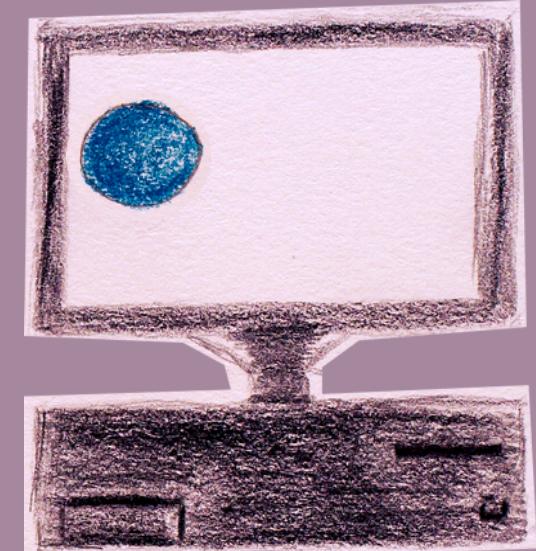
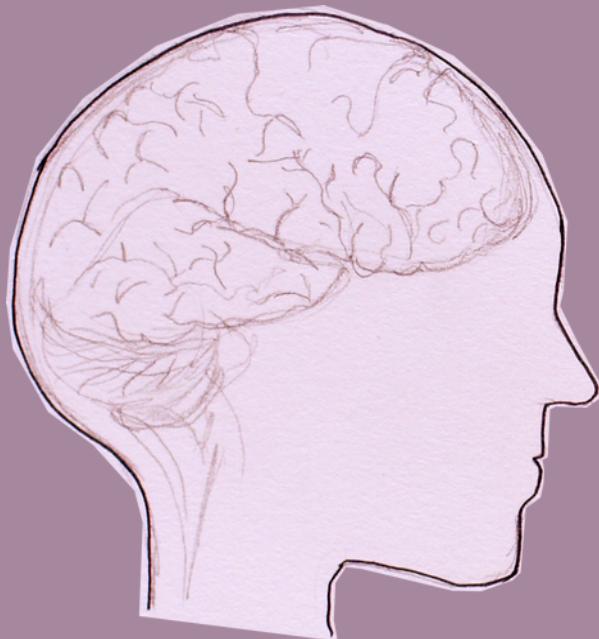
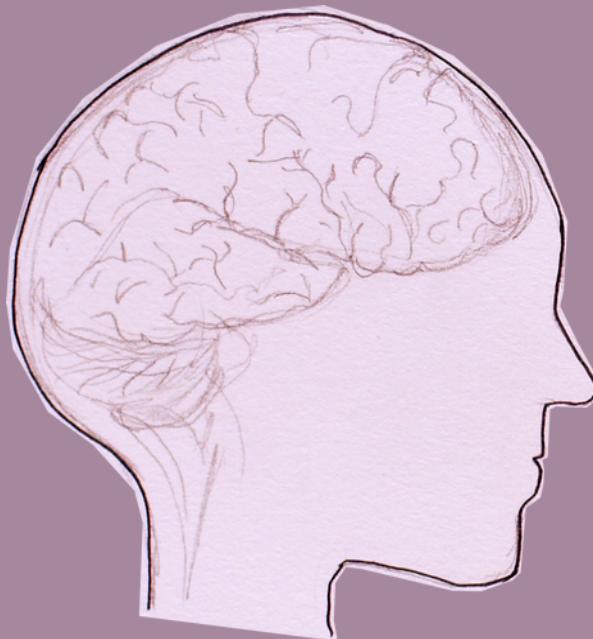


What is a Brain Computer Interface?

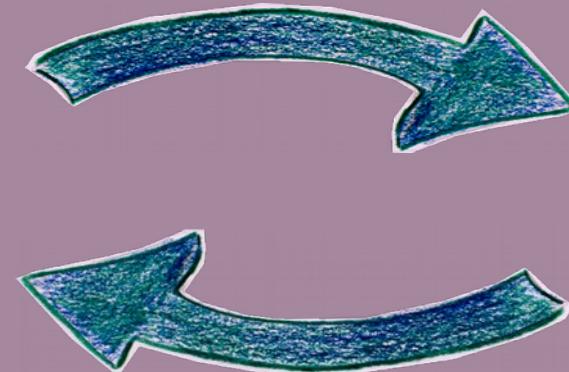


What is a Brain Computer Interface?

BCI is a system which enables a person to manipulate a machine



with only **brain activity**



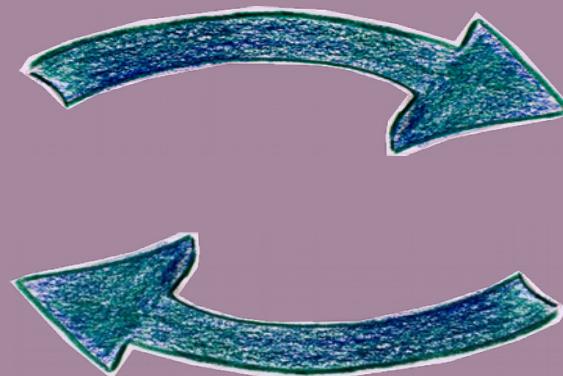
What is a Brain Computer Interface?

passive

BCI is a system which enables a person to monitor and regulate



brain activity



neurofeedback

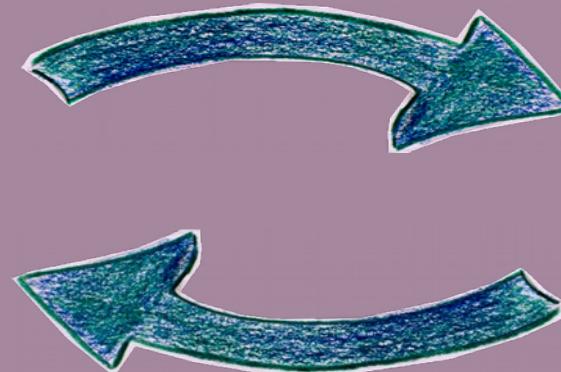
What is a Brain Computer Interface?

passive

BCI adapts a device assisting a person to have more comfort or safety



brain activity



Brain Computer Interface:

1. Measure brain activity



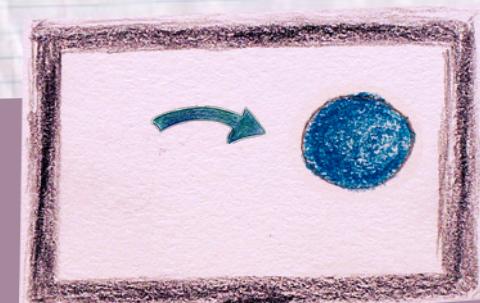
2. Filter, process data



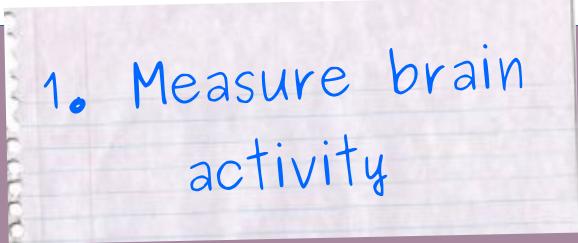
4. Provide feedback



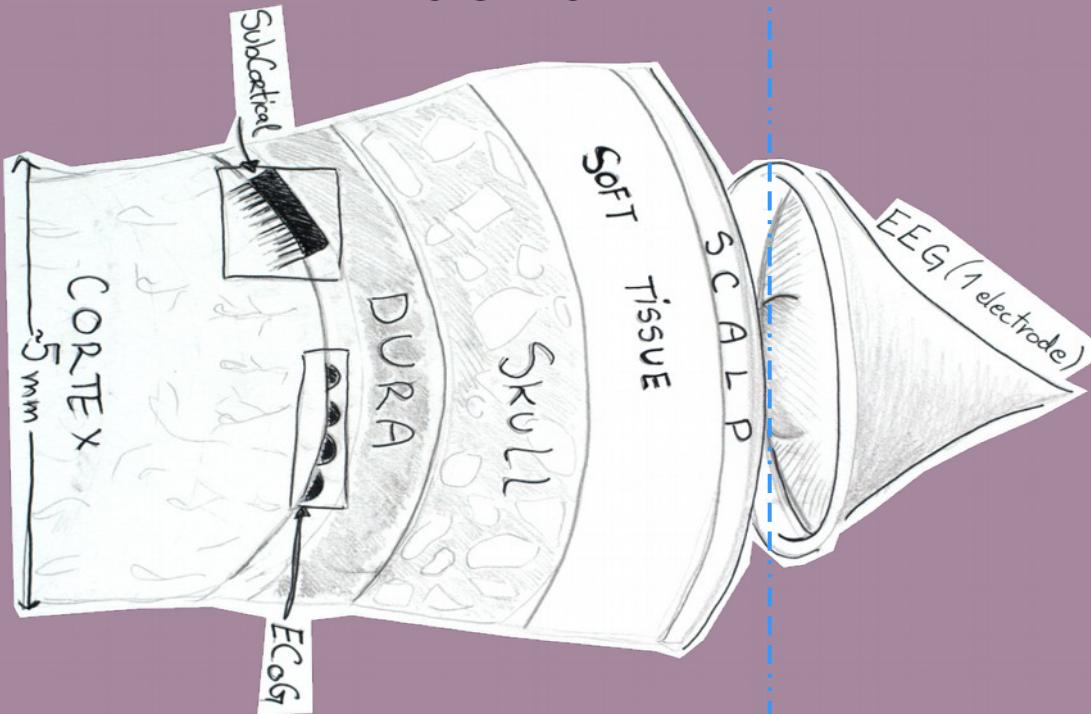
3. Translate data into commands



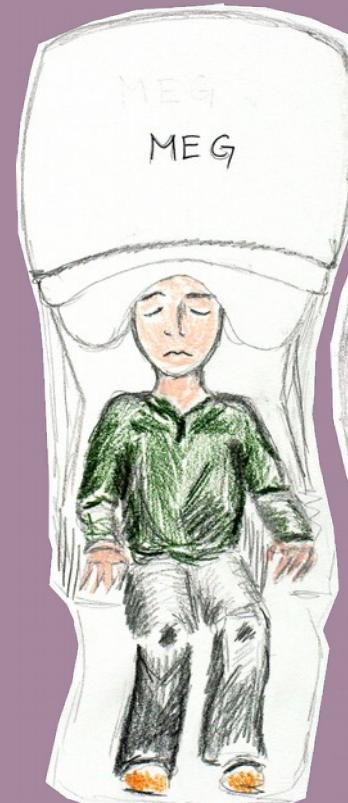
Brain Computer Interface:



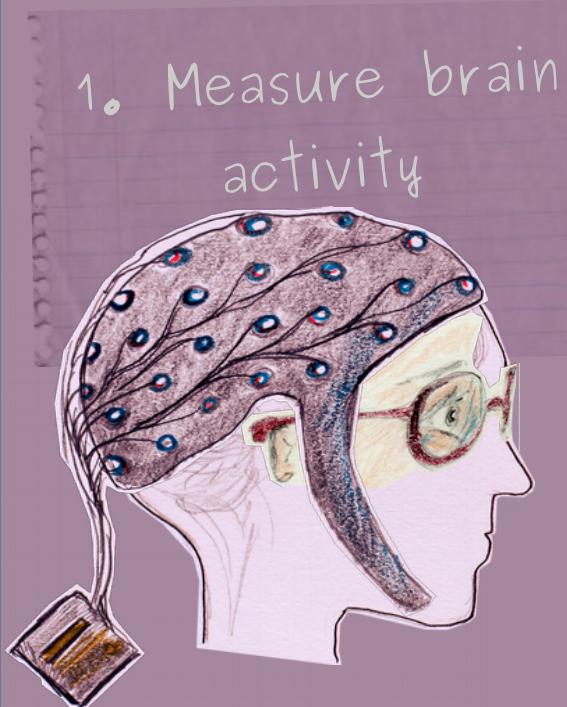
Invasive



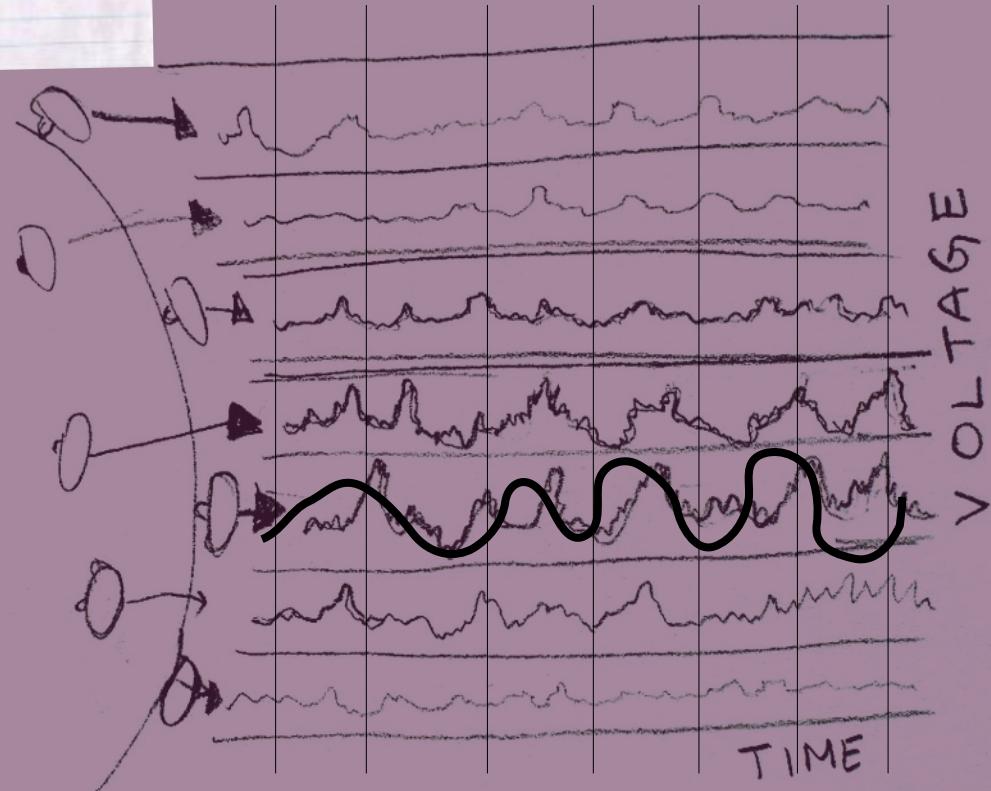
Non-Invasive



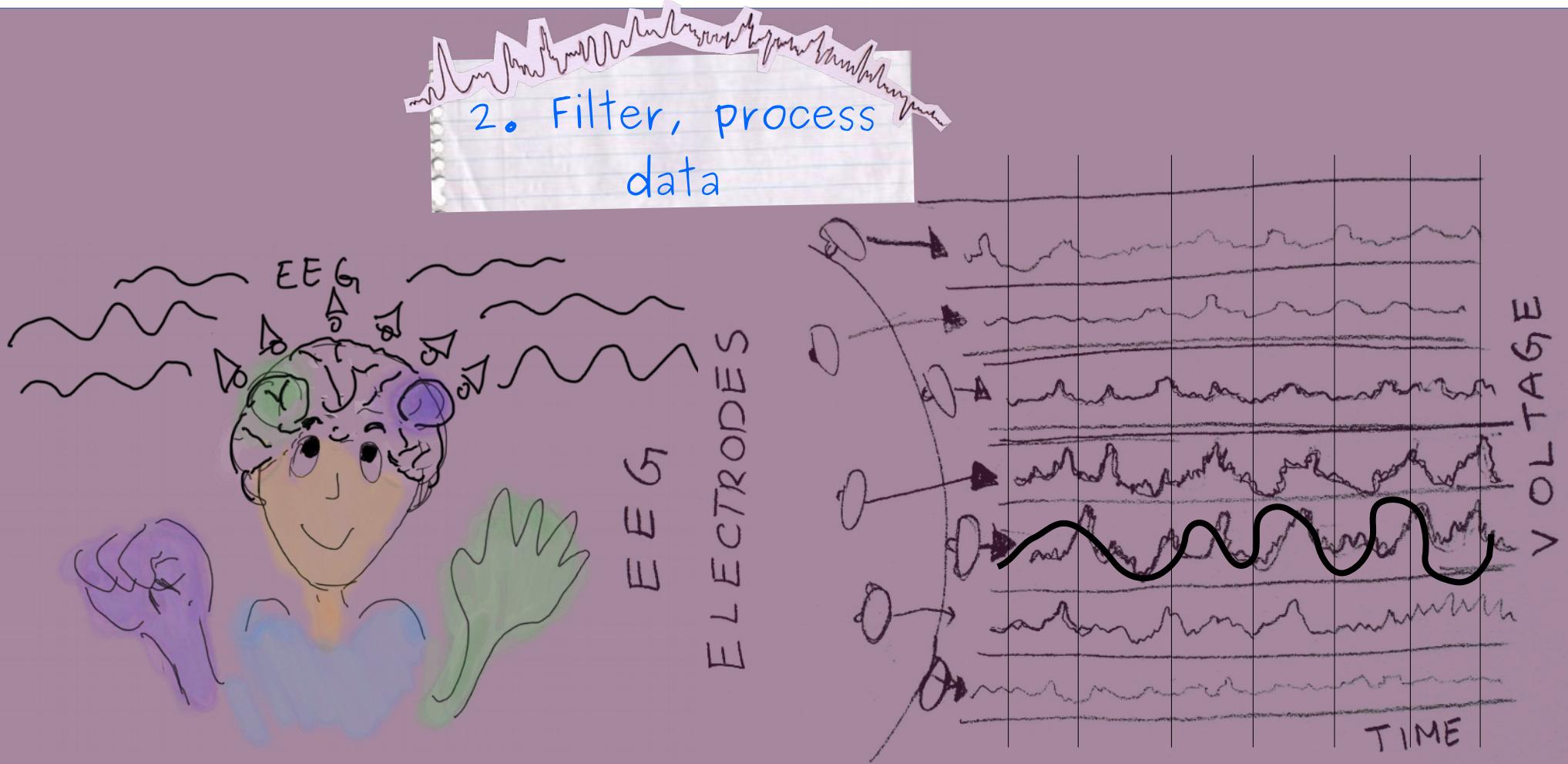
Brain Computer Interface:



