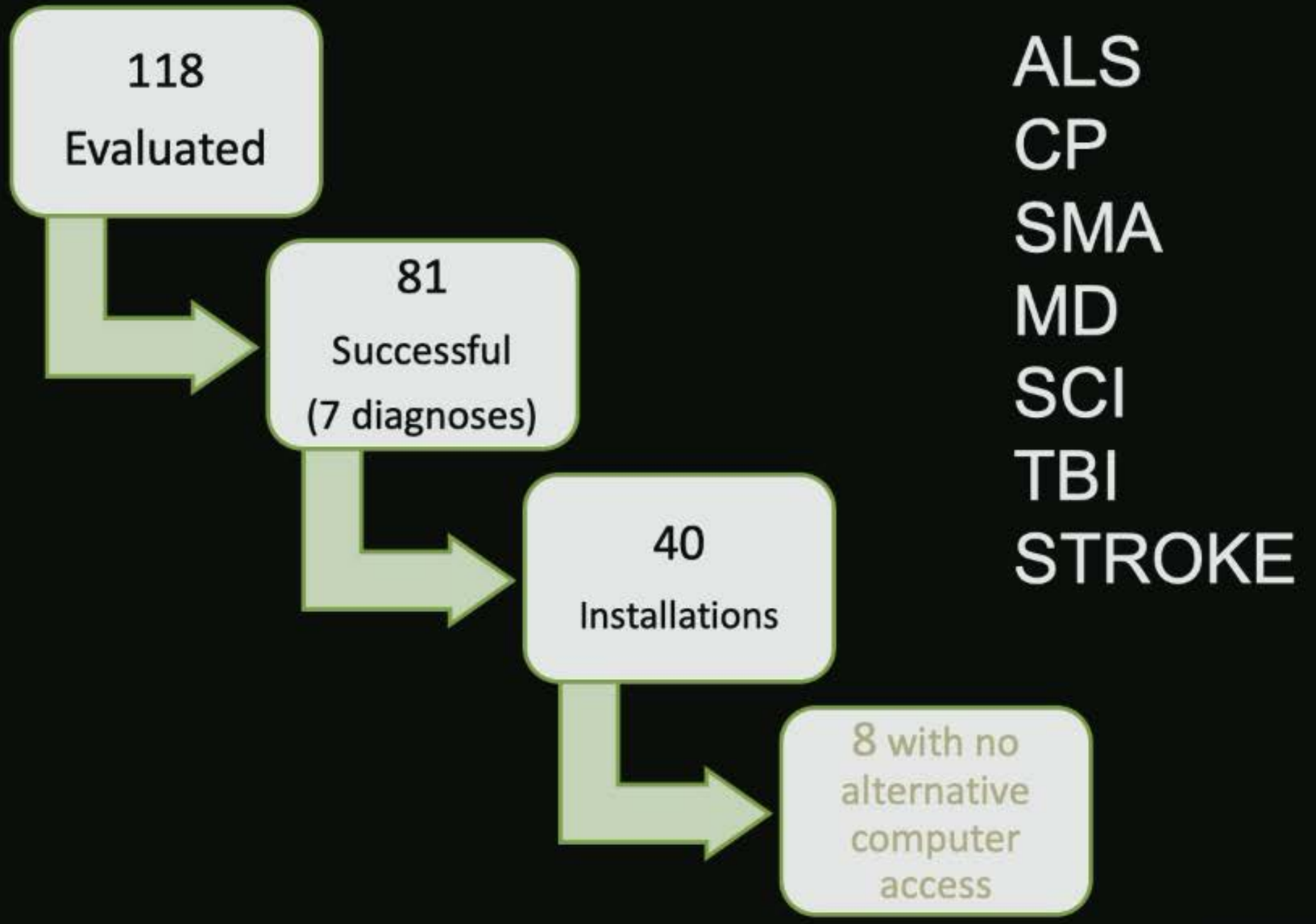
Patients and Therapists Say, “It’s…..

accurate but slow.	**R&D, e.g., FACES**	**200%**
functional but not spontaneous.	**MSAA Screen Reading**	**OTS Software**
difficult to set-up.	**Online Diagnostics & Manuals**	**Onscreen Setup & manual**
too many components.	**BCI as Access Method**	**Works on a laptop**
time consuming to wash hair after & can be uncomfortable.	**Gel Cap upgrades & new technology**	**Greater comfort and dry sensors**
difficult to position.	**Now using adjustable stands (e.g., DAESSY, Rehadapt)**	**3D & folding joints**

Who Else can Use the Speller?



Who Else can Use the Speller?



CALIBRATION
20-Character
Cued Task

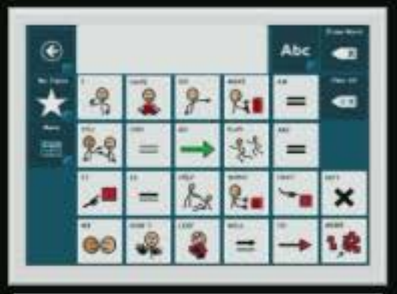
~20 min

VALIDATION
Free Spell

~10 min

NAVIGATION
OTS Software

~10 min



SESSION TWO
Optimization & Use

~40 min

Successful Evaluation

1/17/2019

54 year old PAL (ALSFRS=2) currently working as a computer programmer.
Eye-tracking becoming unreliable
★ Using BCI within 90 minutes with 100% accuracy @ rate of
10 selections/minute

Translation To Other Groups

1/18/2019 (Spaulding/Boston Children)

PAL (ALSFRS=#). Currently spending time ## and ###
Eye-tracking good for now.
★ Using BCI within ## minutes.
85-90% accuracy @

New York State Department of Health | Wadsworth Center

SS(V)EP

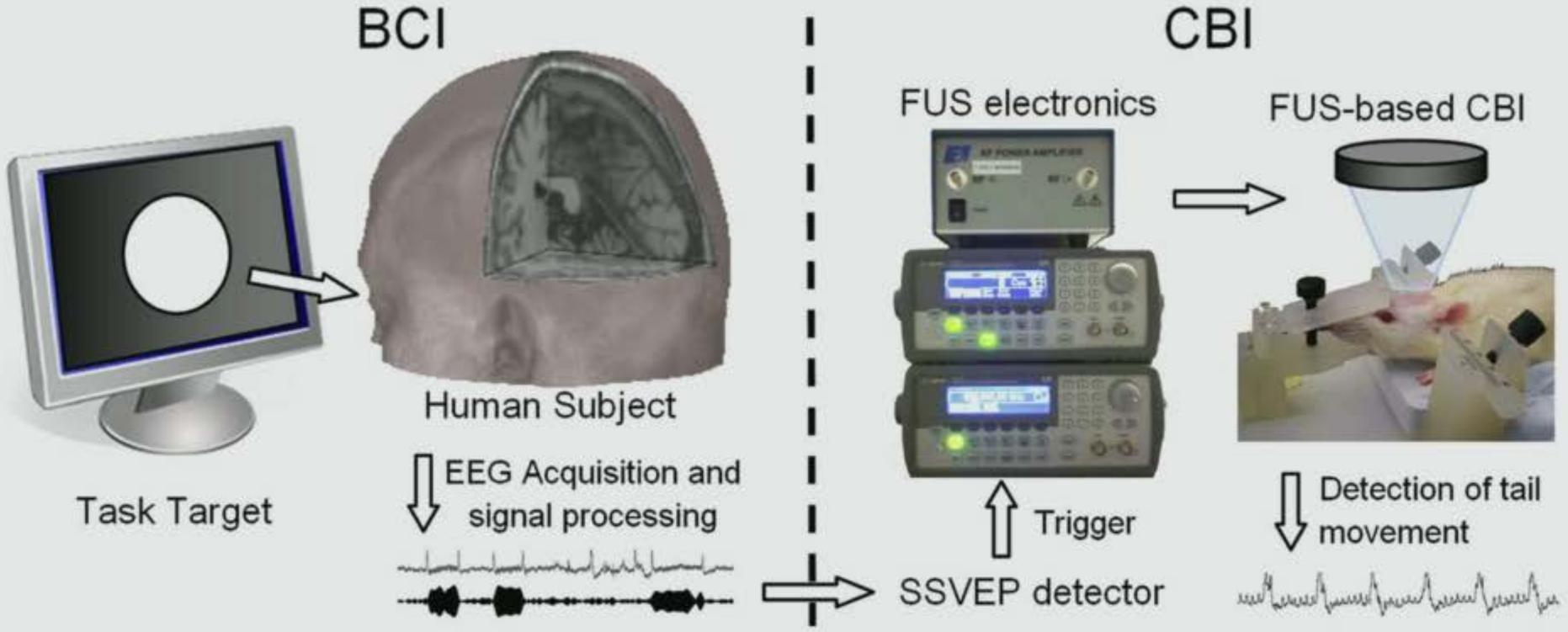
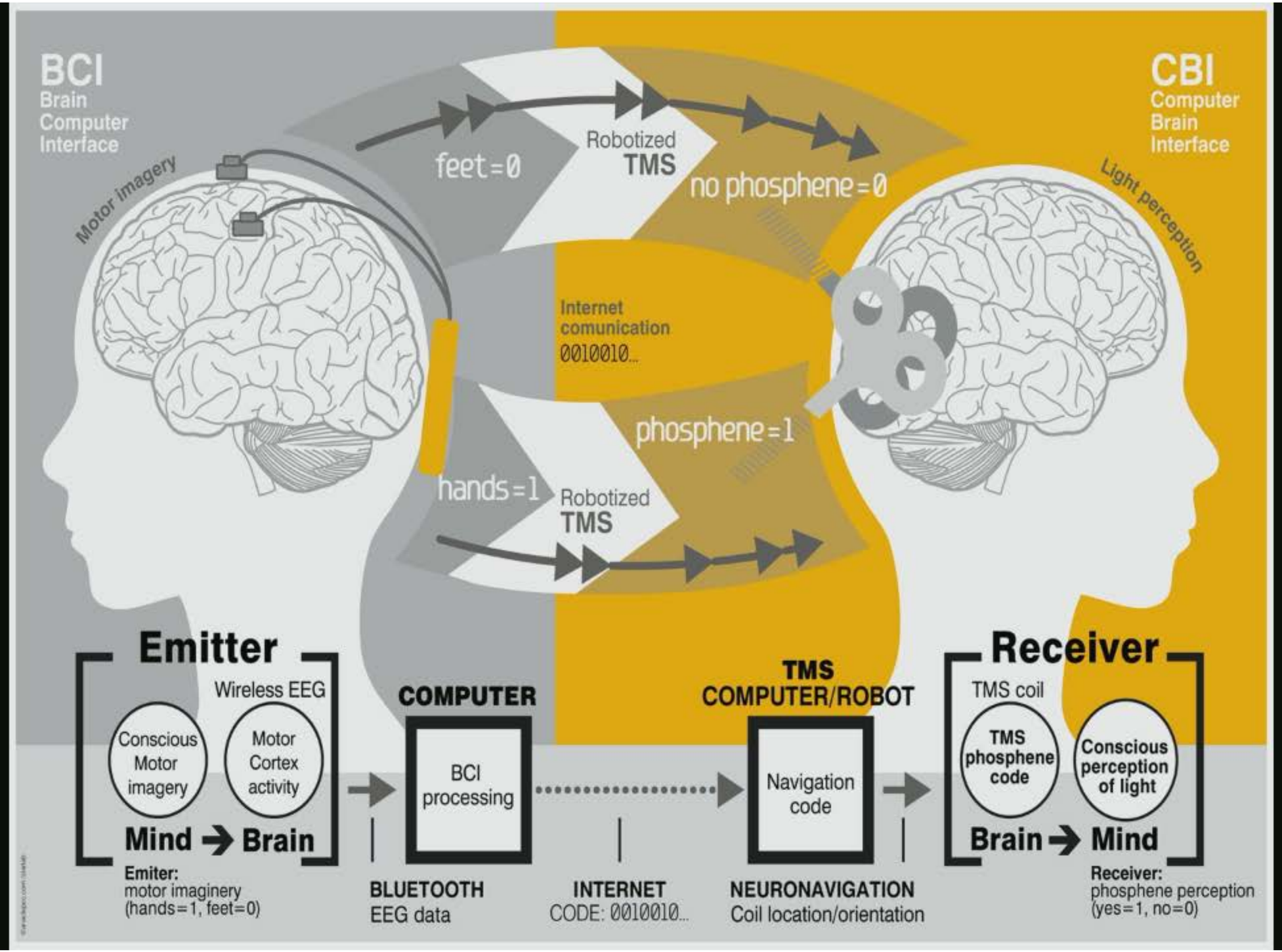


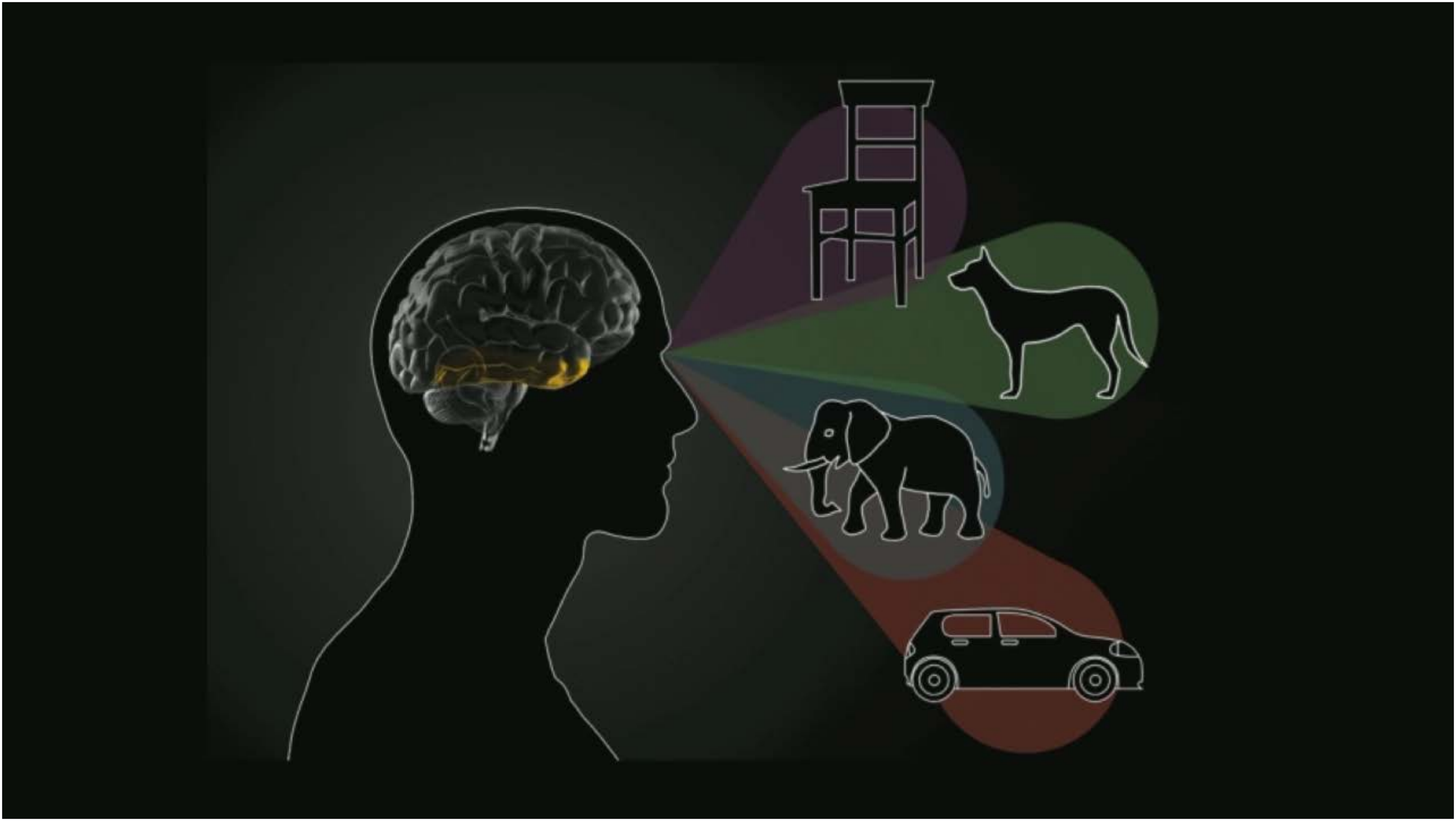
Figure 1. The schematics of the implemented brain-to-brain interface (BBI). The implementation consists of steady-state visual evoked potential (SSVEP)-based brain-to-computer interface (BCI: on the left column) and focused ultrasound (FUS)-based computer-to-brain interface (CBI) segments (on the right column).
doi:10.1371/journal.pone.0060410.g001

ERD – Motor Imagery


BCI
Brain
Computer
Interface
Motor imagery
feet=0
Robotized
TMS
no phosphene=0
CBI
Computer
Brain
Interface
Light perception
Internet
comunication
0010010...
phosphene=1
hands=1
Robotized
TMS
Emitter
Wireless EEG
Conscious
Motor
imagery
Motor
Cortex
activity
Mind → Brain
Emiter:
motor imaginery
(hands=1, feet=0)
COMPUTER
BCI
processing
BLUETOOTH
EEG data
INTERNET
CODE: 0010010...
TMS
COMPUTER/ROBOT
Navigation
code
NEURONAVIGATION
Coil location/orientation
Receiver
TMS coil
TMS
phosphene
code
Conscious
perception
of light
Brain → Mind
Receiver:
phosphene perception
(yes=1, no=0)

(Grau et al, 2014)

Motor Imagery…and?