EEG
ELECTRODES

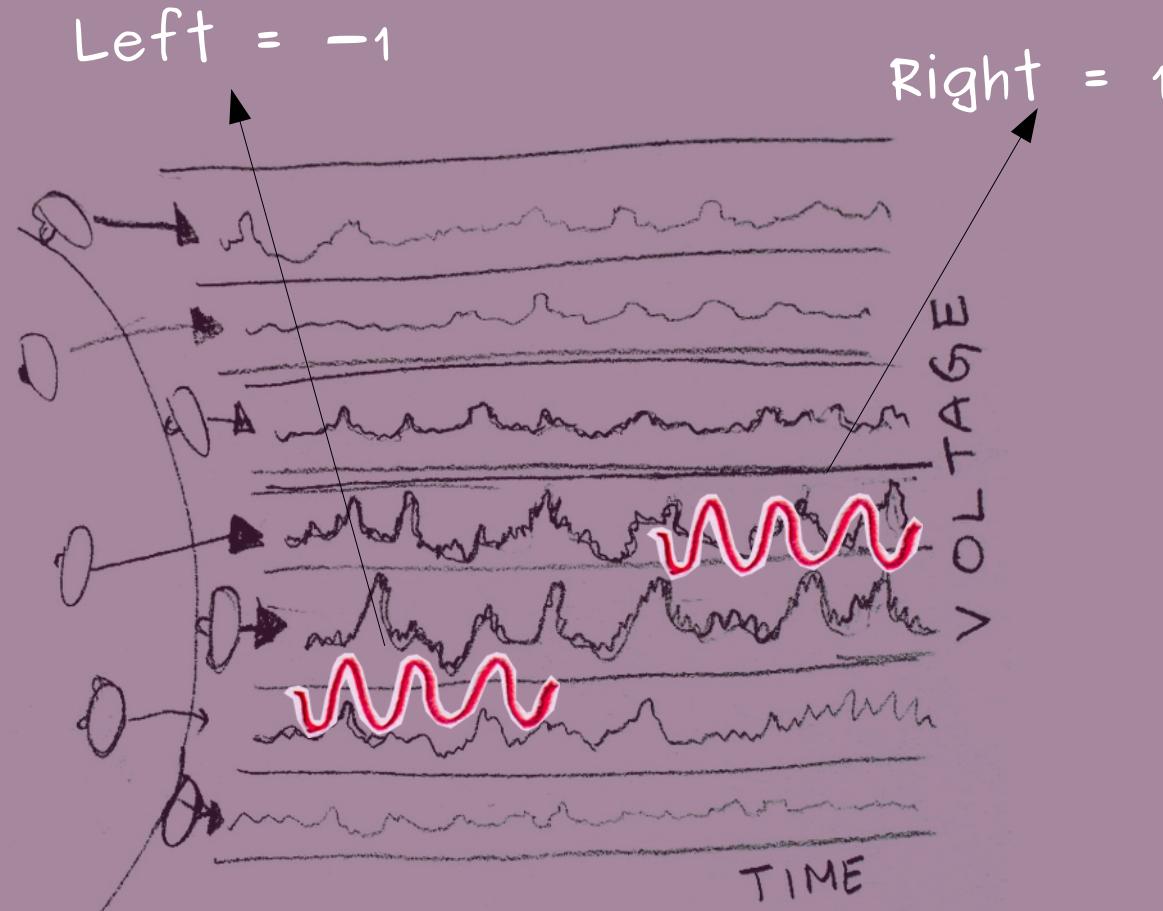


Brain Computer Interface:

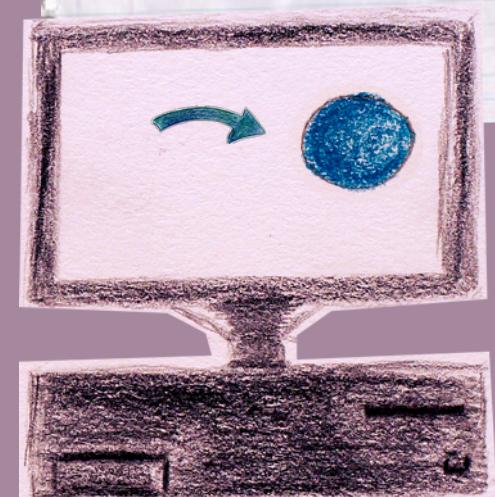


Brain Computer Interface:

EEG

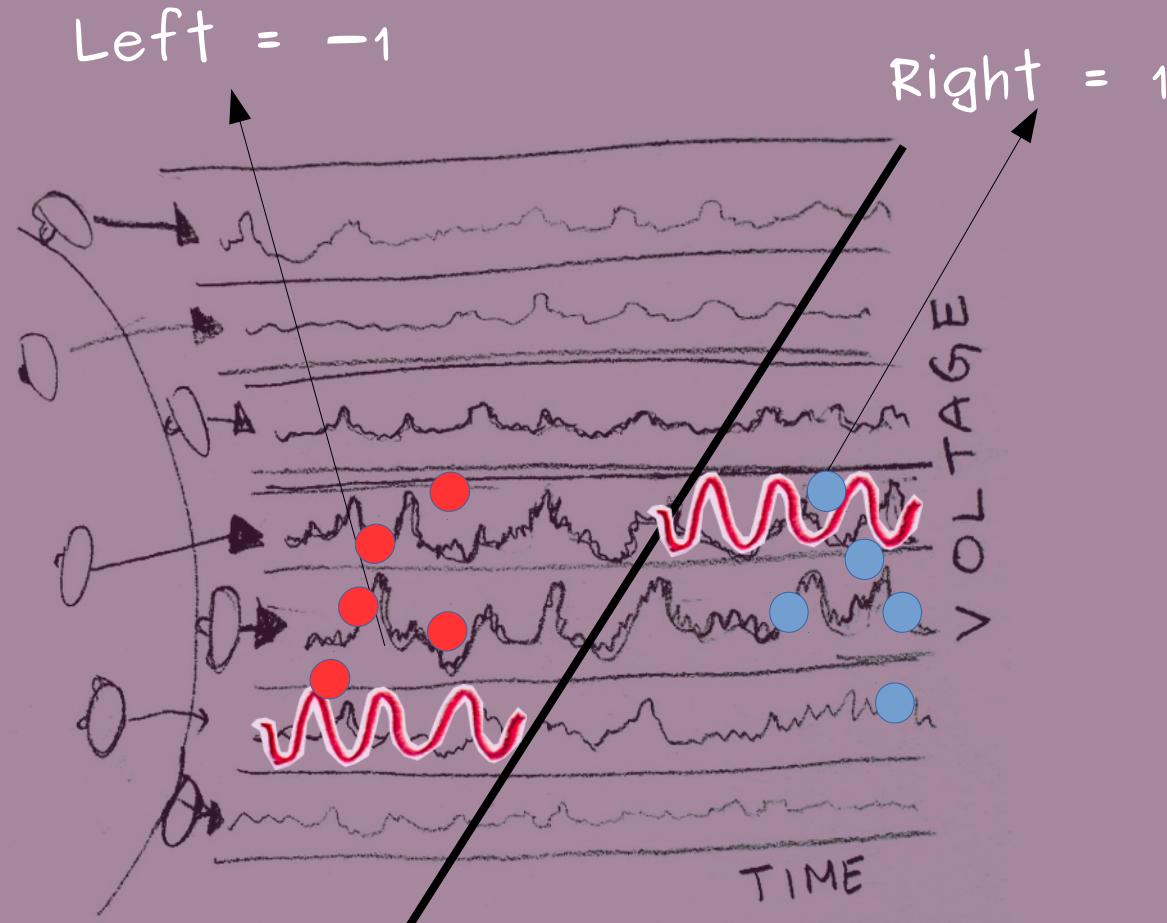


3. Translate data
into commands

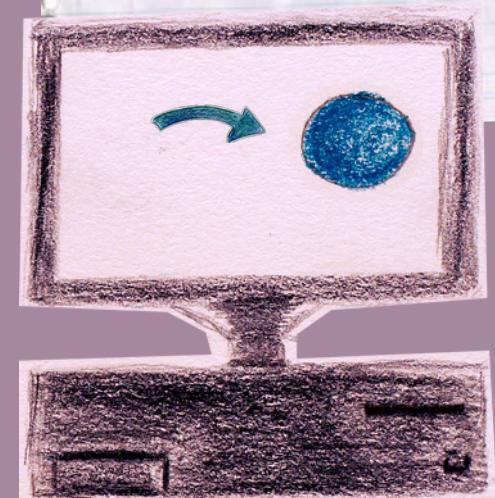


Brain Computer Interface:

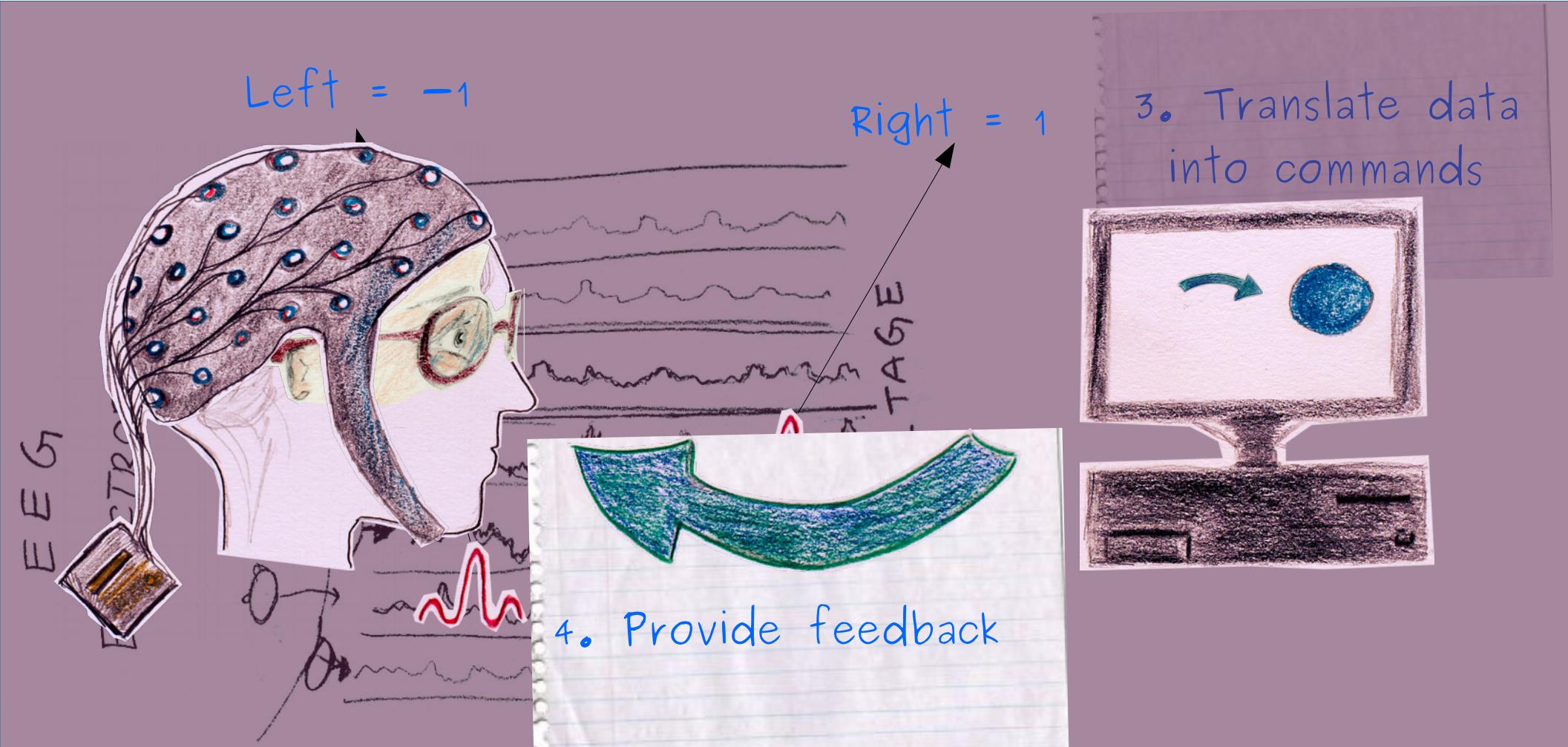
EEG



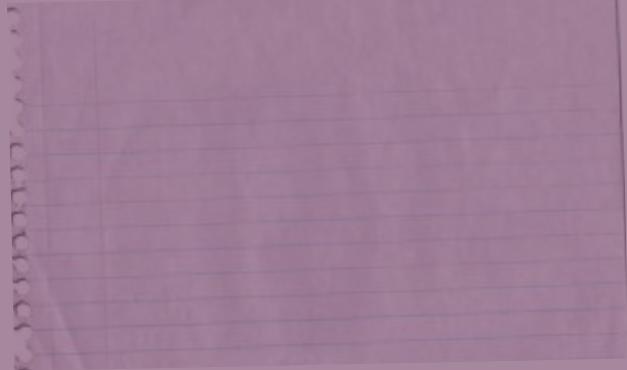
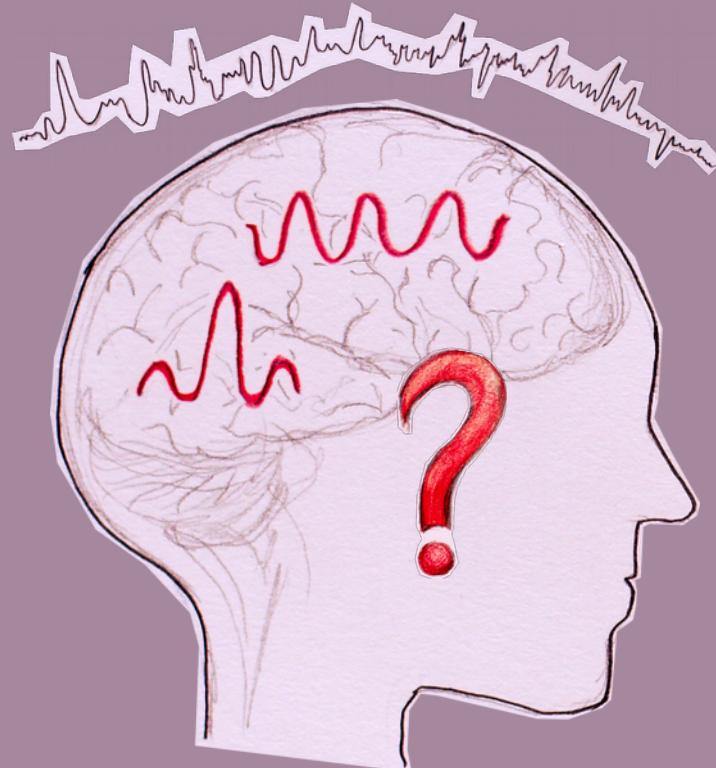
3. Translate data into commands



Brain Computer Interface:



Why is feedback important?