Visual Observation vs Visual Imagery

(Kosmyna et al., 2018)

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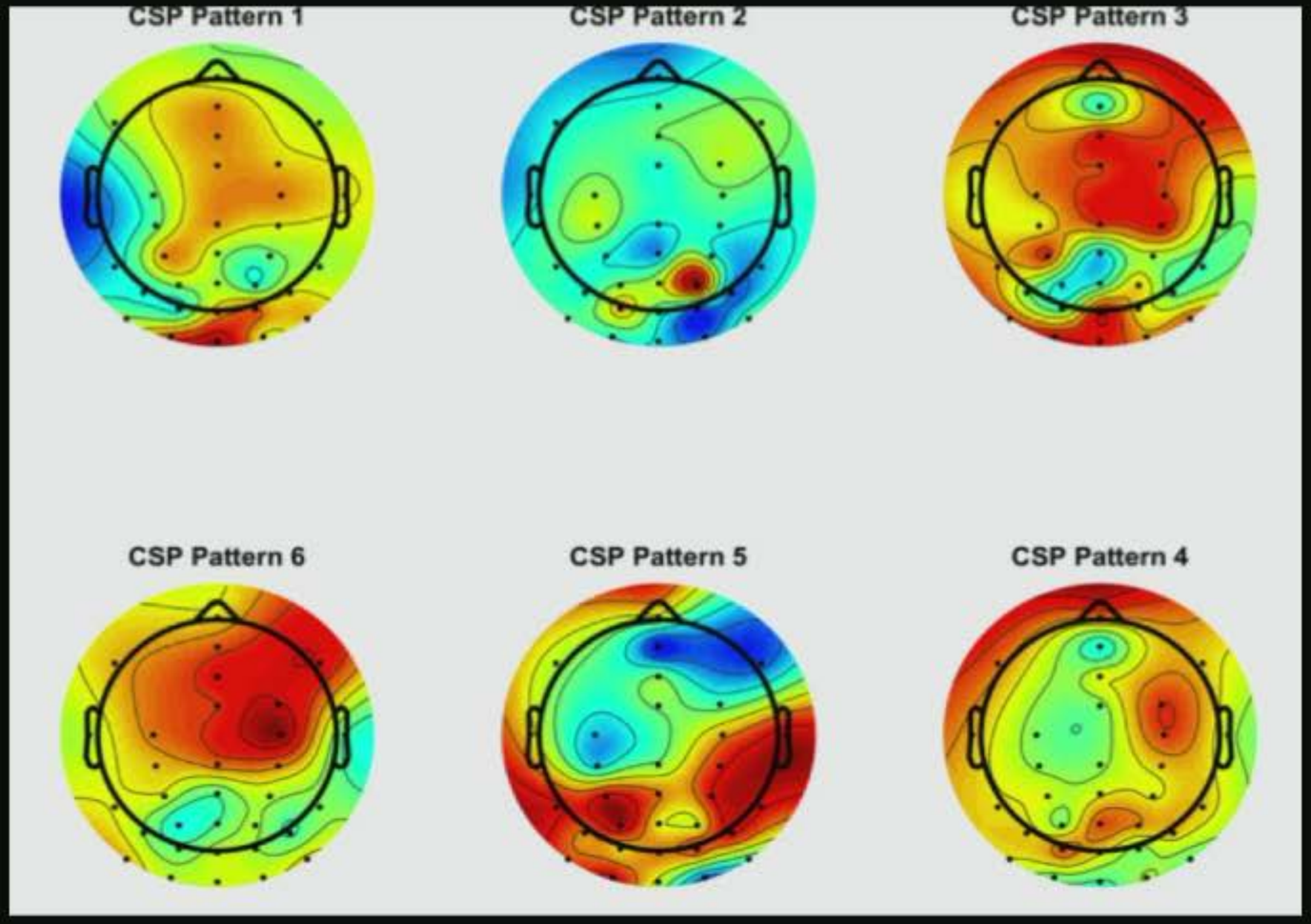
Results



(Kosmyna et al., 2018)

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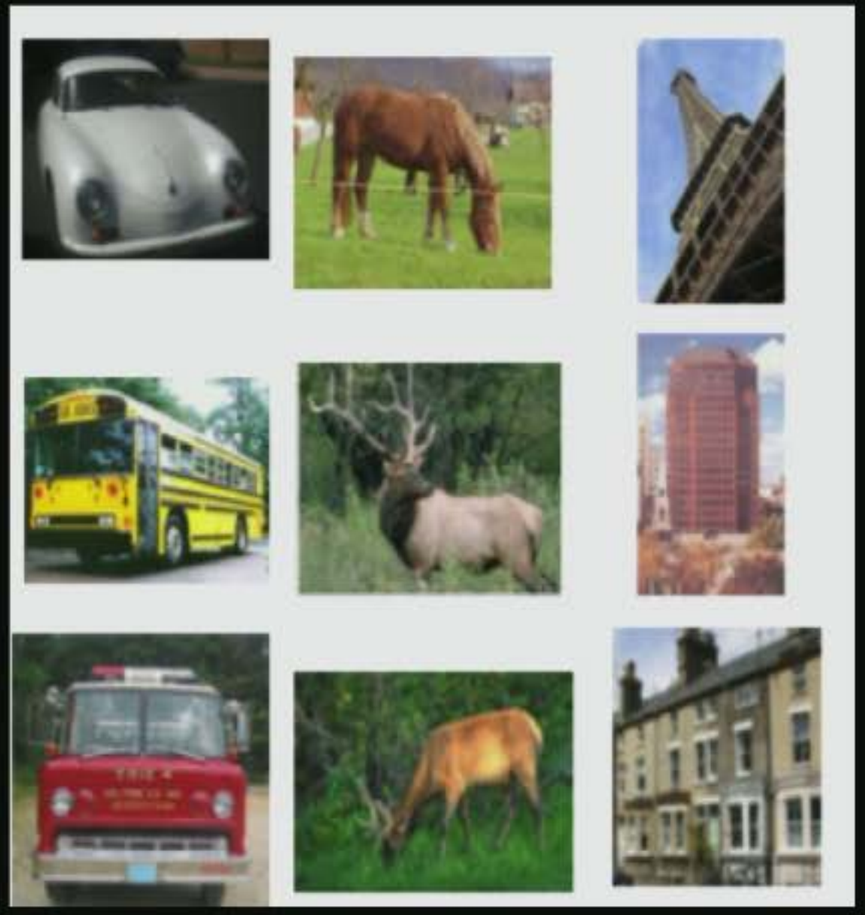
Human-Aided Computing



(Shenoy and Tan, 2009)

cBCI –Collaborative BCIs

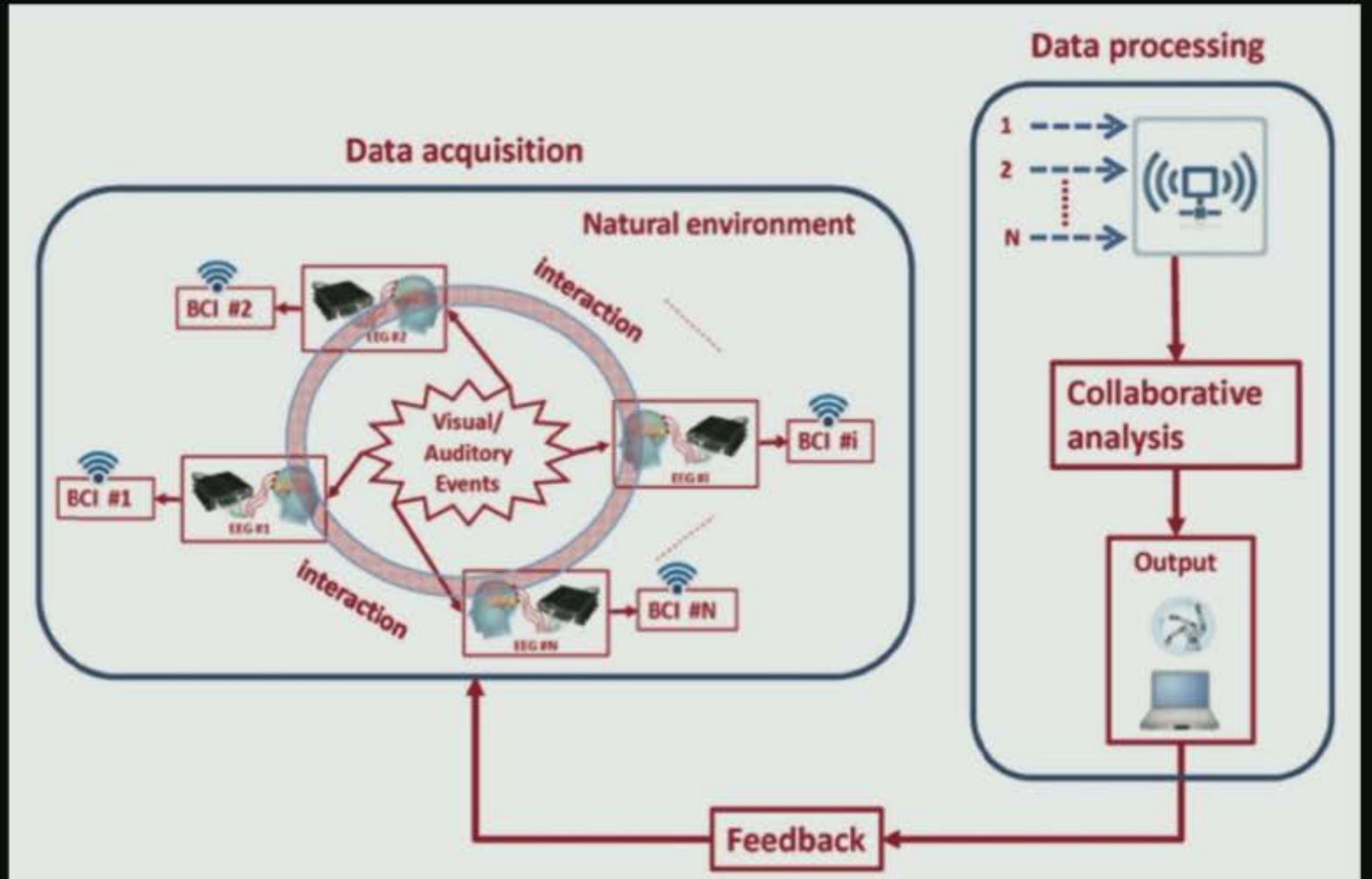
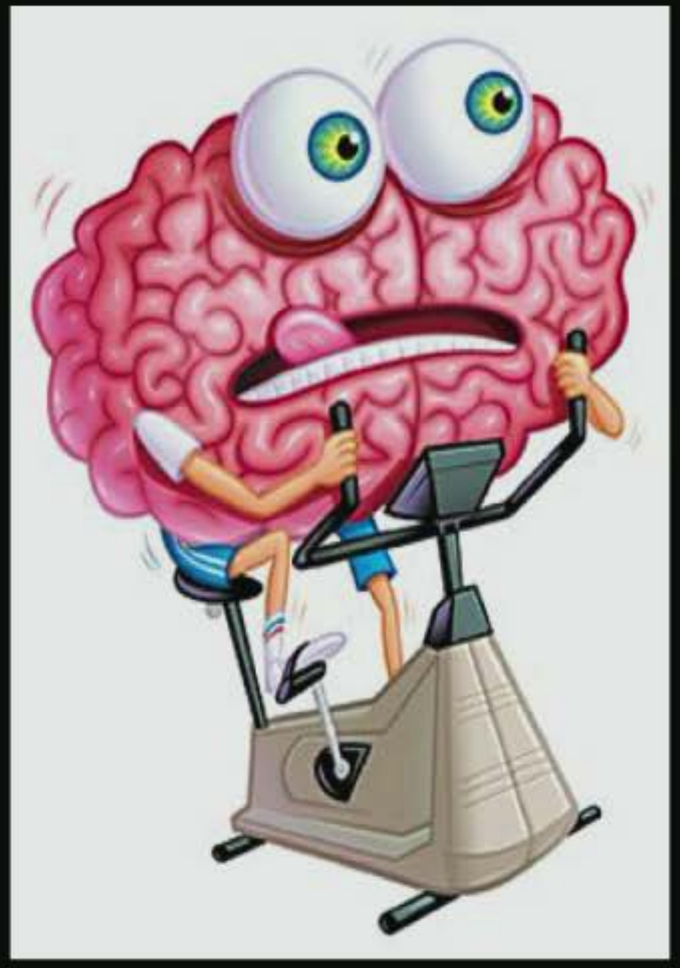


Figure 1. System diagram of a collaborative BCI.

(Wang et al., 2011)

BCI Training



BCIs Today

Neural mechanism	Nature	Synchronous		Asynchronous		Training Time
Motor Imagery	ERD/ERS	2 classes 72-96% Random < 70%	4 classes 65-75% Random < 55%	2 classes 70-75% Random < 70%	4 classes 60-65% Random < 55%	ML 10-30 min OC 1-2 months
P300	ERPs	6x6 Symbol matrix 80% after 5 repetitions (xDawn) (Rivet et al. 2009)		95% (Pinegger et al. 2015)		10 min at most
SSVEP	SSEP			95.5% (Guger et al. 2012)		10 min at most

(Kosmyna et al., 2019)

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Priming

We present users with a stimulus (prime) in order to modify the response to a later stimulus (probe)

(Meyer and Schvaneveldt 1971)

State of the art: Priming types

Semantic priming – The prime is a word

Visual priming – The prime is an image (Matsukawa et al. 2005)

Subliminal Priming – The priming stimulus is shown for 30-40ms and usually masked

(Strahan et al. 2002)

State of the art: Priming types

Semantic priming – The prime is a word

Visual priming – The prime is an image (Matsukawa et al. 2005)

Subliminal Priming – The priming stimulus is shown for 30-40ms and usually masked

(Strahan et al. 2002)

Semantic Priming

Visual Priming

(Meyer and Schvaneveldt 1971)


I'm so thirsty...
I need to buy
something to drink...
Walmart

Visual Priming: Probe and Reaction

Implicit BCIs inside the Game

Where can we use BCIs nowadays?

- Communication
- Typing
- Web surfing
- Human-Aided Computing (labeling the data)
- Creativity applications
- Health-related application
- Cognitive state monitoring applications

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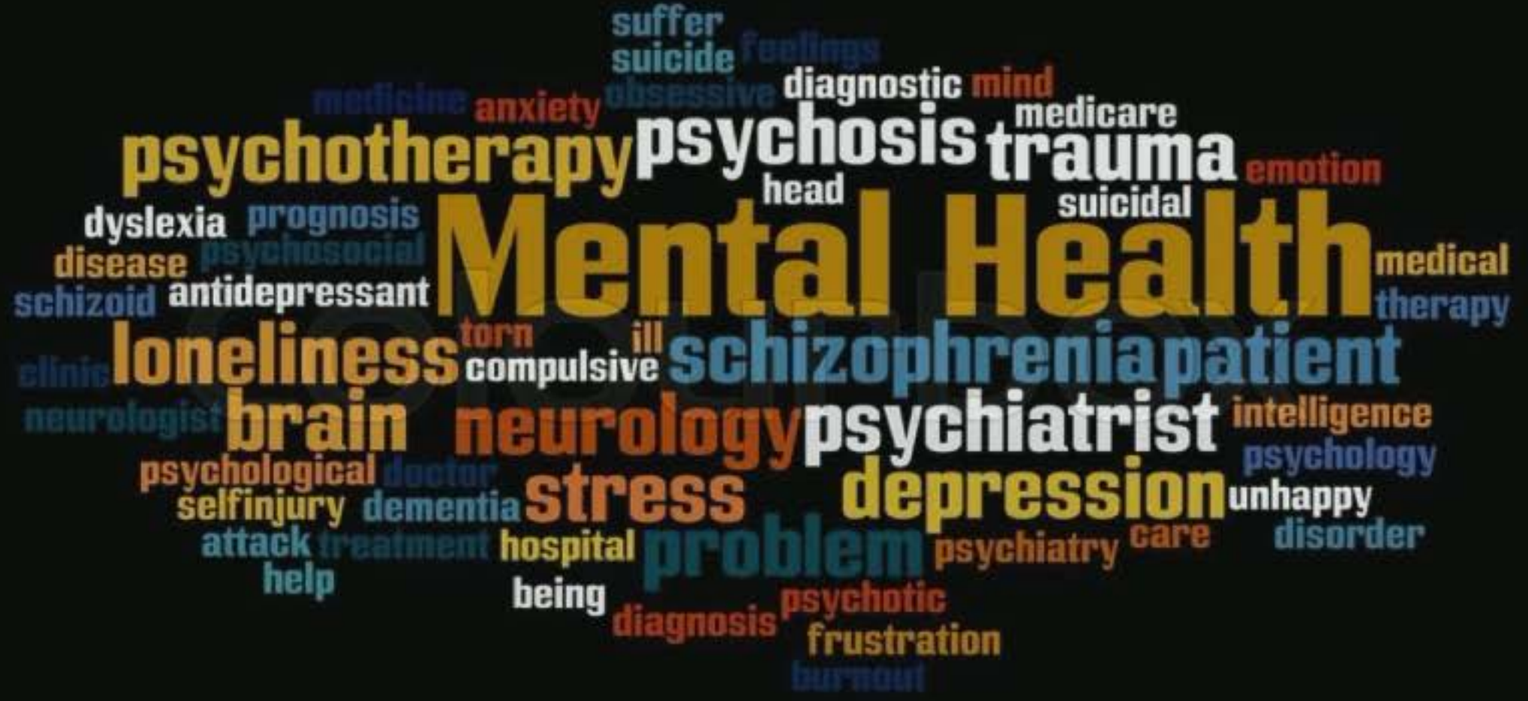