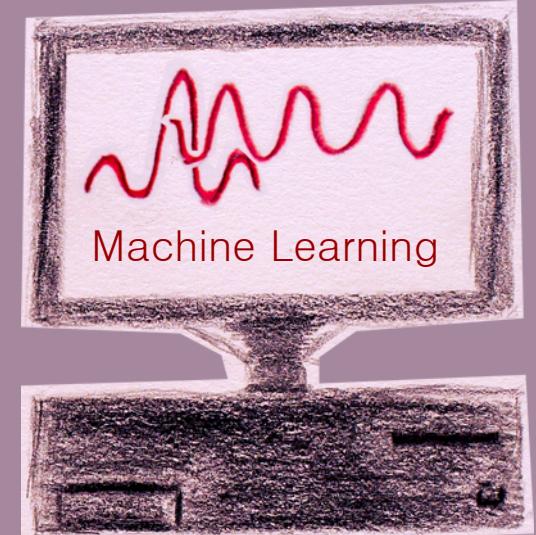
*Not All Created Equal:
Individual-Technology Fit of
Brain-Computer Interfaces, A.
Randolph, 2012*

Why is feedback important?



*Predicting Mental Imagery-Based BCI Performance
from Personality, Cognitive Profile and
Neurophysiological Patterns. Jeunet et al. 2016*

Why is feedback important?



*Towards Improved BCI
based on Human Learning
Principles, Lotte & Jeunet, 2015*

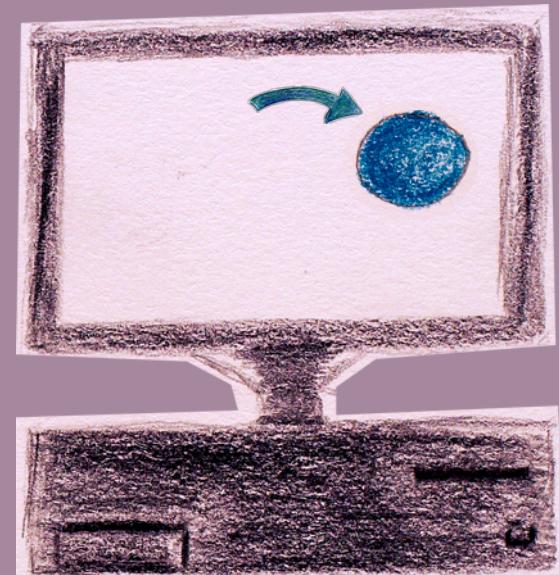
BCI experiment:



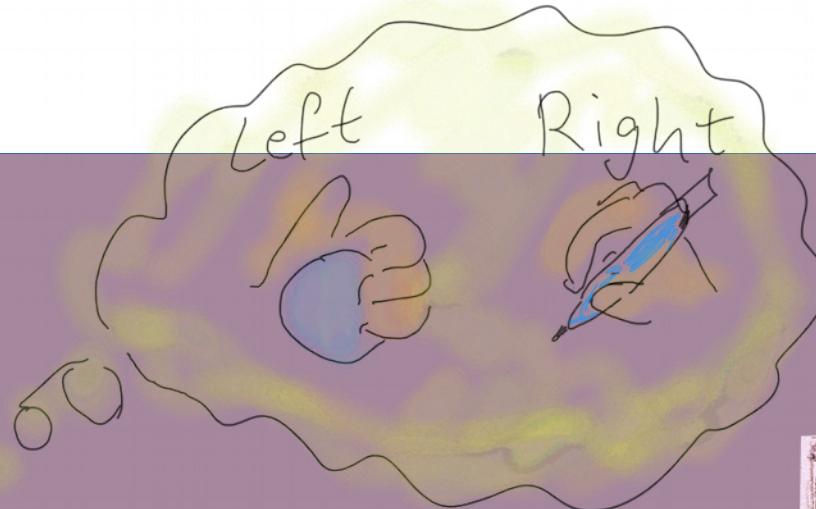
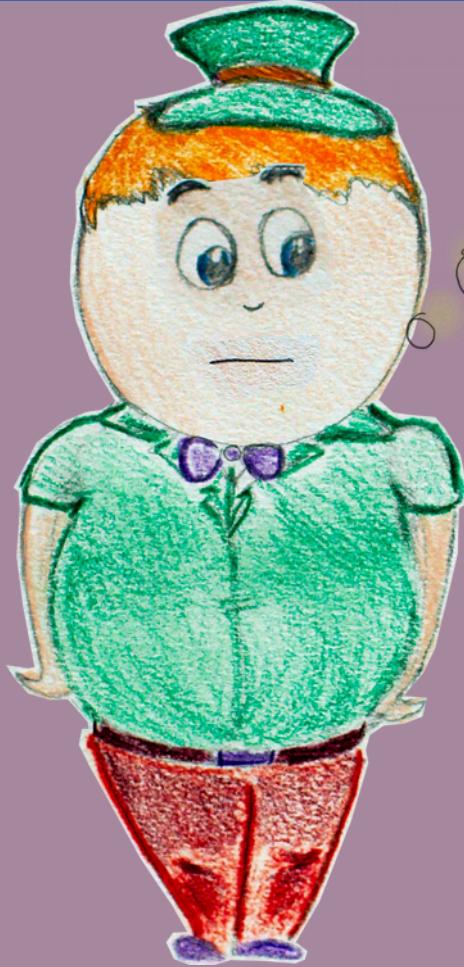
Typical Motor Imagery
BCI experiment

Instructions to follow through the experiment:

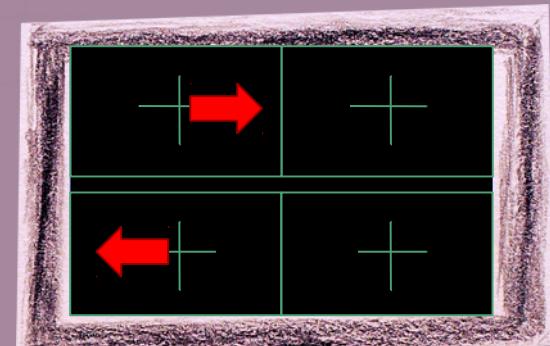
•Imagine left or right hand movement to manipulate an object on screen"



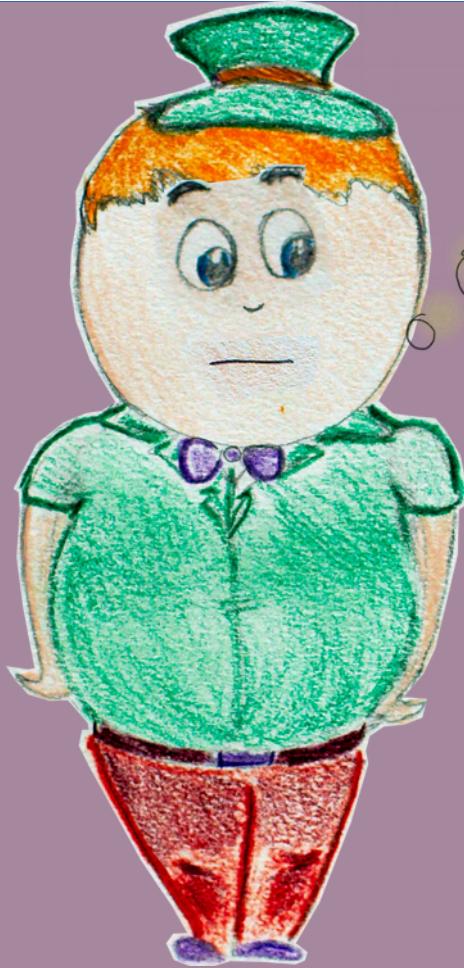
BCI PHASE1:



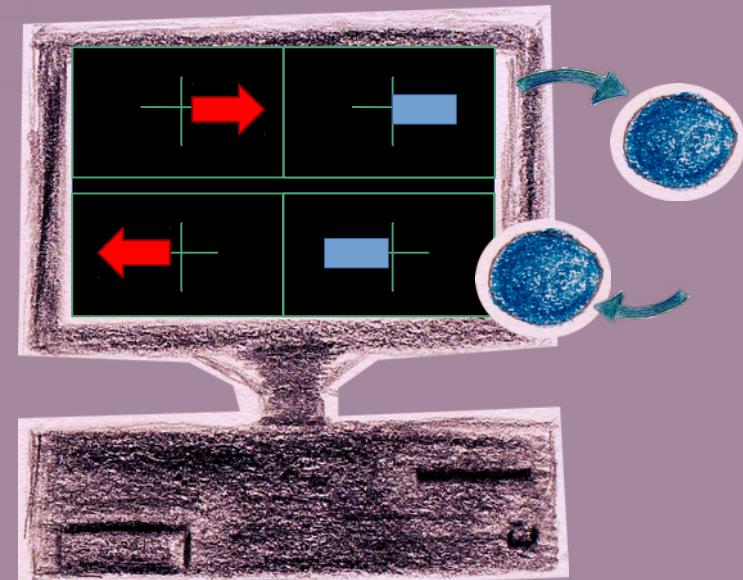
1. Calibration
Machine learns
to decode user's
commands



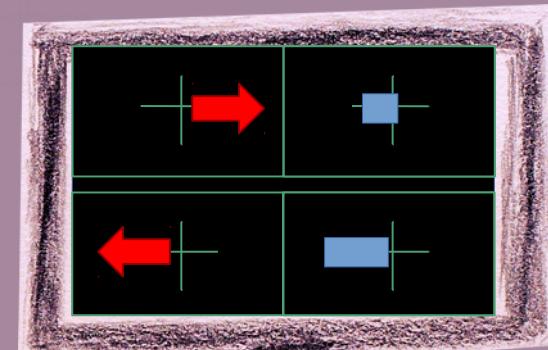
BCI PHASE2:



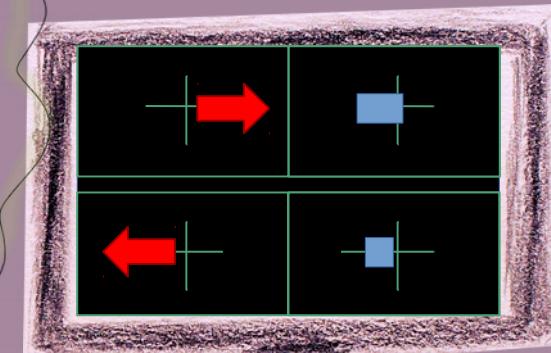
2. Testing
With feedback, user
“learns” to regulate brain
patterns and control the
machine



BCI PHASE2:



BCI PHASE2:



1. Measure brain activity

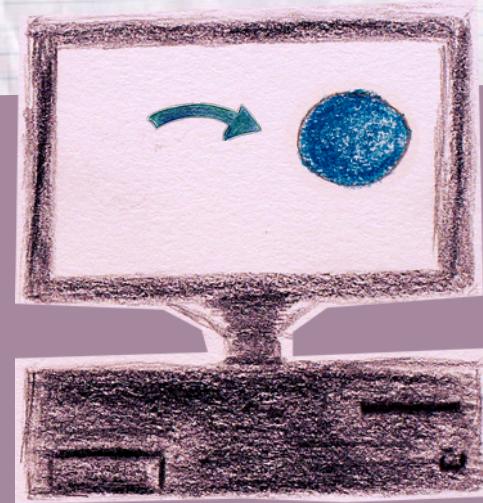


Changes neural activity (attention, mood) in time



2. Filter, process data

3. Translate data into commands



Expecting same behavior from calibration



4. Provide feedback

1. Measure brain activity

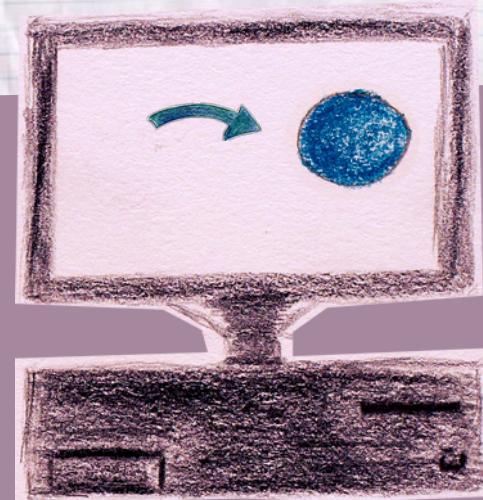


Changes neural activity (attention, mood) in time



2. Filter, process data

3. Translate data into commands



Adapt accordingly
to user
(recalibrate)

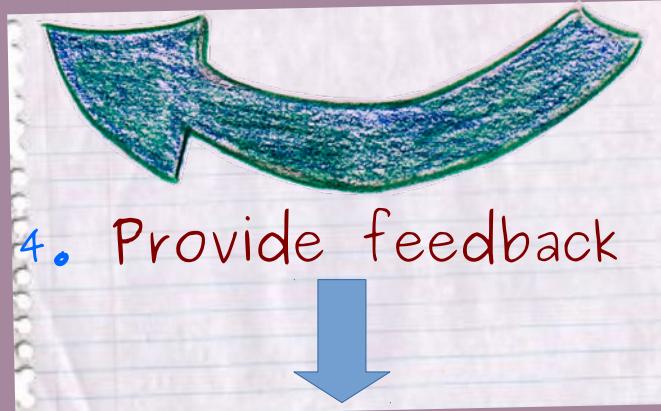
1. Measure brain activity



Changes neural activity (attention, mood) in time



2. Filter, process data

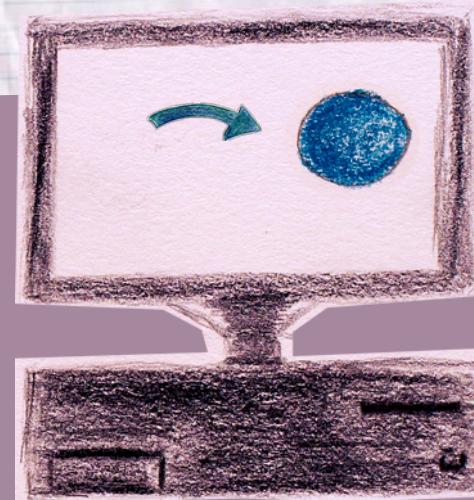


4. Provide feedback

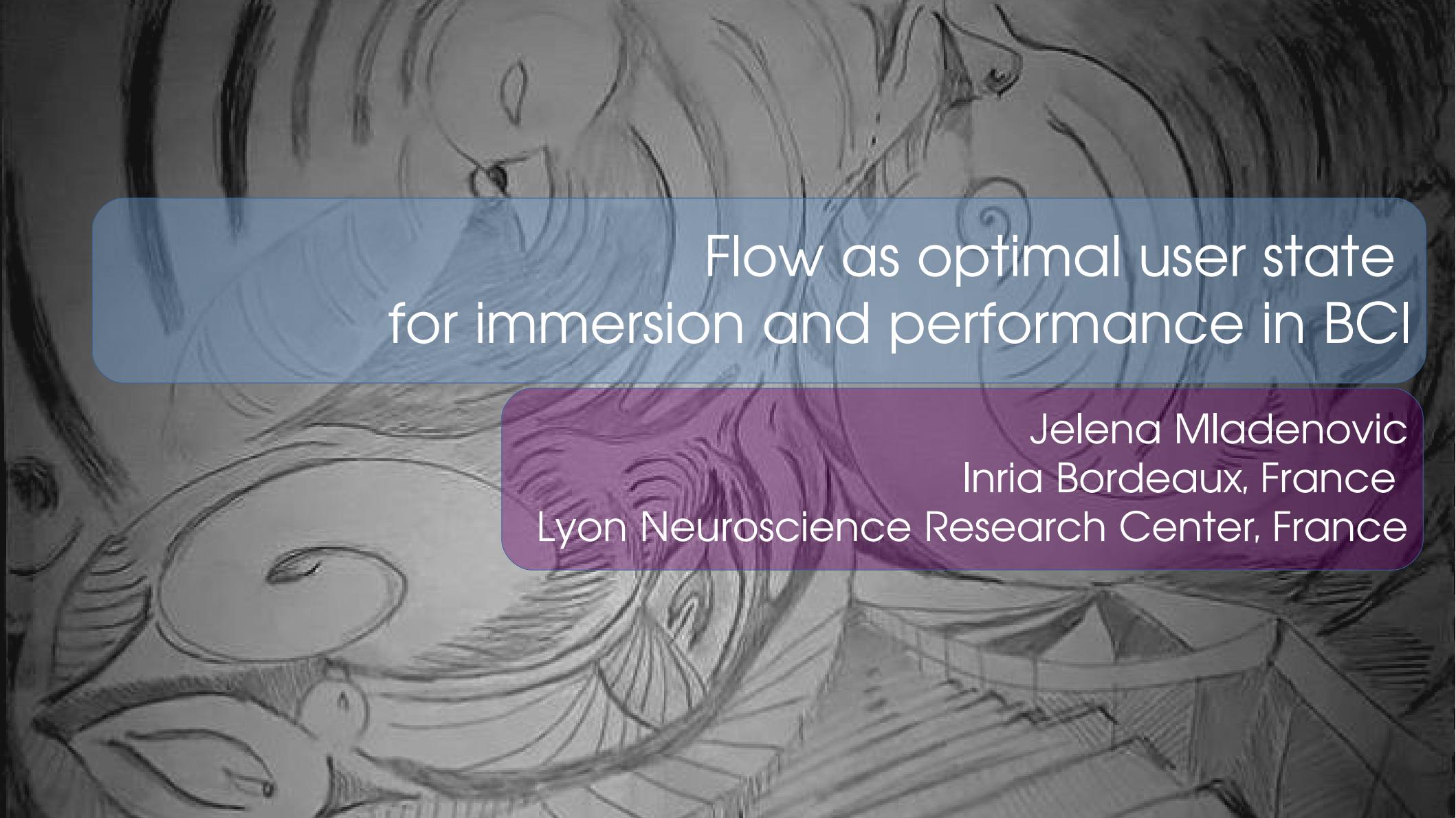


Influence for a desired reaction

3. Translate data into commands

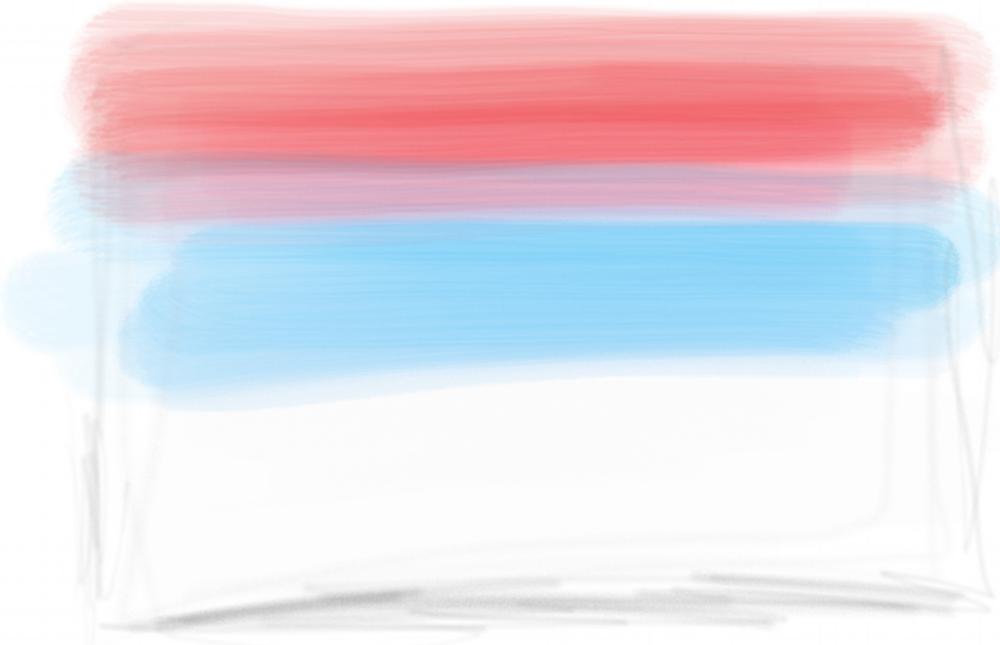


Adapt accordingly to user (recalibrate)

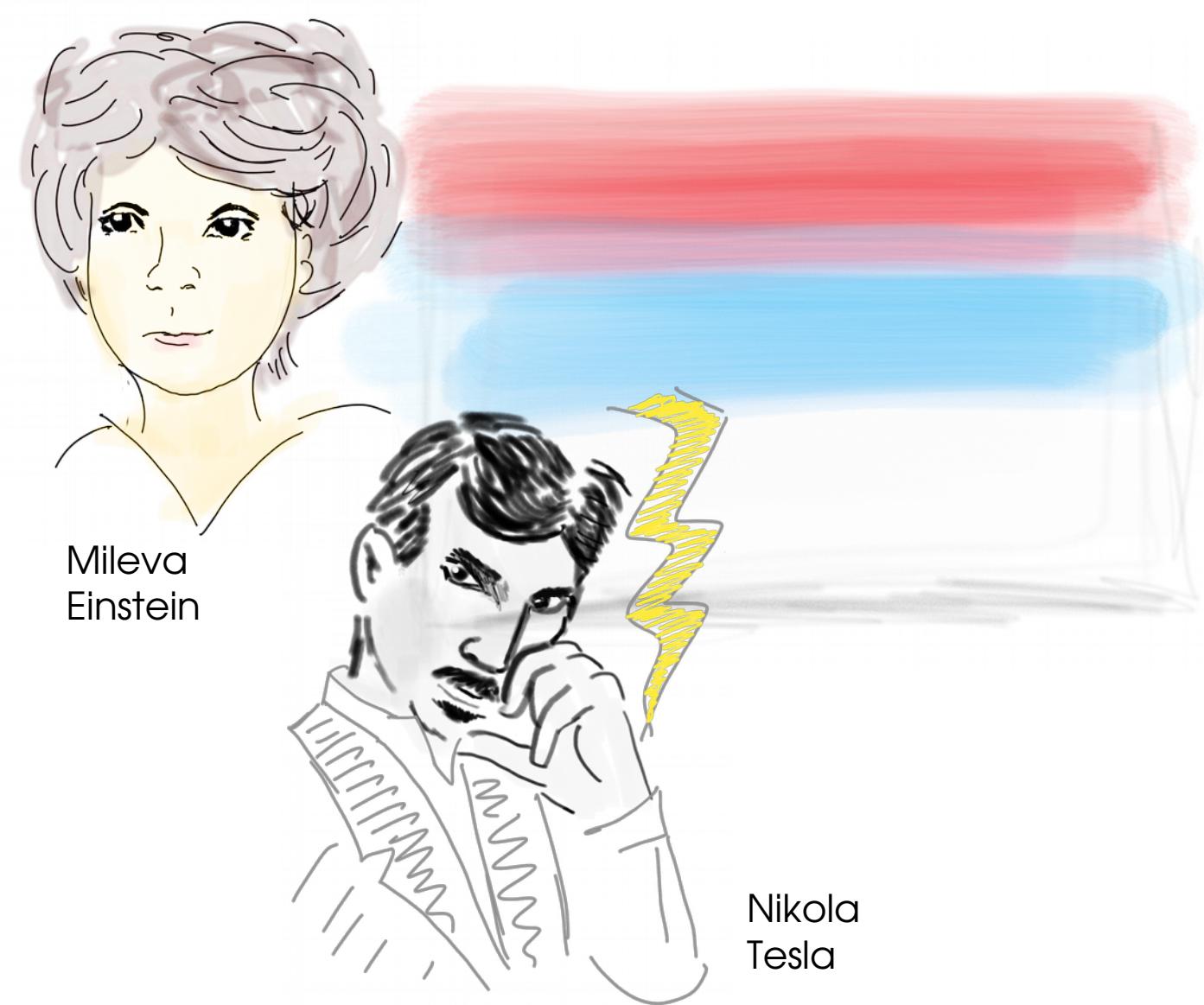


Flow as optimal user state for immersion and performance in BCI

Jelena Mladenovic
Inria Bordeaux, France
Lyon Neuroscience Research Center, France

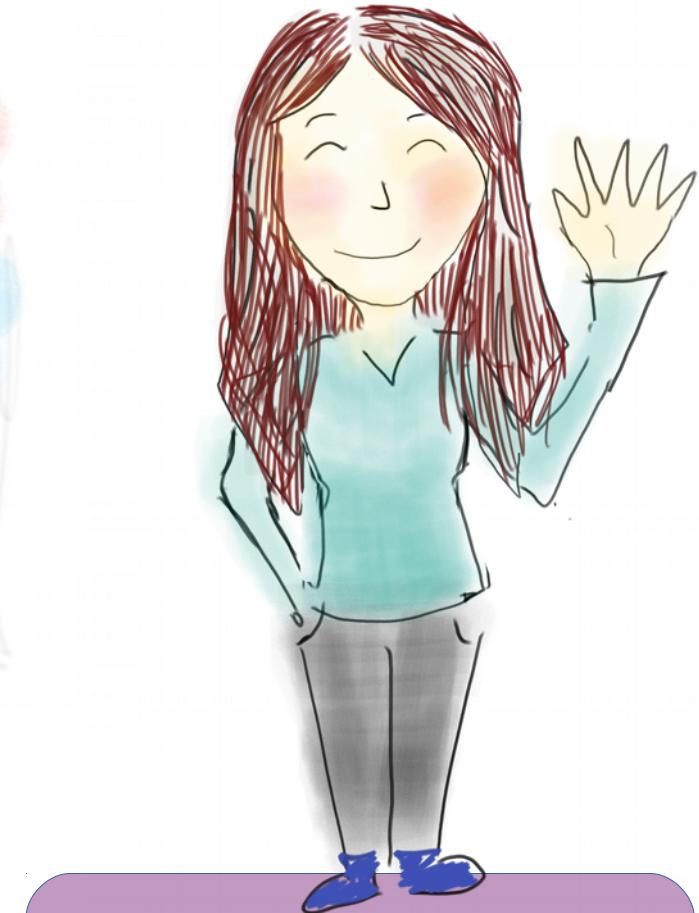


Jelena Mladenovic
Serbia

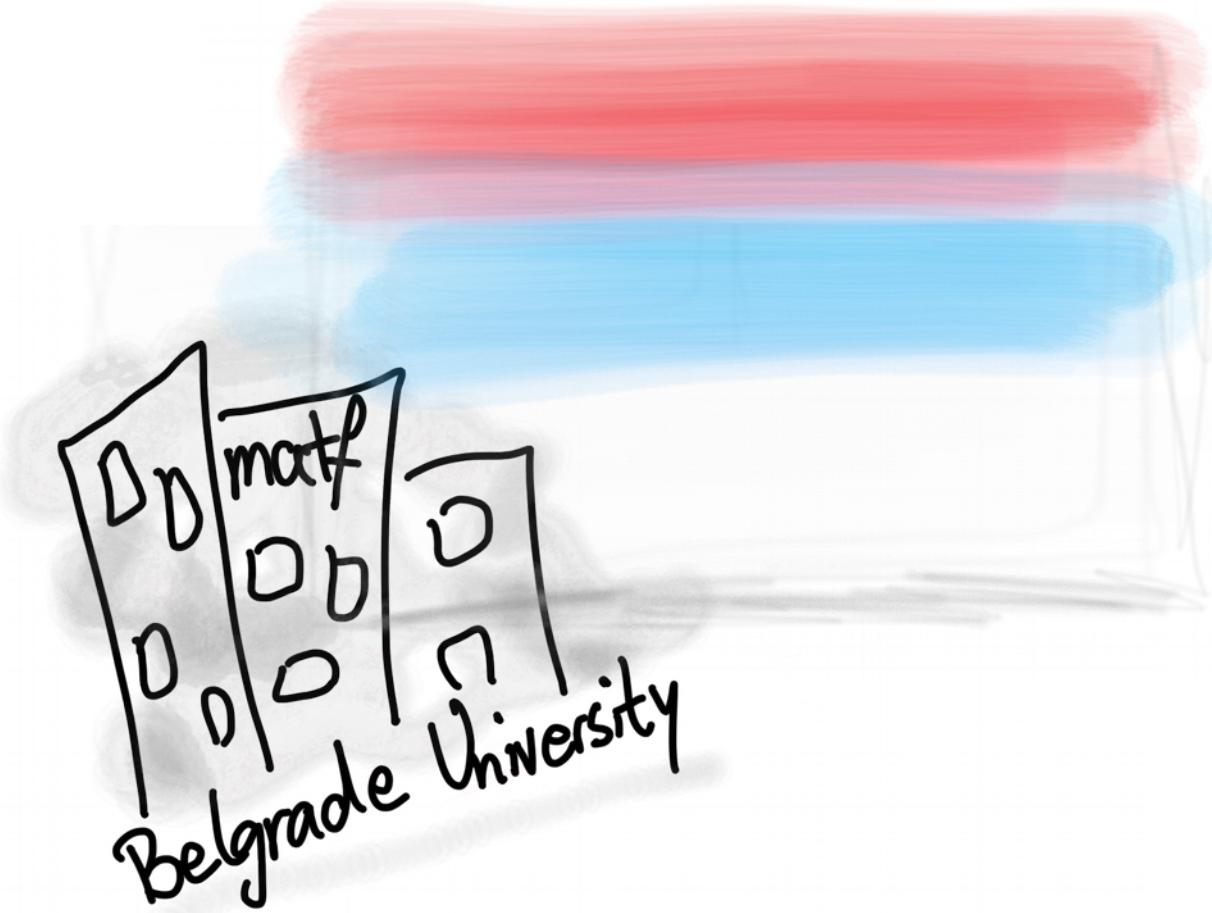


Mileva
Einstein

Nikola
Tesla



Jelena Mladenovic
Serbia



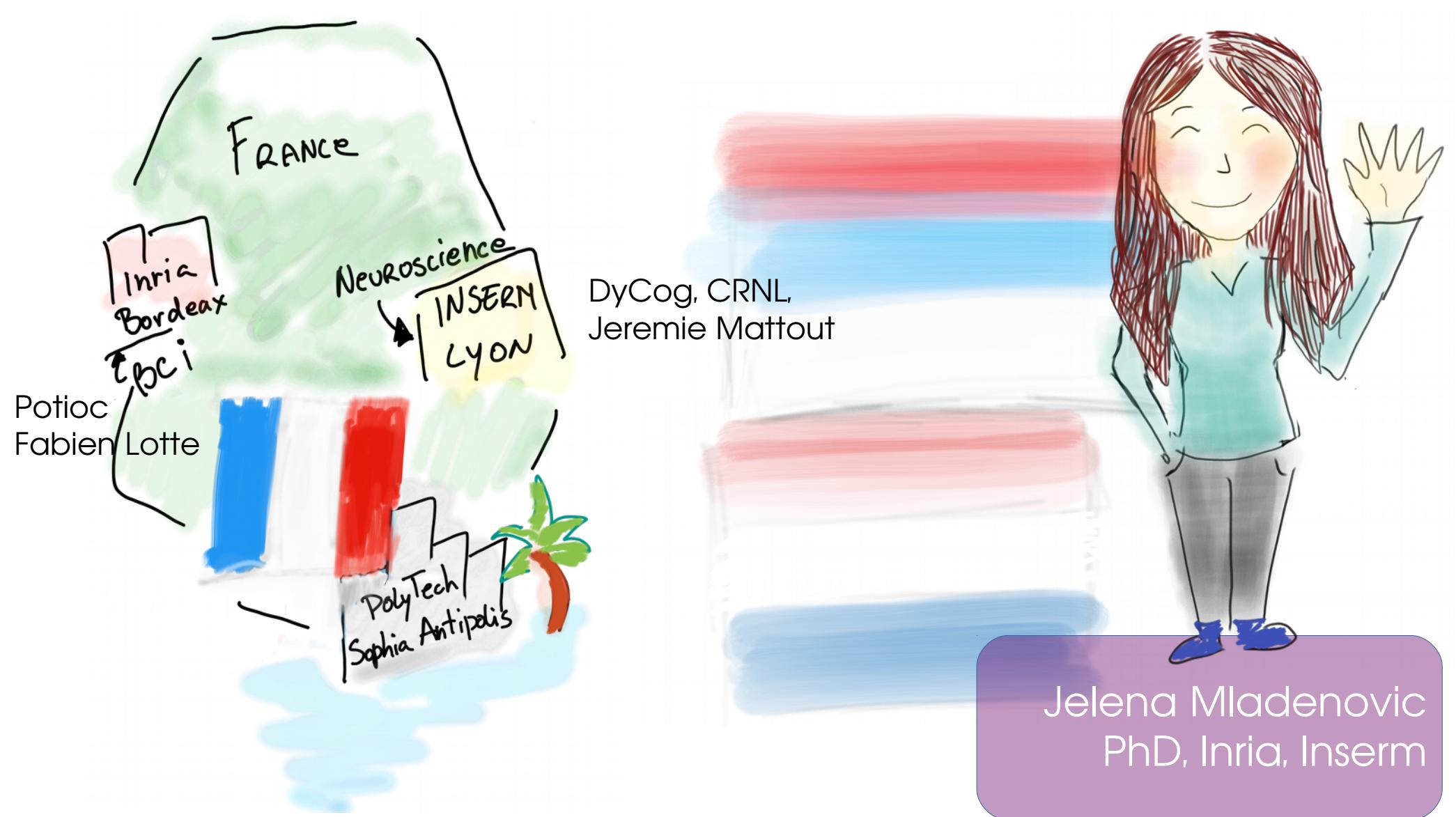
Jelena Mladenovic
Belgrade,
Mathematics Faculty