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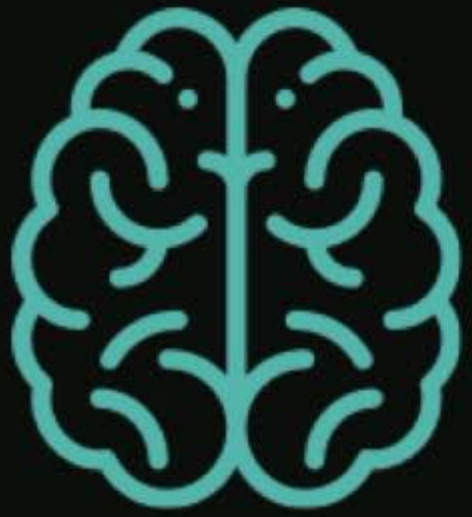

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What can we do about it?

- measure attention level of users in real-time without adding a cognitive burden,

- provide feedback when their attention level is low in order to help them improve their attention to and performance on the task at hand.

Definition

Attention is a mechanism that “alleviates computational burden by prioritizing processing of that subset of [sensory] information deemed to be of the highest relevance to the organism's goals”.

Ole Jensen

State of the art: Monitoring User Attention

- heart-rate variability [Byrne and Parasuraman, 1996],
- galvanic skin response [Boucsein et al., 2007],
- electroencephalography (EEG) [Zander et al., 2010; Cutrell and Tan, 2007].

-> EEG signals used to identify subtle shifts in user alertness, attention, perception, and workload in laboratory, simulation, and real-world contexts [Berka et al., 2007; Freeman et al., 1999; Szafiir and Mutlu, 2013].

Any ways we can measure it?

- By looking at oscillatory alpha activity (spontaneously)
- By evoking it (event-based)

Why alpha activity?

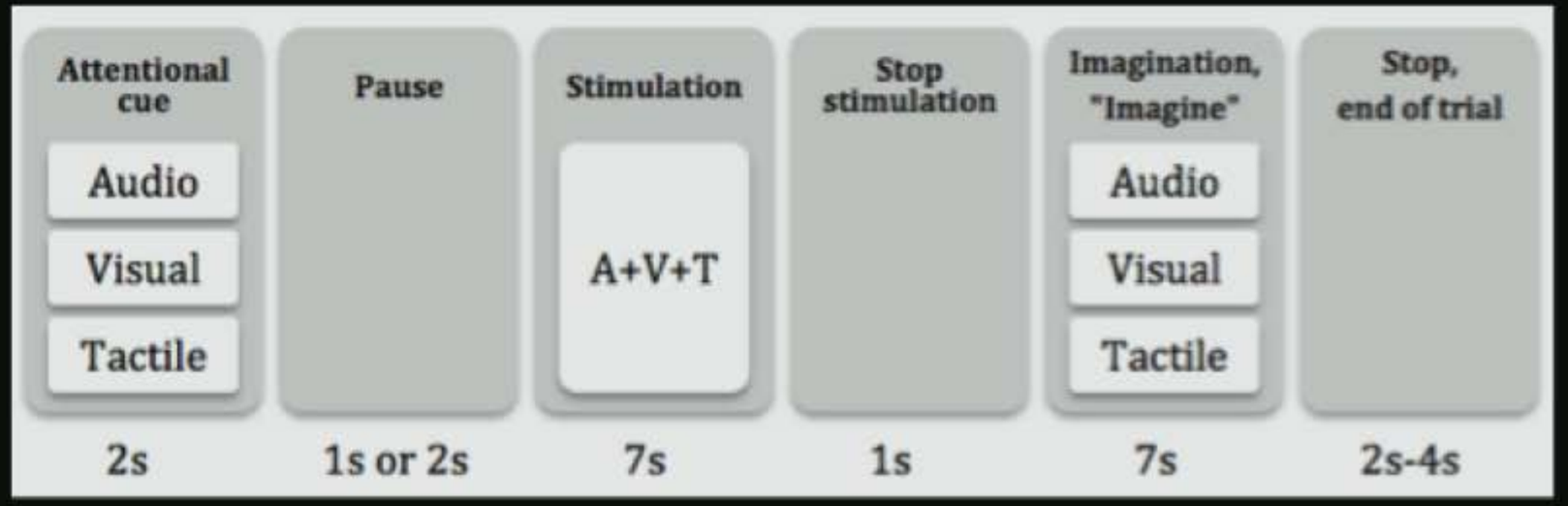
Alpha is fundamental in inhibiting task-irrelevant regions and gating information throughout a distributed cortical architecture

Alpha power effects are consistently observed across diverse attention domains, such as spatial, selective, and internal attention

Types of attention

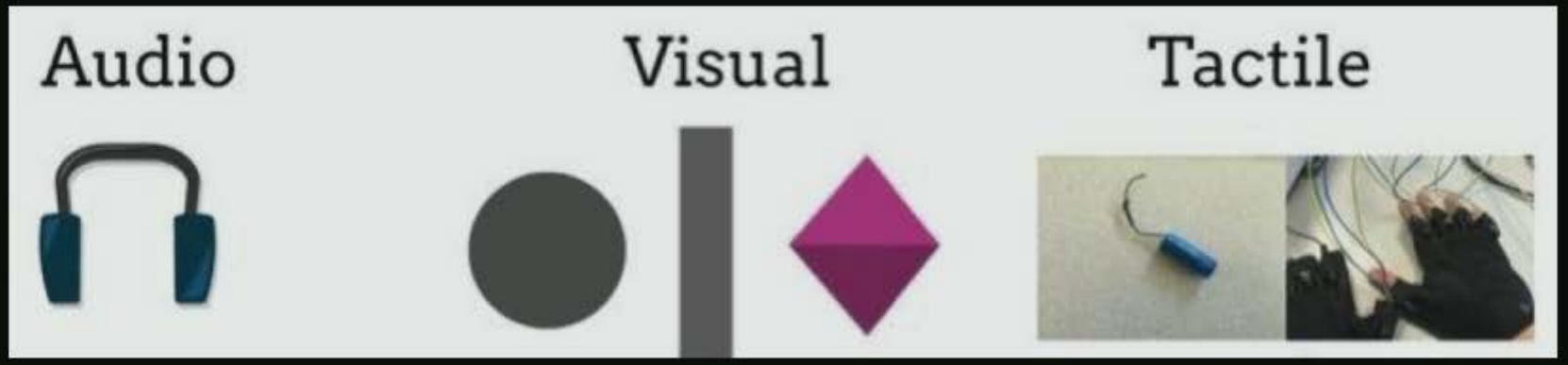
- **spatial attention**, in which you attend to a spatial location or body part,
- **temporal attention**, in which you attend to a point in time,
- **selective attention**, in which you either attend to a modality or one feature within a modality,
- **internal attention**, in which you attend to an internal representation during working memory performance.