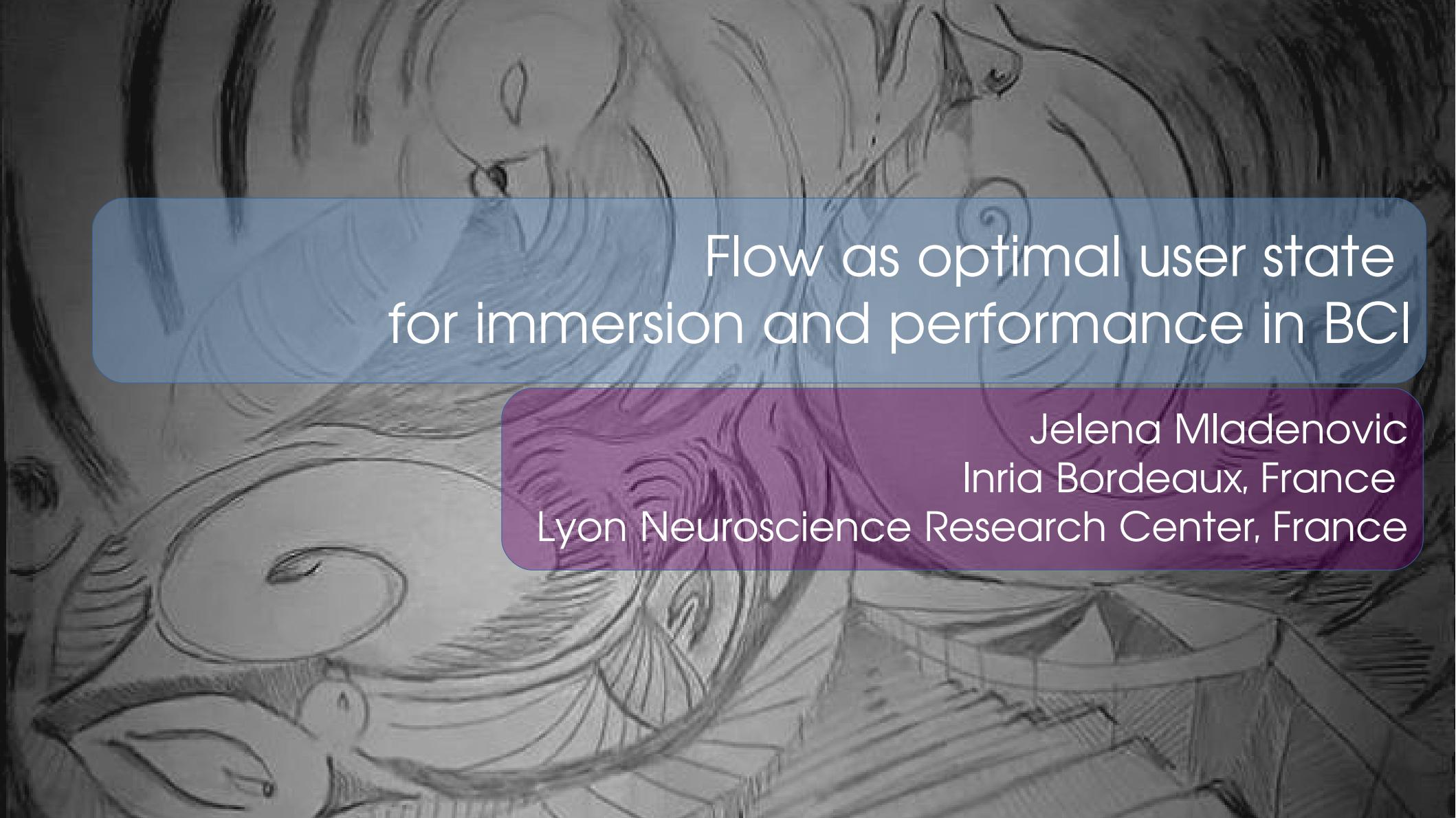


Jelena Mladenovic
Amsterdam
Computer Science



Jelena Mladenovic
Nice, Sophia Antipolis





Flow as optimal user state for immersion and performance in BCI

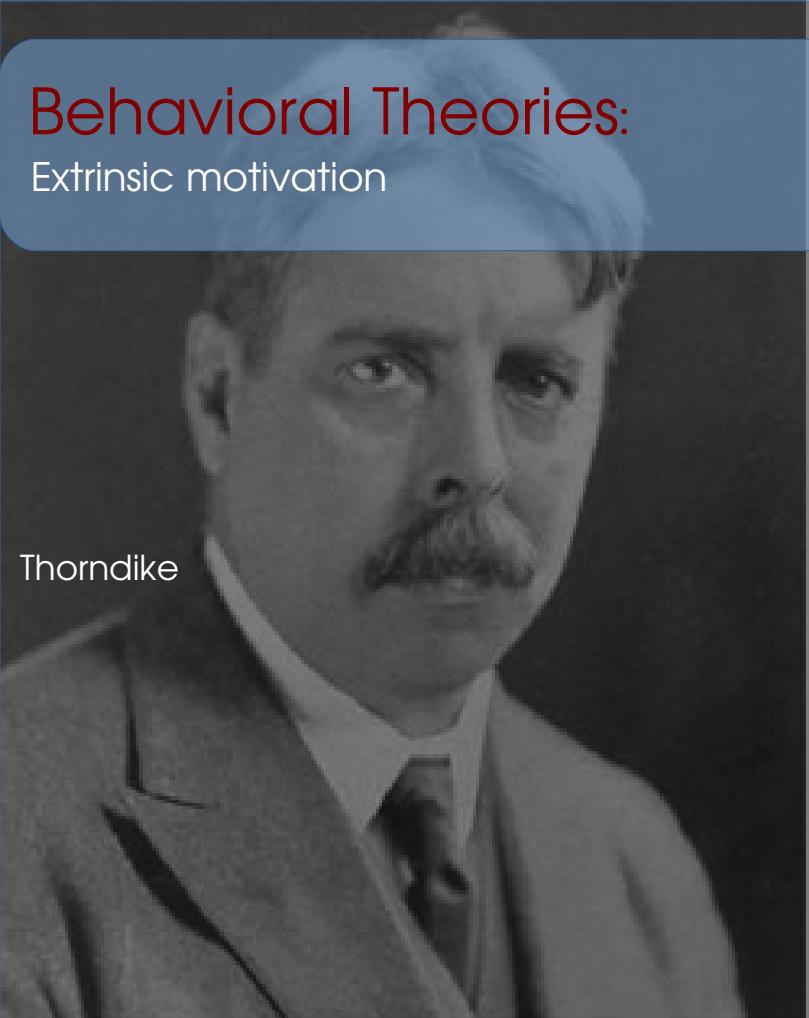
Jelena Mladenovic
Inria Bordeaux, France
Lyon Neuroscience Research Center, France

Feedback for learning

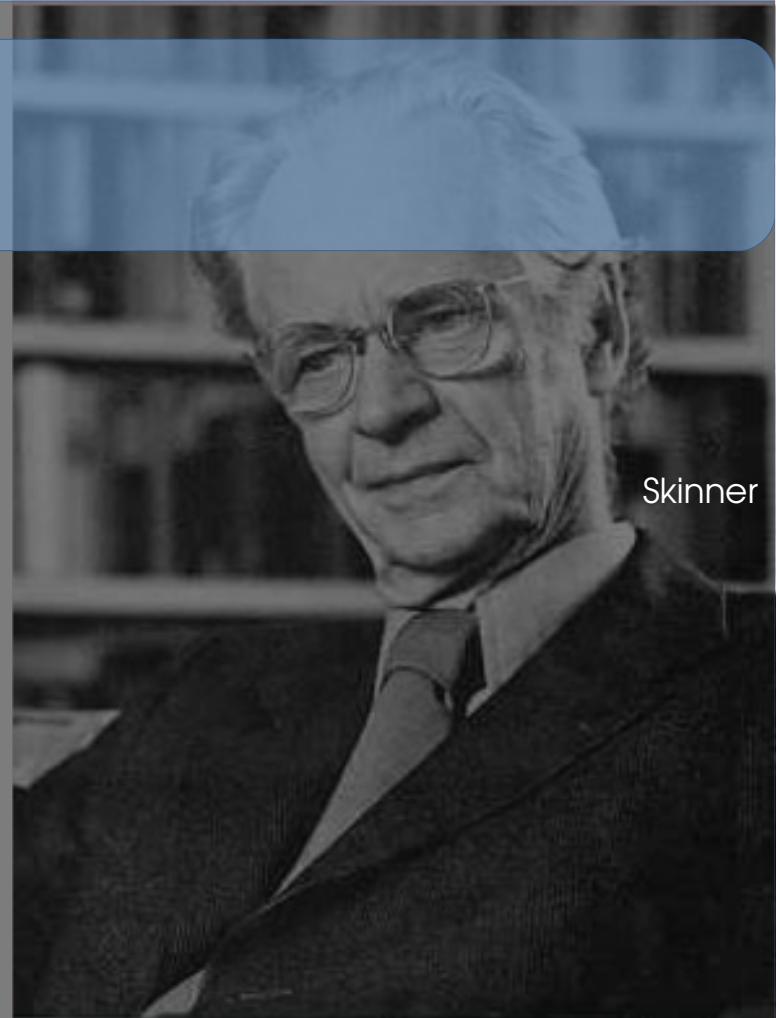
Behavioral Theories:

Extrinsic motivation

Thorndike



Skinner

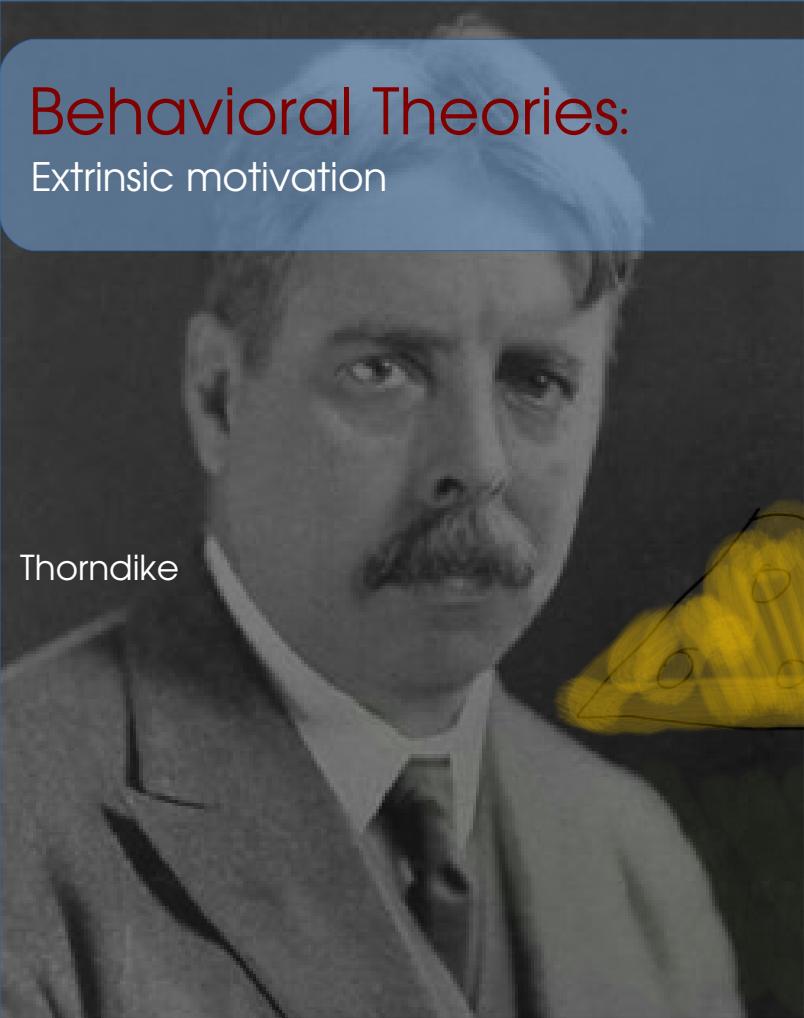


Feedback for learning

Behavioral Theories:

Extrinsic motivation

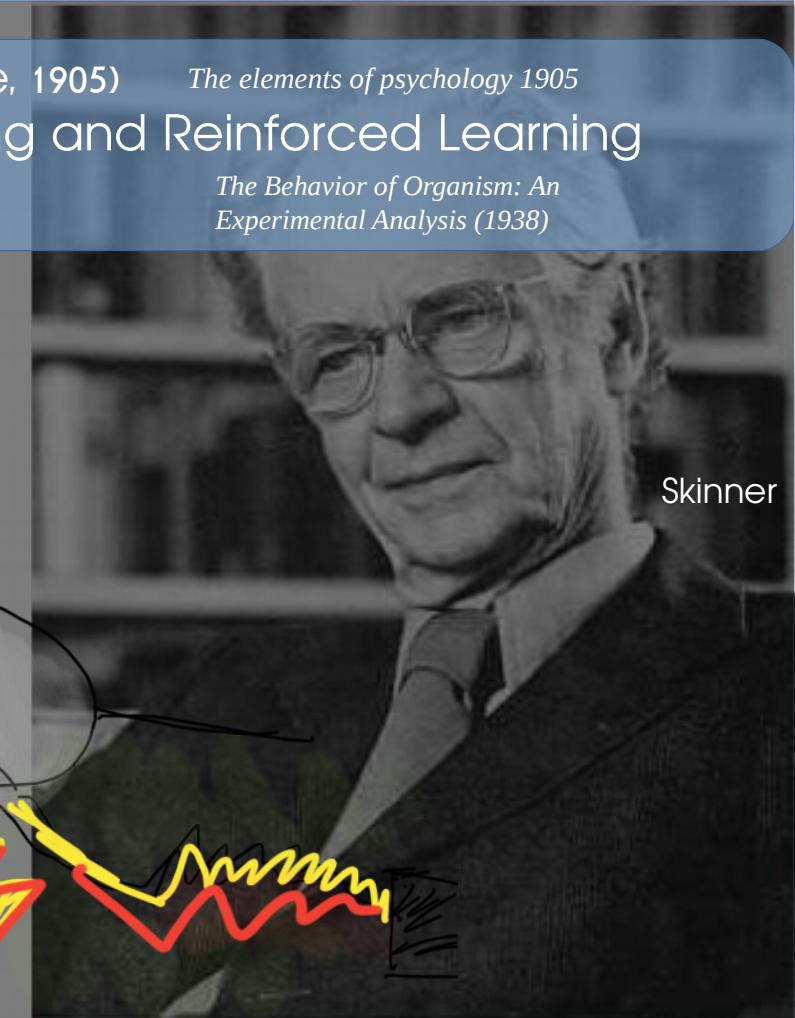
Thorndike



Law of effect (Thorndike, 1905)
Operant Conditioning and Reinforced Learning
(Skinner, 1938)

The elements of psychology 1905
The Behavior of Organism: An Experimental Analysis (1938)

Skinner

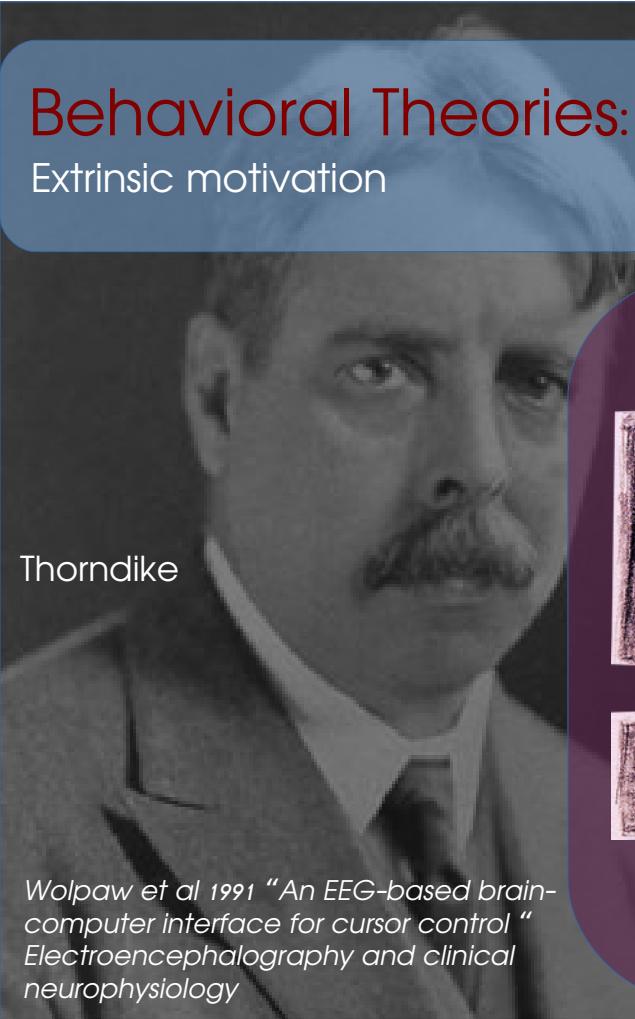


Feedback for learning

Behavioral Theories:

Extrinsic motivation

Thorndike



Law of effect (Thorndike, 1905)

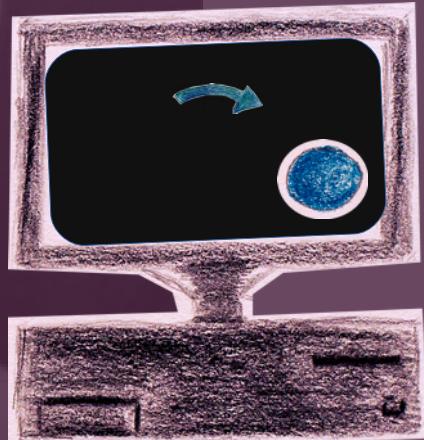
Operant Conditioning and Reinforced Learning
(Skinner, 1938)

The elements of psychology 1905

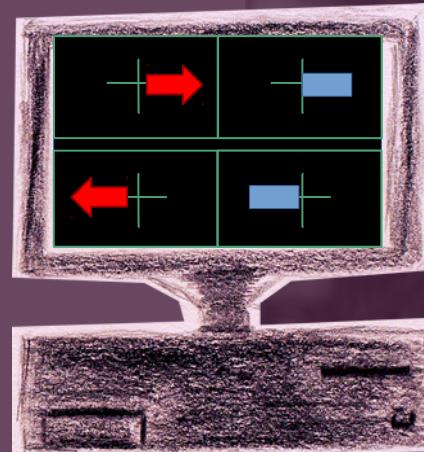
The Behavior of Organism: An Experimental Analysis (1938)

Skinner

in BCI



Wolpow

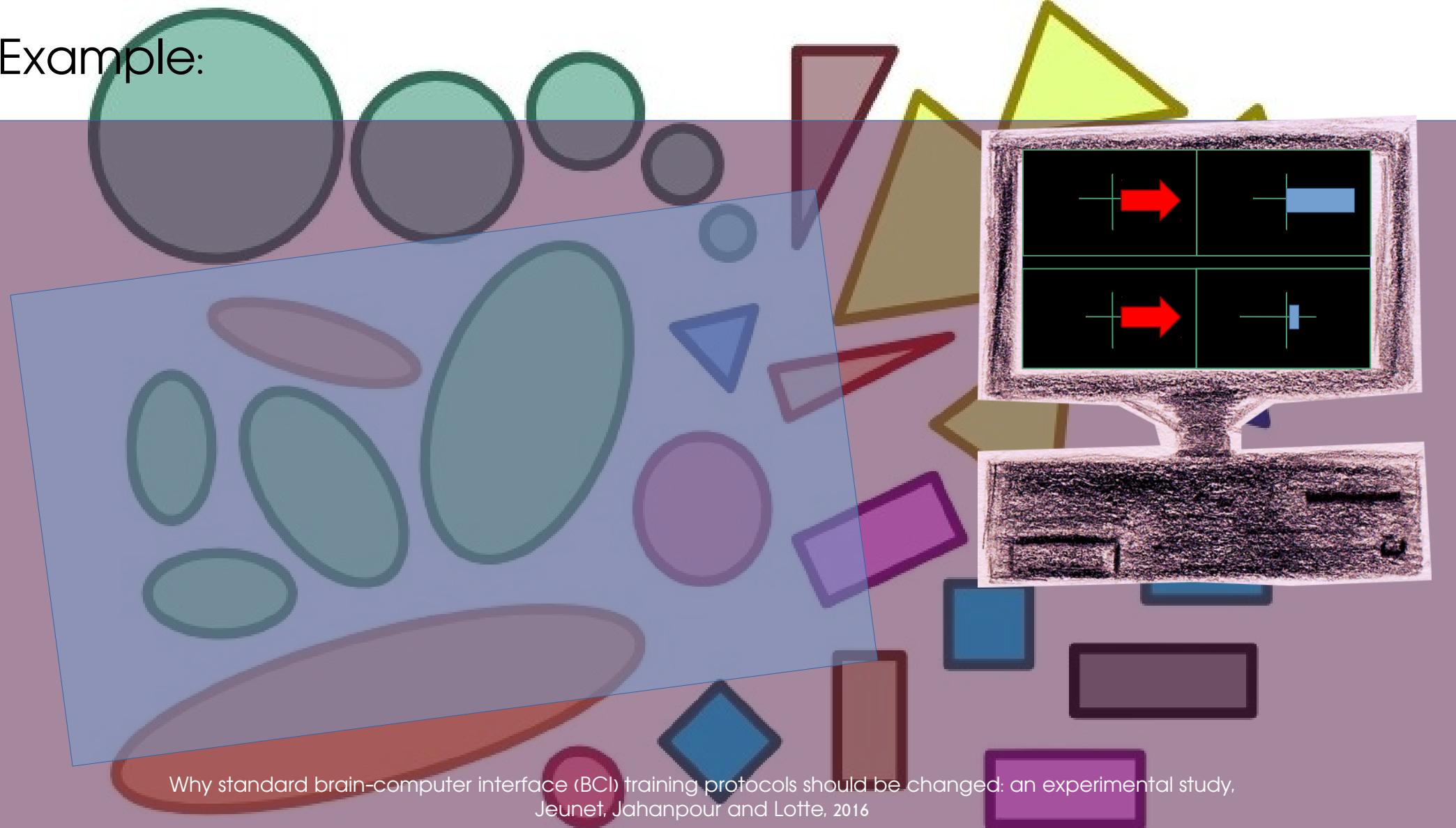


Pfurtscheller
Graz protocol

Wolpow et al 1991 "An EEG-based brain-computer interface for cursor control" *Electroencephalography and clinical neurophysiology*

Pfurtscheller et al. 1993 Brain-Computer Interface-a new communication device for handicapped persons, *journal of microcomputer application*,

Example:



Why standard brain-computer interface (BCI) training protocols should be changed: an experimental study.
Jeunet, Jahanpour and Lotte, 2016

Example:

54 subjects

17% failed

Feedback for learning

Behavioral Theories:
Extrinsic motivation

Law of effect (Thorndike, 1905)
Operant Conditioning and Reinforced Learning (Skinner, 1948)

Cognitive Developmental
Theories:
Intrinsic motivation



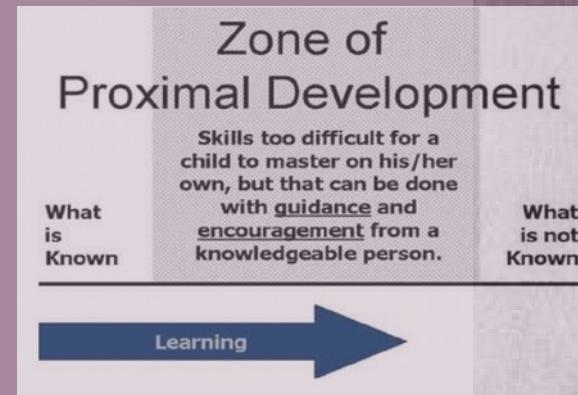
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Operant Conditioning and Reinforced Learning (Skinner, 1948)

Cognitive Developmental Theories:
Intrinsic motivation

Zone of Proximal Development
(Vygotsky, 1930)



*Mind in society : The development of higher psychological processes.
Cambridge: Harvard University Press (1980)*



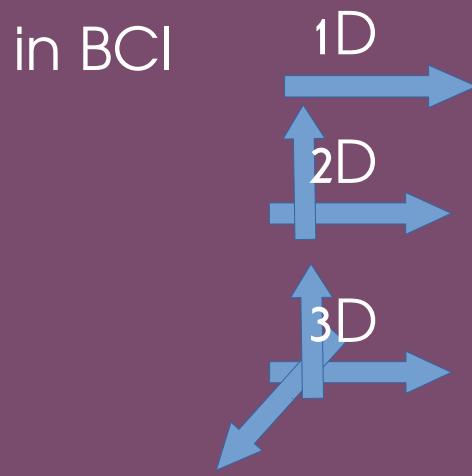
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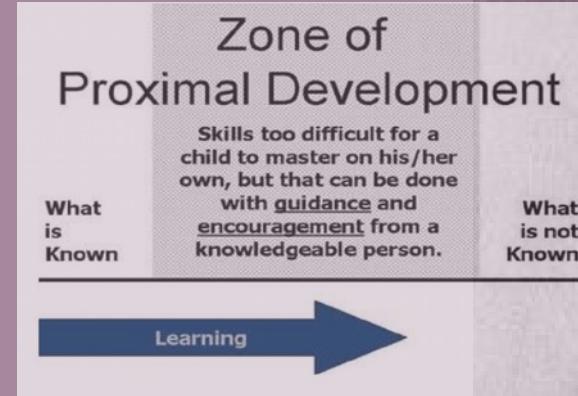
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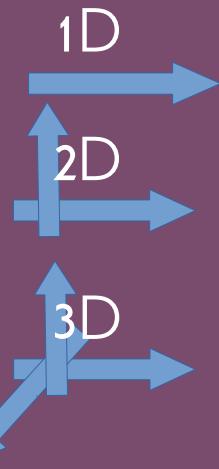
Feedback for learning

Behavioral Theories:
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Cognitive Developmental Theories:
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in BCI



McFarland, et al. (2010).
Electroencephalographic (EEG) control of three-dimensional movement.

Pillette et al. 2017., PEANUT:
Personalised Emotional Agent for Neurotechnology User-Training.

Law of effect (Thorndike, 1905)
Operant Conditioning and Reinforced Learning (Skinner, 1948)

Zone of Proximal Development
(Vygotsky, 1930)

Zone of
Proximal Development

Skills too difficult for a child to master on his/her own, but that can be done with guidance and encouragement from a knowledgeable person.

What
is
Known

What
is not
Known

Learning

*Mind in society : The development of higher psychological processes.
Cambridge: Harvard University Press (1980)*

Feedback for learning

Behavioral Theories:

Extrinsic motivation

Cognitive Developmental Theories:

Intrinsic motivation

Motivational Theories:

Extrinsic + intrinsic motivation



Malone

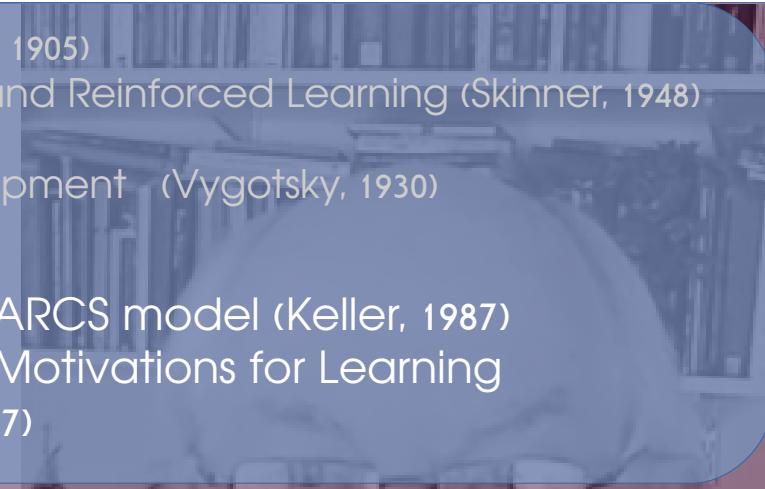
Law of effect (Thorndike, 1905)

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Zone of Proximal Development (Vygotsky, 1930)

Instructional Design - ARCS model (Keller, 1987)

Taxonomy of Intrinsic Motivations for Learning (Malone & Lepper, 1987)



Keller

Feedback for learning

Behavioral Theories:

Extrinsic motivation

Cognitive Developmental Theories:

Intrinsic motivation

Motivational Theories:

Extrinsic + intrinsic motivation



Malone

Law of effect (Thorndike, 1905)

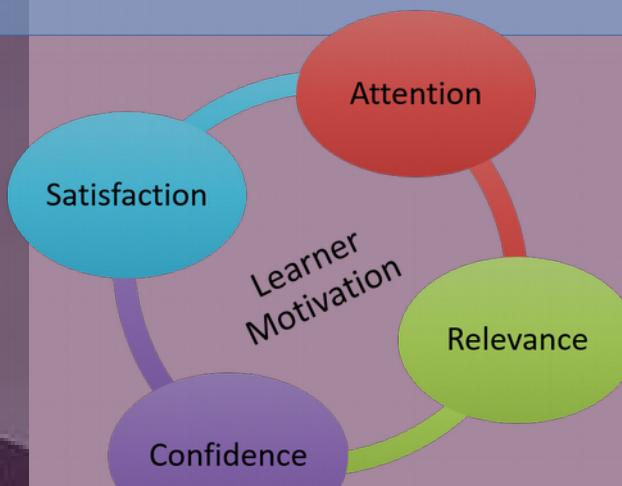
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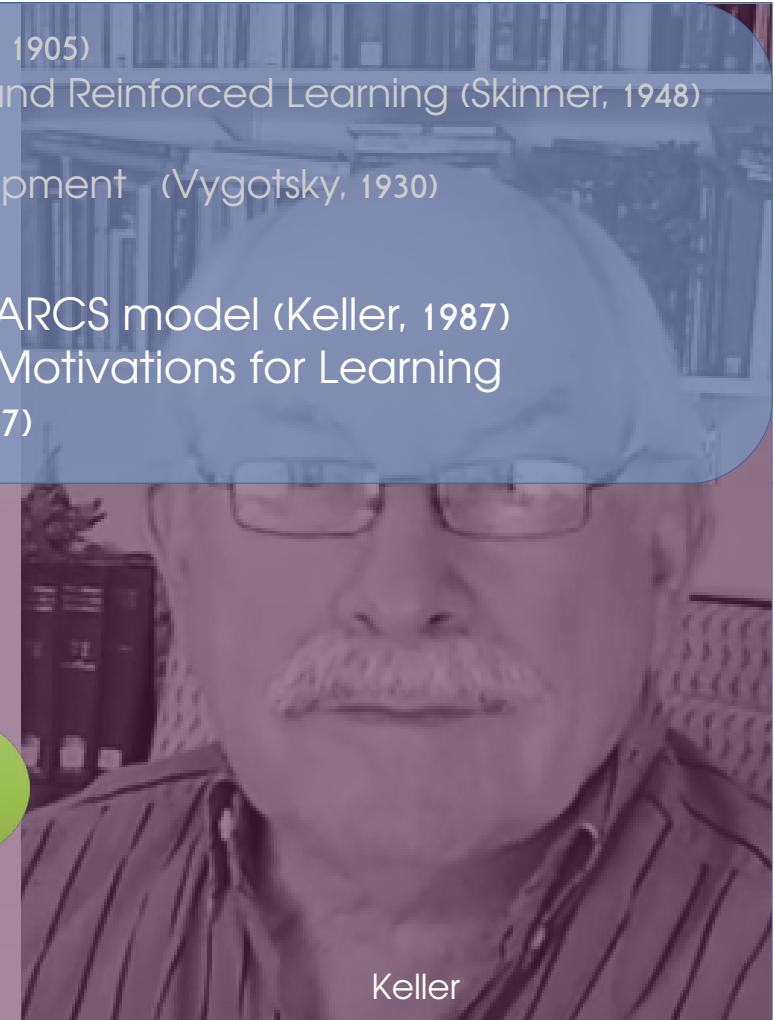
Instructional Design - ARCS model (Keller, 1987)