XP set-up



(Kosmyna et al., 2018, under review)

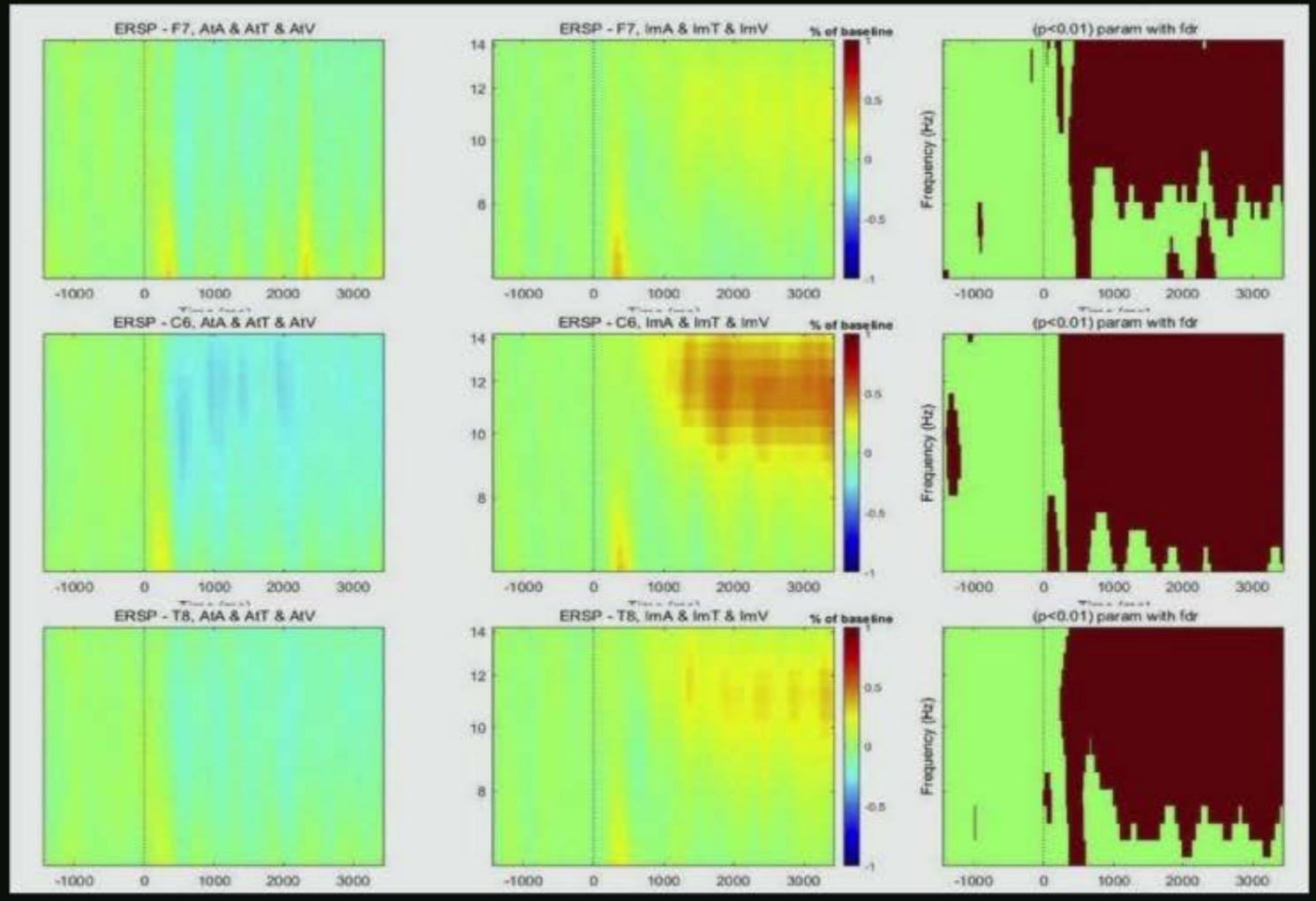
Towards multisensory BCIs



Within-subject, 28 participants, 4563 trials, 28h of EEG recordings

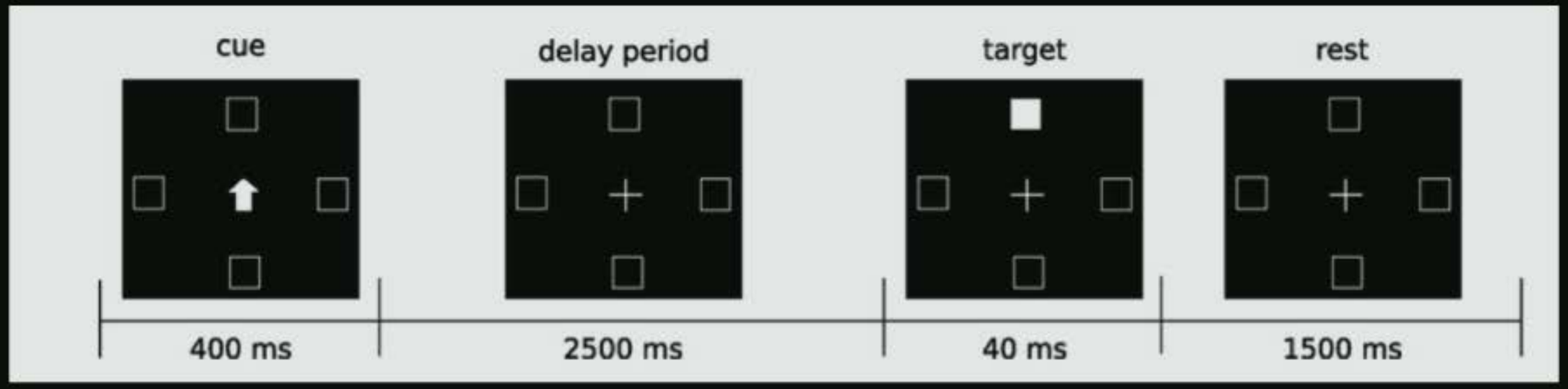
(Kosmyna et al., 2018, under review)

ERSP



(Kosmyna et al., 2018, *Nature Sci Reports*)

Locations of attention



(van Gerven and Jensen, 2009)

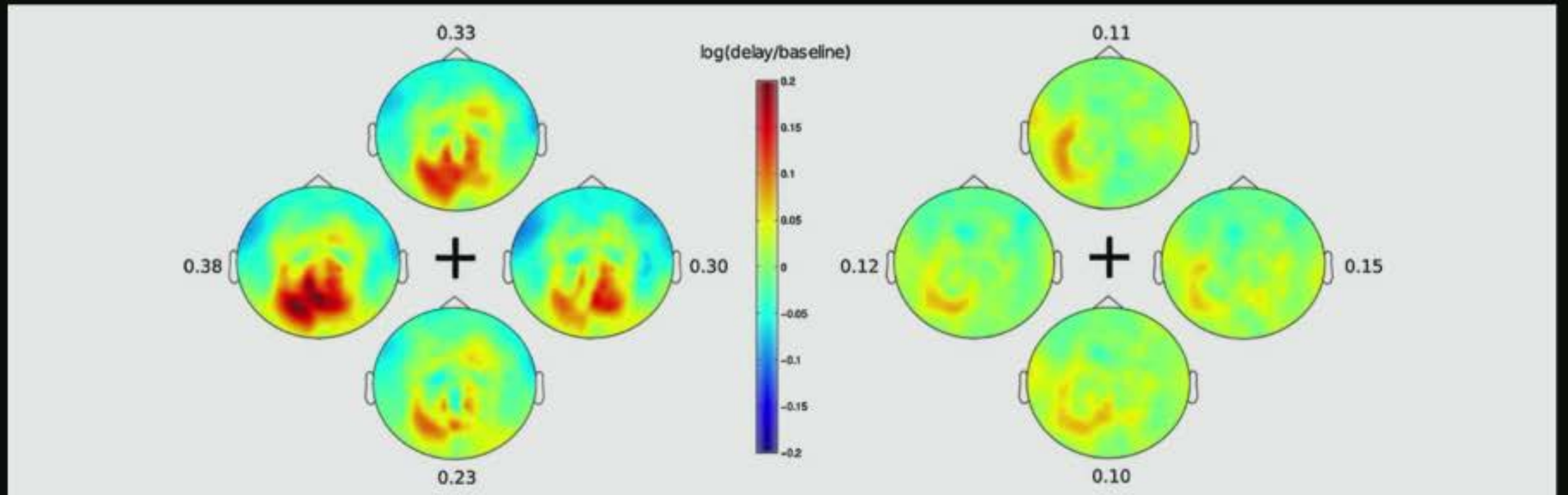


Fig. 3. Log of the alpha power (8–14 Hz) for the covert attention conditions (top, right, bottom, left) from 500 to 2500 ms after cue offset divided by the log of the alpha power in the −500 to −400 ms baseline period for the best (left) and worst (right) five subjects. Average log(delay/baseline) of occipito-parietal channels is shown per orientation.

System for attention and engagement monitoring

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AttentivU: Monitoring and improving engagement using biofeedback

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AttentivU: Components

1. an EEG sensing device;
2. a device that gives minimally disruptive haptic feedback;
3. software for real-time signal processing of brain signals;
4. an application to provide real-time data about the attention levels of users

AttentivU – 24 prototypes

AttentivU – Multiple Session XP

AttentivU – XP1

- 3 different lectures of increasing difficulty
- 1 lecture/week
- Same 12 students
- Real lectures with a professor
- Recorded sessions

AttentivU – XP1

1) Neurofeedback (accurate feedback), meaning the scarf was vibrating each time a drop in attention was detected by the EEG

2) Random feedback, where the vibrations did not correlate or depend on the attention level detected by the system

3) No feedback, no vibrations were administrated.