Taxonomy of Intrinsic Motivations for Learning

(Malone & Lepper, 1987)



Keller, *Strategies for stimulating the motivation to learn*, ISPI 1987



Keller

Feedback for learning

Social/ collaborative

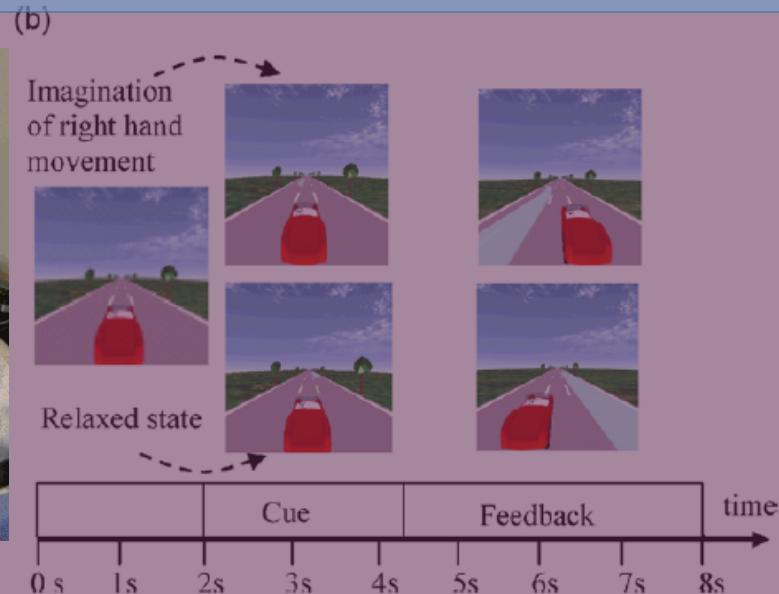


J. Erp, F. Lotte, M. Tangermann, "Brain- Computer Interfaces: Beyond Medical Applications", Computer, vol. 45, no. 4, 2012

Feedback for learning

Social/ collaborative

Playful



J. Erp, F. Lotte, M. Tangermann, "Brain- Computer Interfaces: Beyond Medical Applications", Computer, vol. 45, no. 4, 2012

Ron-Angevin et al. Brain-computer interface: Changes in performance using virtual reality techniques, Neuroscience Letters 2008

Performance increases with user experience/motivation

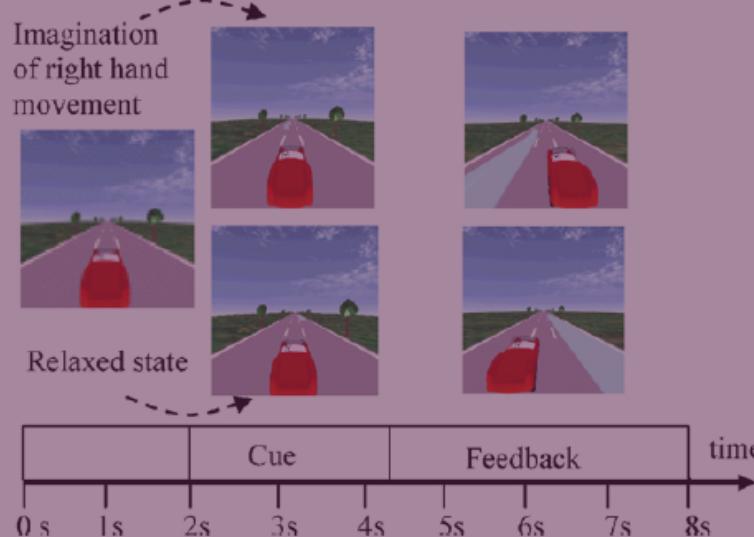
Feedback for learning

Social/ collaborative

Playful

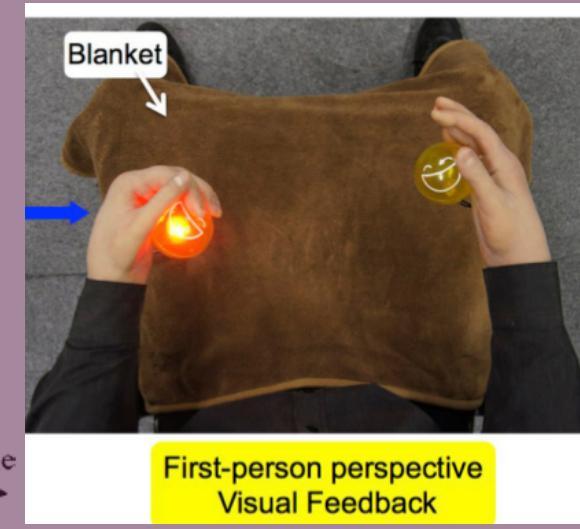
Immersive/ body ownership

(b)



J. Erp, F. Lotte, M. Tangermann, "Brain- Computer Interfaces: Beyond Medical Applications", Computer, vol. 45, no. 4, 2012

Ron-Angevin et al. Brain-computer interface: Changes in performance using virtual reality techniques, Neuroscience Letters 2008



Alimardani, Shuichi, and Hiroshi. "Effect of biased feedback on motor imagery learning in BCI-teleoperation system." Frontiers in systems neuroscience 8 (2014): 52

Performance increases with confidence/motivation

Desired user states:

- 1. Sense of Agency
- 2. Attention
- 3. Immersion
- 4. Pleasure

Self-rewarding (autotelic) experience
(intrinsic motivation)

Optimal State?

1. Sense of Agency
2. Attention
3. Immersion
4. Pleasure

Self-rewarding (autotelic) experience
(intrinsic motivation)



Flow

FLOW



- Mihaly Csikszentmihalyi, (1975)
Flow: The Psychology of Optimal Experience

FLOW

“...It is when we act freely, for the sake of the action itself rather than for ulterior motives, that we learn to become more than what we were.”

playful content

- Mihaly Csikszentmihalyi, (1975)
Flow: The Psychology of Optimal Experience

FLOW

“...It is when we act freely, for the sake of the action itself rather than for ulterior motives, that we learn to become more than what we were.”

“...the self expands through acts of self forgetfulness.”

Immersive,
playful content

FLOW

“...It is when we act freely, for the sake of the action itself rather than for ulterior motives, that we learn to become more than what we were.”

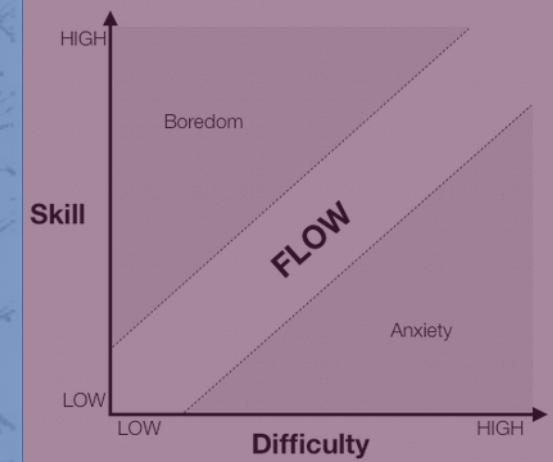
“...the self expands through acts of self forgetfulness.”

“Enjoyment appears at the boundary between boredom and anxiety, when the challenges are just balanced with the person's capacity to act.”

- Mihaly Csikszentmihalyi, (1975)
Flow: The Psychology of Optimal Experience

Immersive,
playful content

Matching task
difficulty with skill



Reaching Sense of Agency

“It is not the skills we actually have that determine how we feel but the ones we think we have.”

1. Body-ownership illusion
2. Adaptive biased feedback

Experiment: Tux Flow

Jeremy Frey



14 participants

Engaging,
Playful environment



14 participants

Engaging,
Playful environment



Experiment: Tux Flow

Jeremy Frey



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



Experiment: Tux Flow

Jeremy Frey



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



Intrinsic + Extrinsic
Motivation



Intrinsic + Extrinsic
Motivation

Experiment: Tux Flow

Jeremy Frey



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



Intrinsic + Extrinsic
Motivation



Experiment: Tux Flow

Jeremy Frey



14 participants

Engaging,
Playful environment

Clear goals and
immediate feedback



14 participants

Engaging,
Playful environment



Clear goals and
immediate feedback

Intrinsic + Extrinsic
Motivation



Intrinsic + Extrinsic
Motivation

Online **adaptive**
task difficulty
(biased feedback)

Experiment: Tux Flow

Jeremy Frey

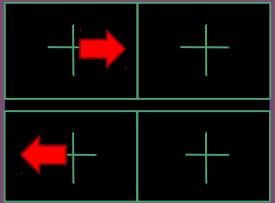


14 participants

Not Adapted
Feedback



~8min



6 x 3min



14 participants

Adapted
Feedback



Experiment: Tux Flow

Jeremy Frey

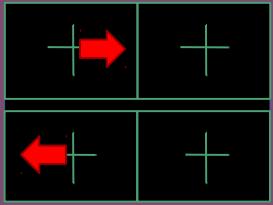


14 participants

Not Adapted
Feedback



~8min



6 x 3min



14 participants

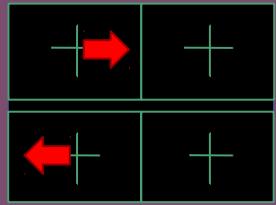
Adapted
Feedback



6 x 3min



~8min



Experiment: Tux Flow

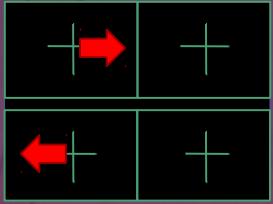
Jeremy Frey



14 participants

Not Adapted
Feedback

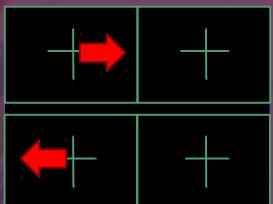
~8min



6 x 3min



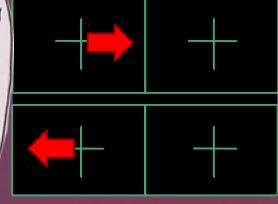
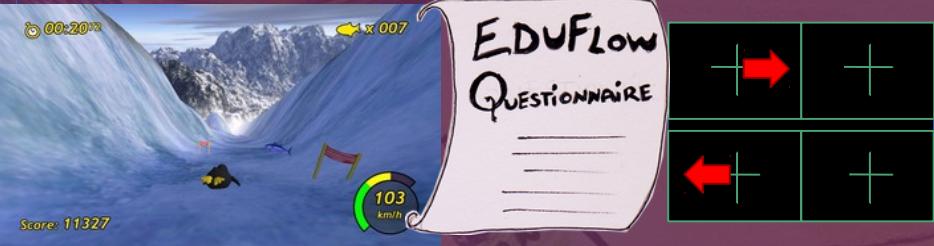
6 x 3min