N. Kosmyna and P. Maes. *Under review*

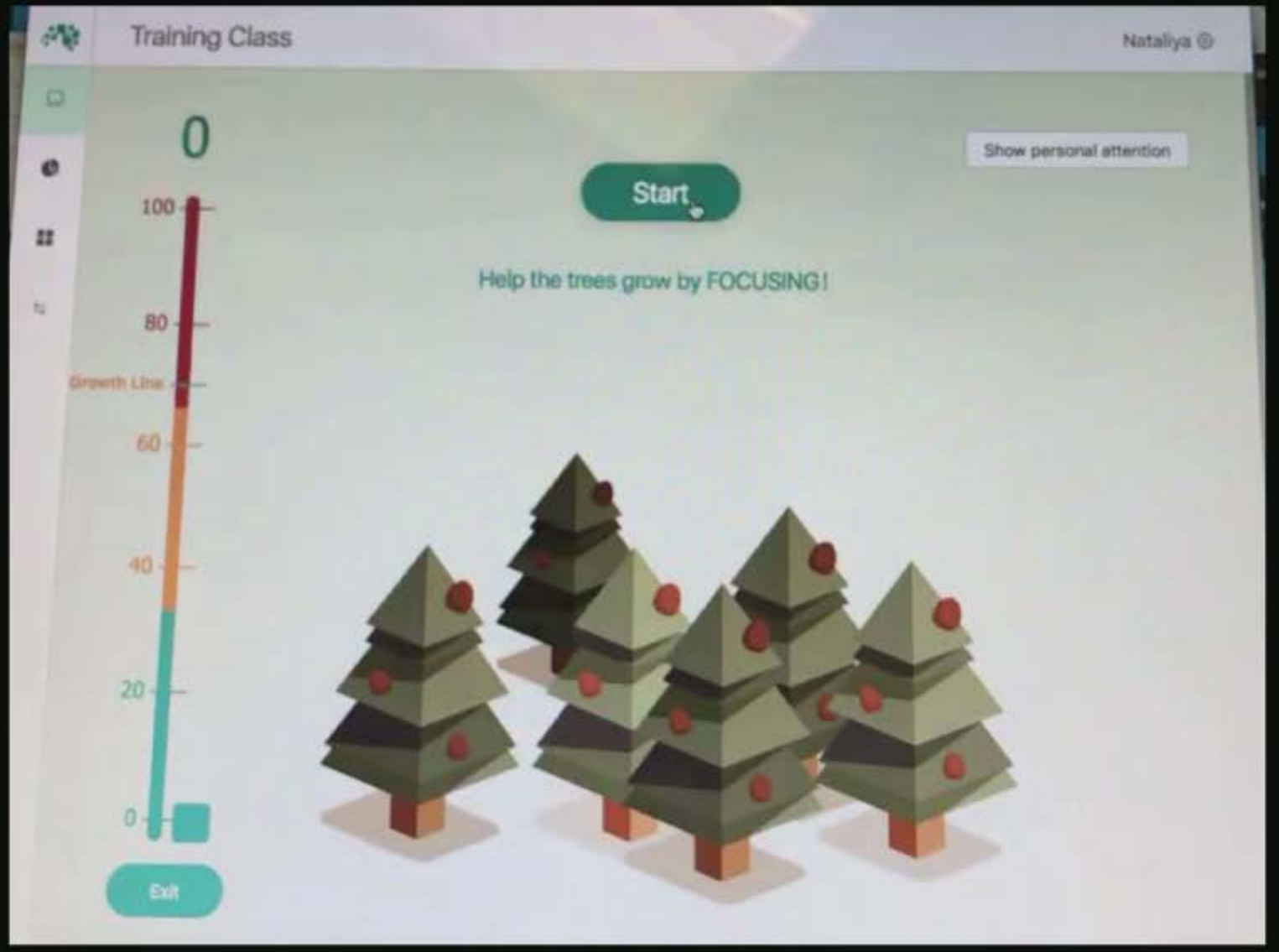
Calibration

- Session 1. Participants were asked to sit still with their eyes closed for 90 seconds.
- Session 2. Participants were asked to sit still with their eyes open for 90 seconds.
- Each subject alternated between 10 instances of an arithmetic task and 10 instances of an image-matching task and auditory-matching task, performing each task for 30 seconds, with 10-second controlled rest periods in between. For the image-matching task, users indicated whether sequences of images match each other, as in an n-back task [11] with n permanently set to 1, similar to the low cognitive workload condition used in previous BCI work [2].

For the engagement measure, we used the calibration session to establish ranges for high and engagement. During the calibration stage users were explicitly instructed not to attend to any particular imagination or other internal process.

N. Kosmyna and P. Maes. *Under review*

AttentivU: calibration



Data Processing

- $E = \beta/(\alpha+\theta)$
  $\alpha(7-11Hz)$, $\beta(11-20Hz)$, and $\theta(4-7Hz)$ frequency bands
- FFT applied to the raw signal to extract the relevant frequency bands (β , α , θ) averaged over 1 sec;
- Signal filtering from muscle artifacts (e.g., blinking)
- Smoothing the engagement index using an Exponentially Weighted Moving Average to pick up general engagement trend and further remove movement artifacts
- Smoothed engagement index per 20 seconds E*smooth*

N. Kosmyna and P. Maes. *Under review*

Baseline

Normalized engagement score between 0 and 100:

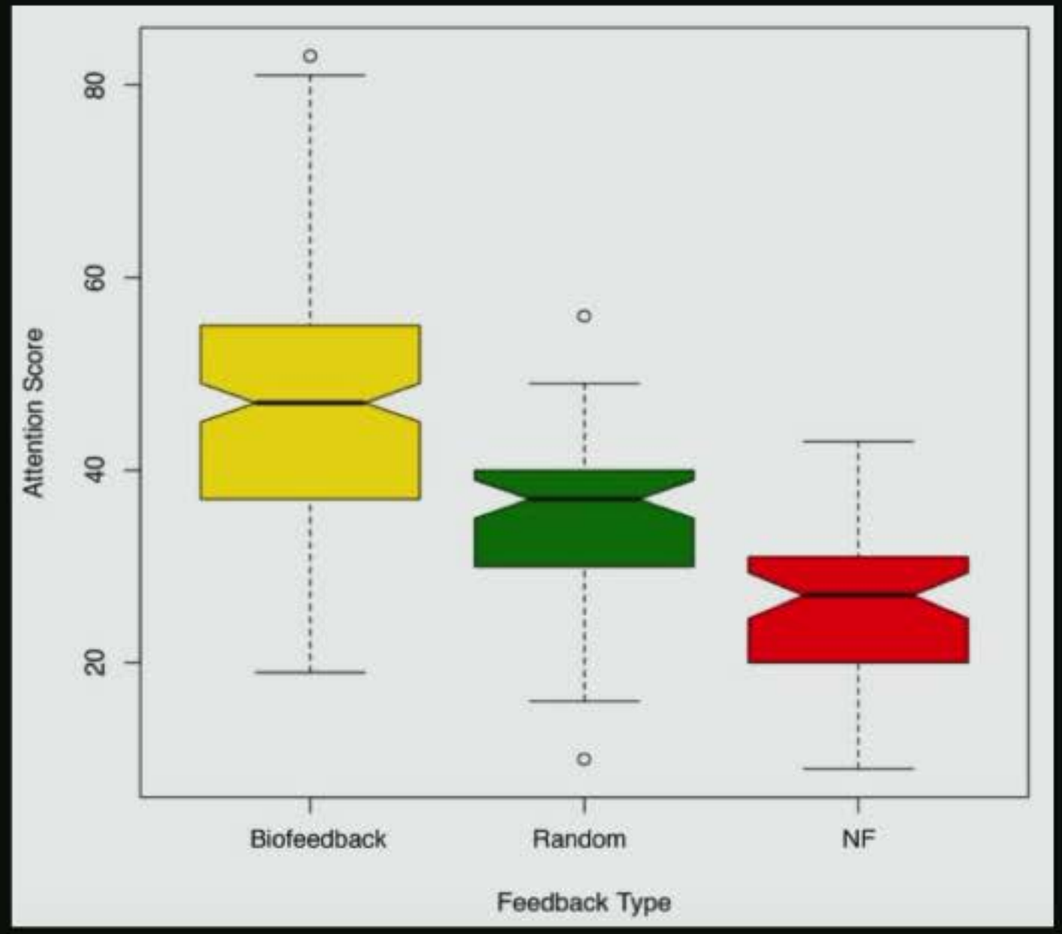
$$E_{norm} = (E_{smooth} - E_{min}) / (E_{max} - E_{min}) * 100$$

0- 30 – low attention,

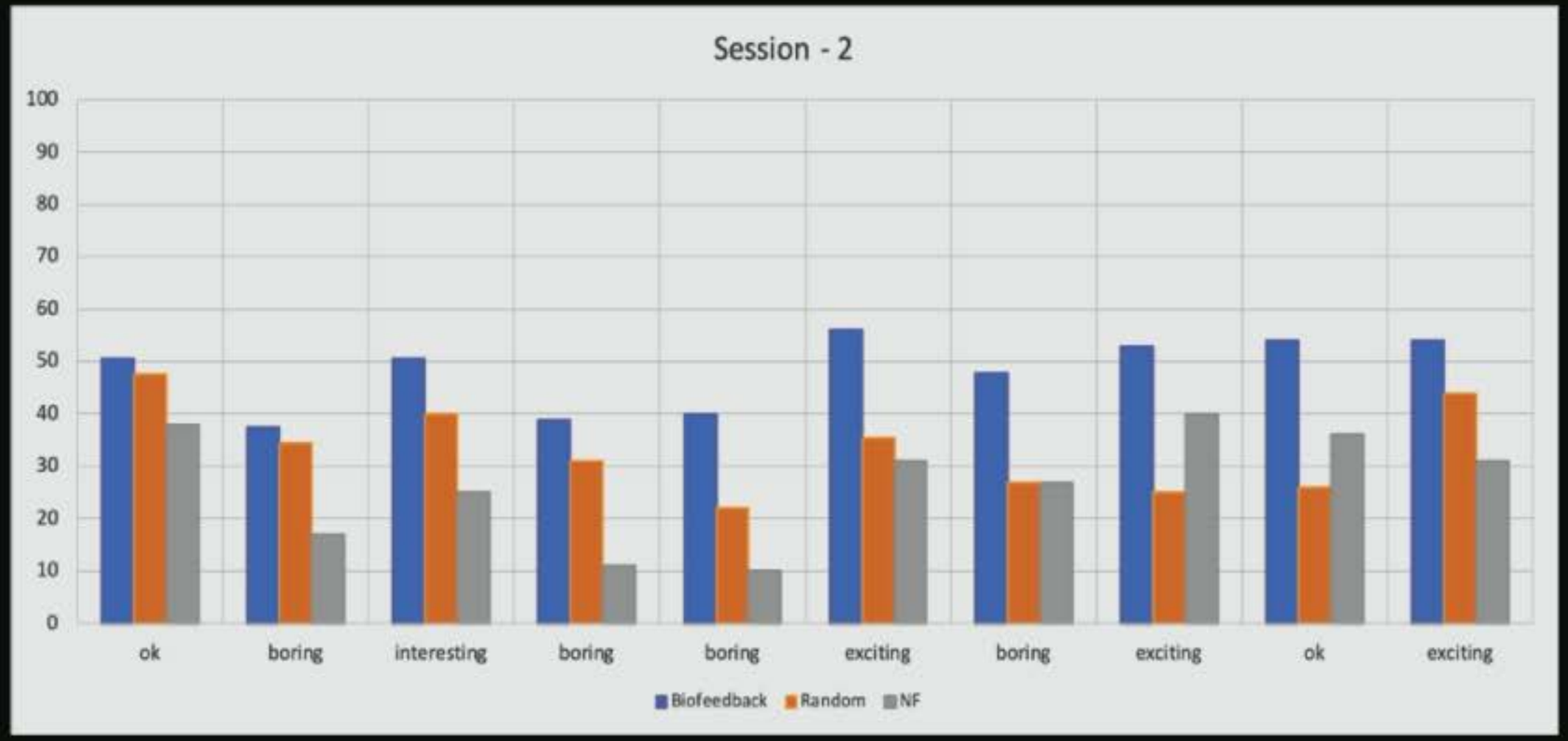
31-70 – medium,

71-100 – high.

Results



Attention scores obtained for biofeedback, random and no feedback (NF) conditions for all three lectures, study 2.



Average objective attention scores (engagement index E on Y-axis) of participants during lecture 2, study 2. The X-axis represents slide type (clusters of slides labeled as “ok”, “boring”, “interesting” or “exciting”).

AttentivU – XP1, XP2, XP3

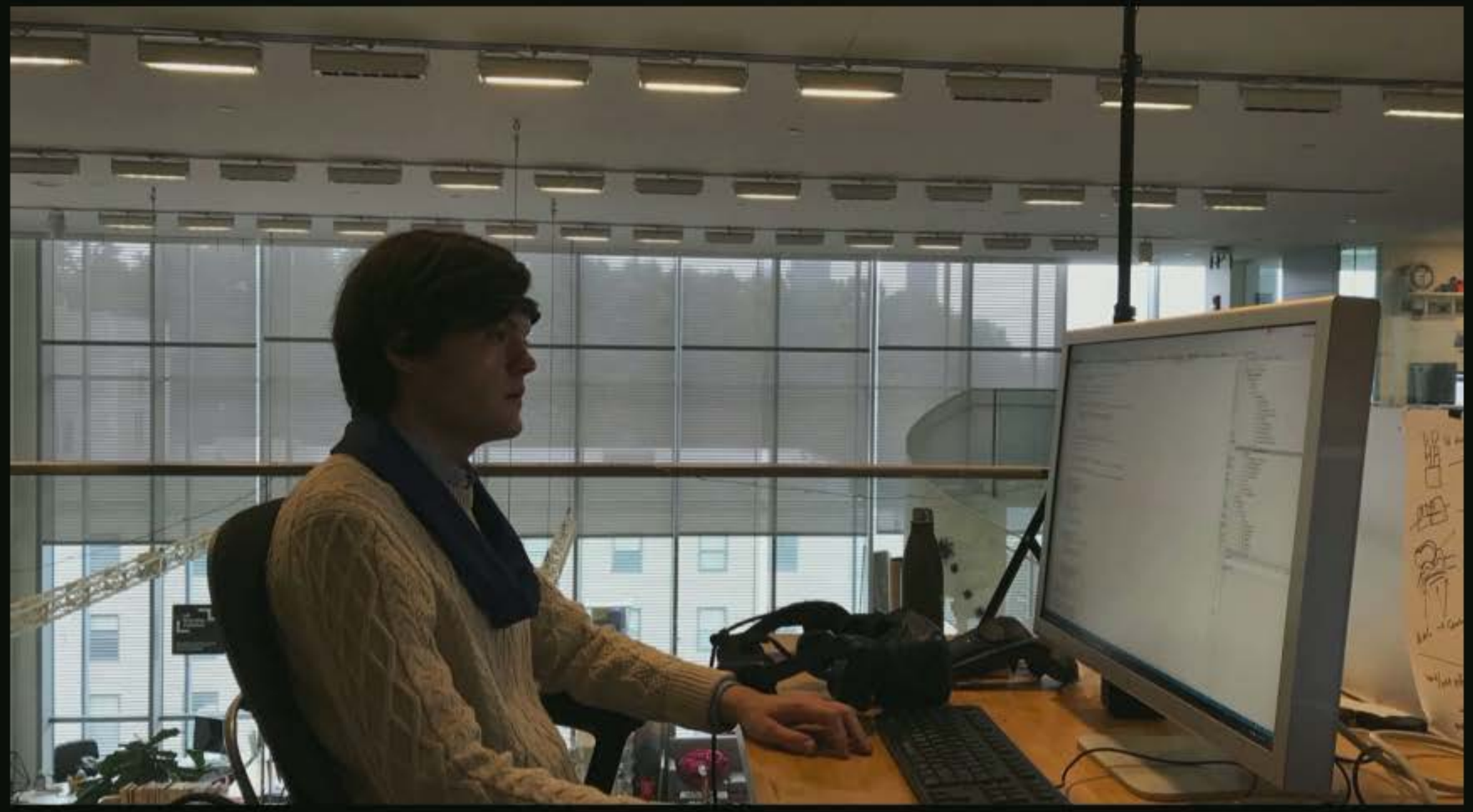
100 unique subjects for THREE experiments

66 hours of EEG recordings

27 full days of experiments

N. Kosmyna and P. Maes. *Under review*

AttentivU at workplace



N. Kosmyna and P. Maes. *Under review*

AttentivU: a Biofeedback System for Real-time Monitoring and Improvement of Engagement

Nataliya Kosmyna, Ph.D

(Kosmyna et al., 2019)

ATTENTIVU

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Form-factor matters