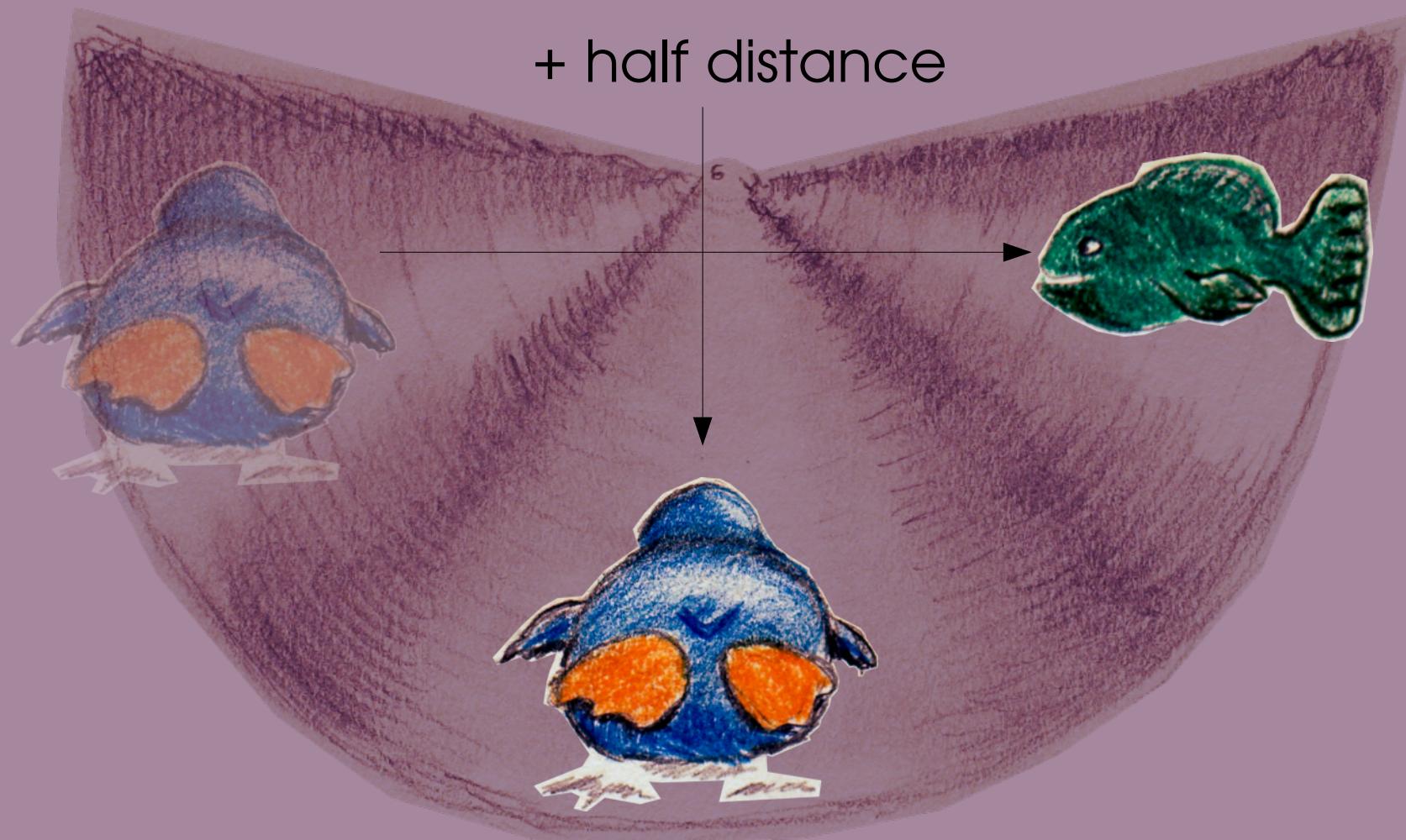
14 participants

Adapted
Feedback

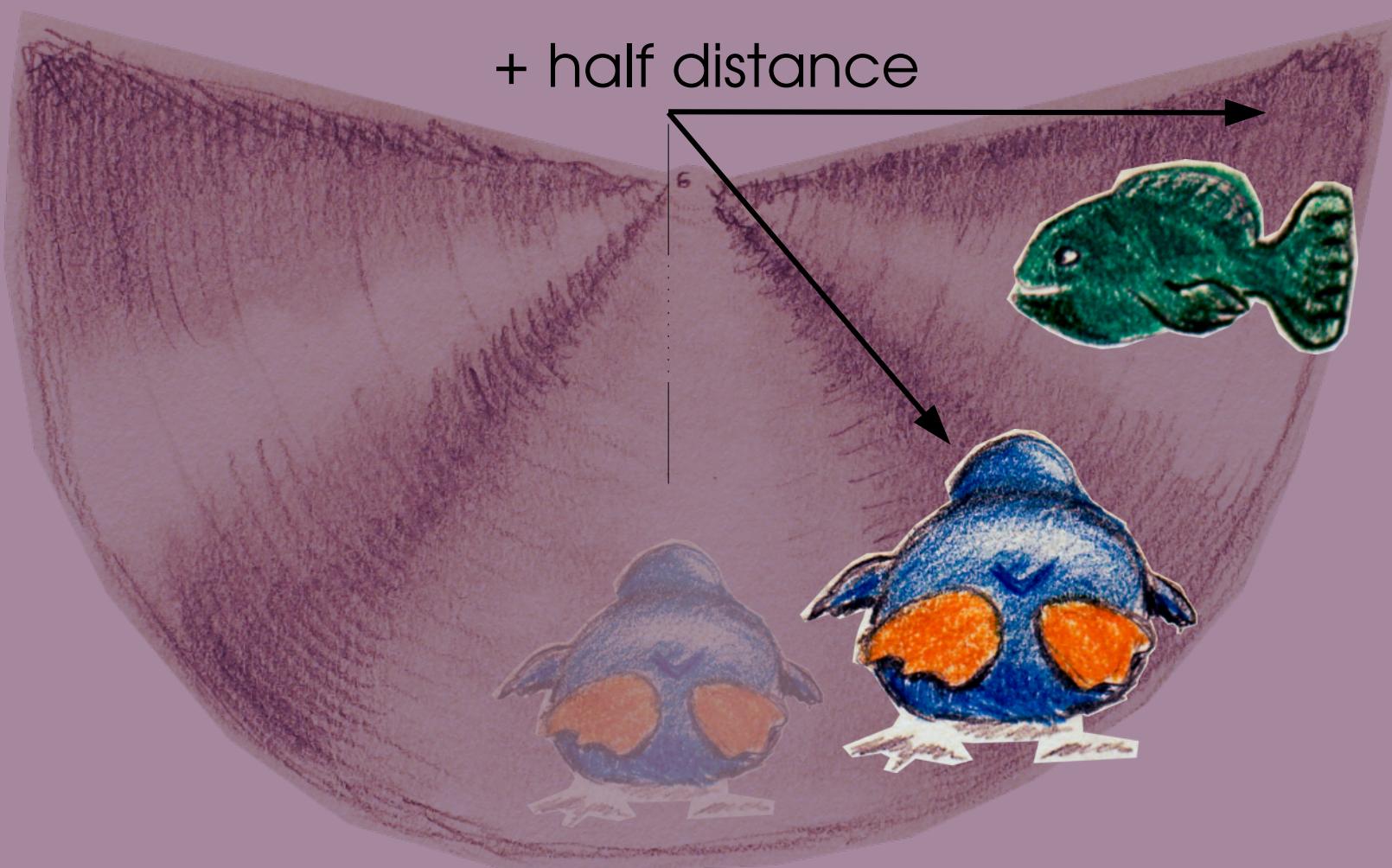
~8min



Biased Feedback (positive)



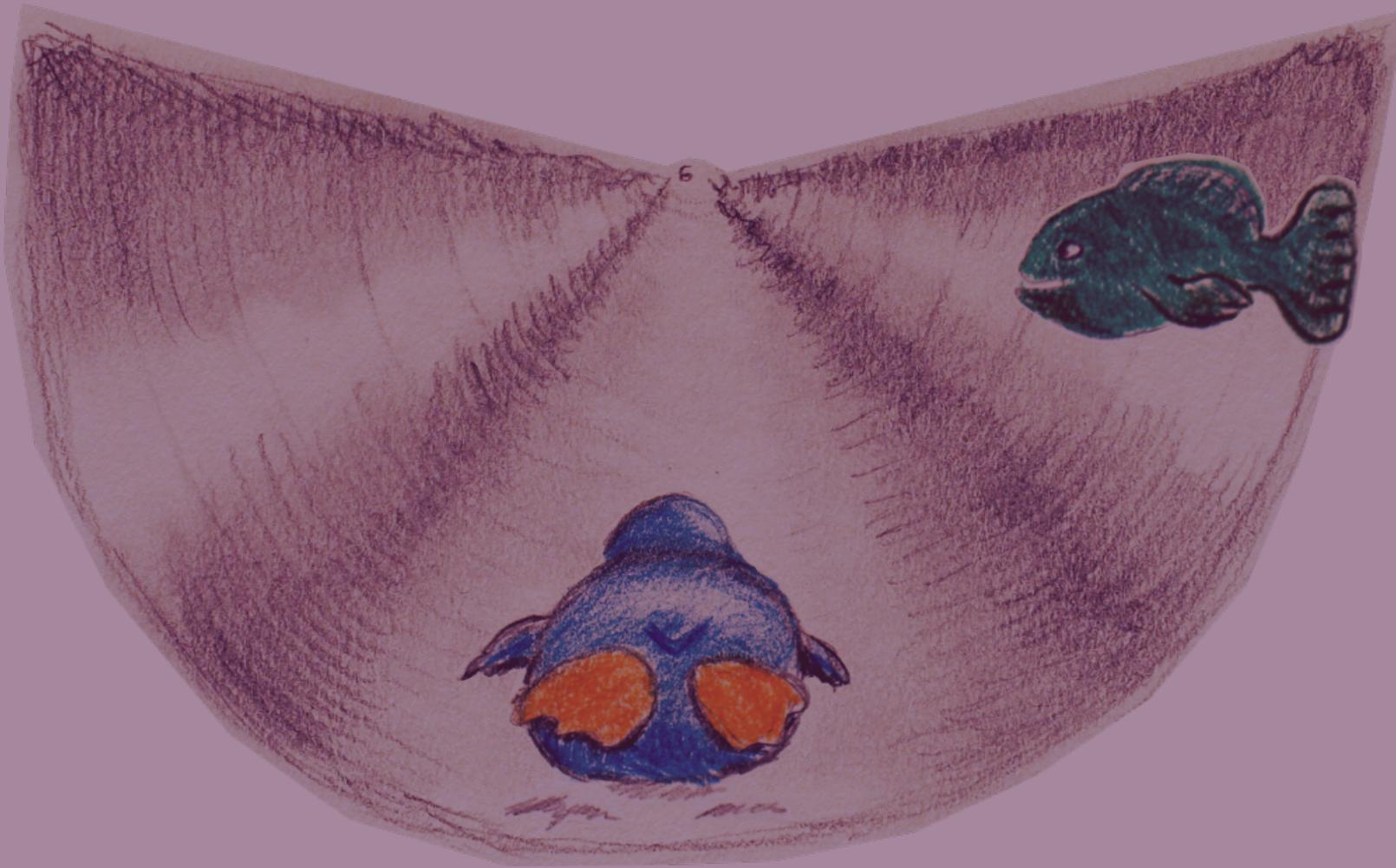
Biased Feedback (positive)



Biased Feedback (negative)



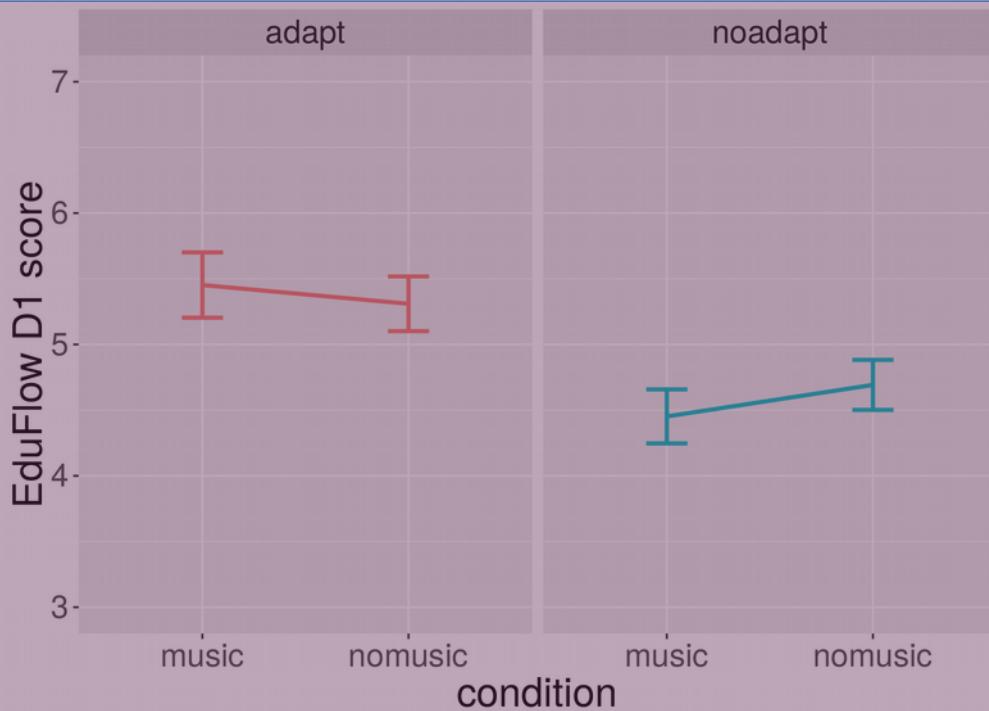
Video



Results

1. Participants felt more in flow in the adapt condition

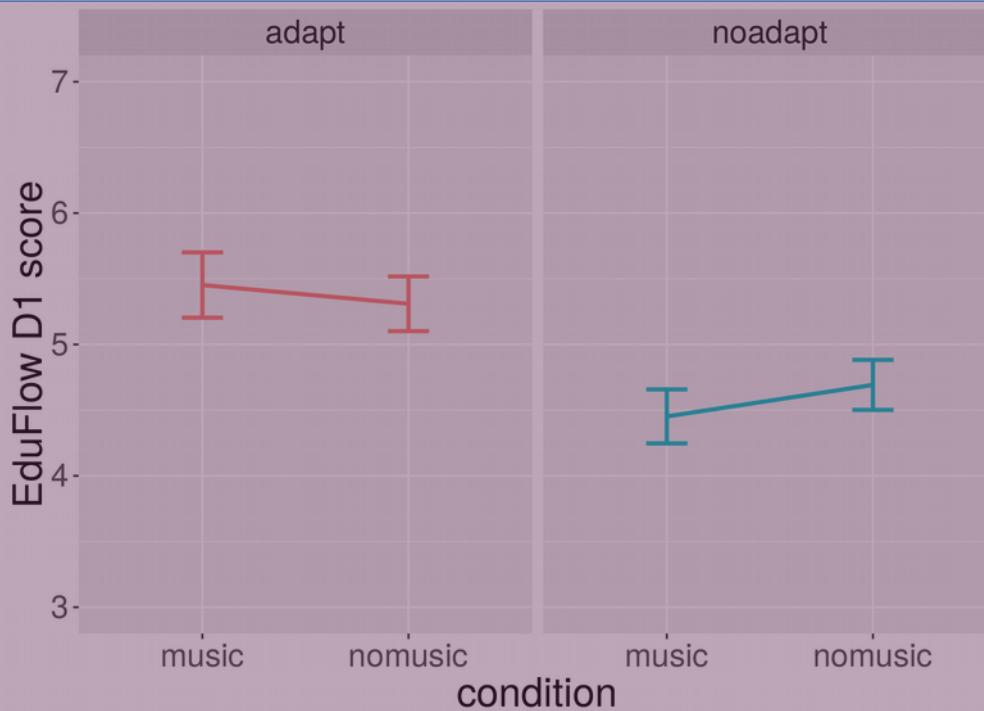
*Flow assessed with EduFlow Questionnaire (Heutte 2016)



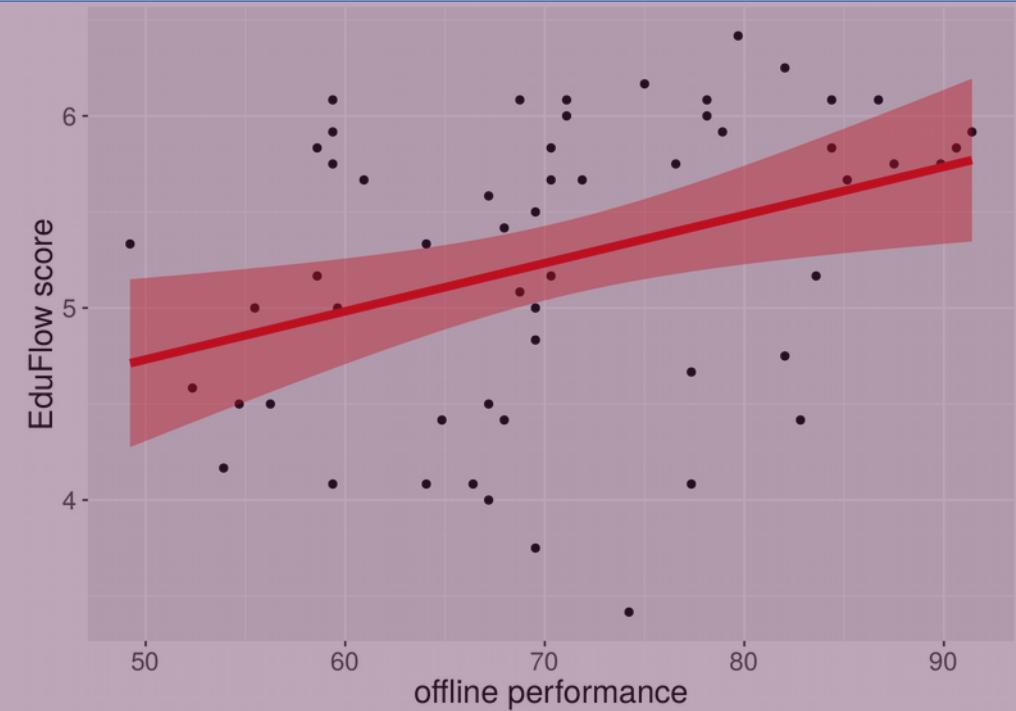
Results

1. Participants felt more in flow in the adapt condition
2. Correlation between offline performance and flow state

*Flow assessed with EduFlow Questionnaire (Heutte 2016)



*Offline performance – k-fold cross-validation

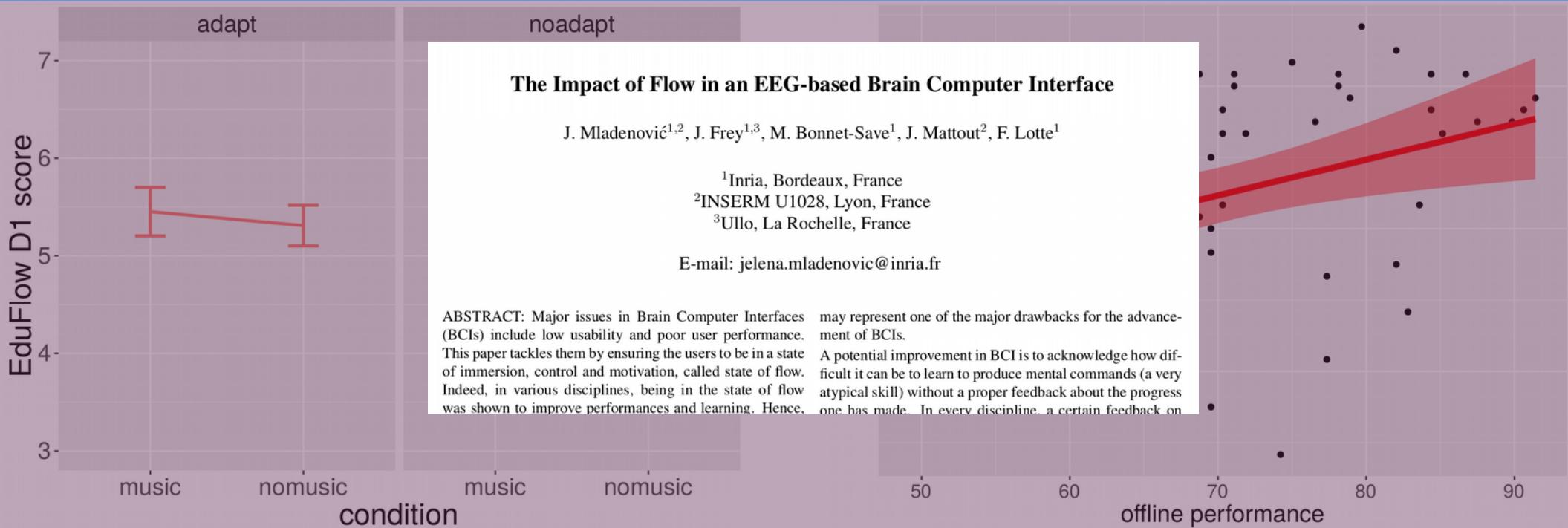


Results

1. Participants felt more in flow in the adapt condition
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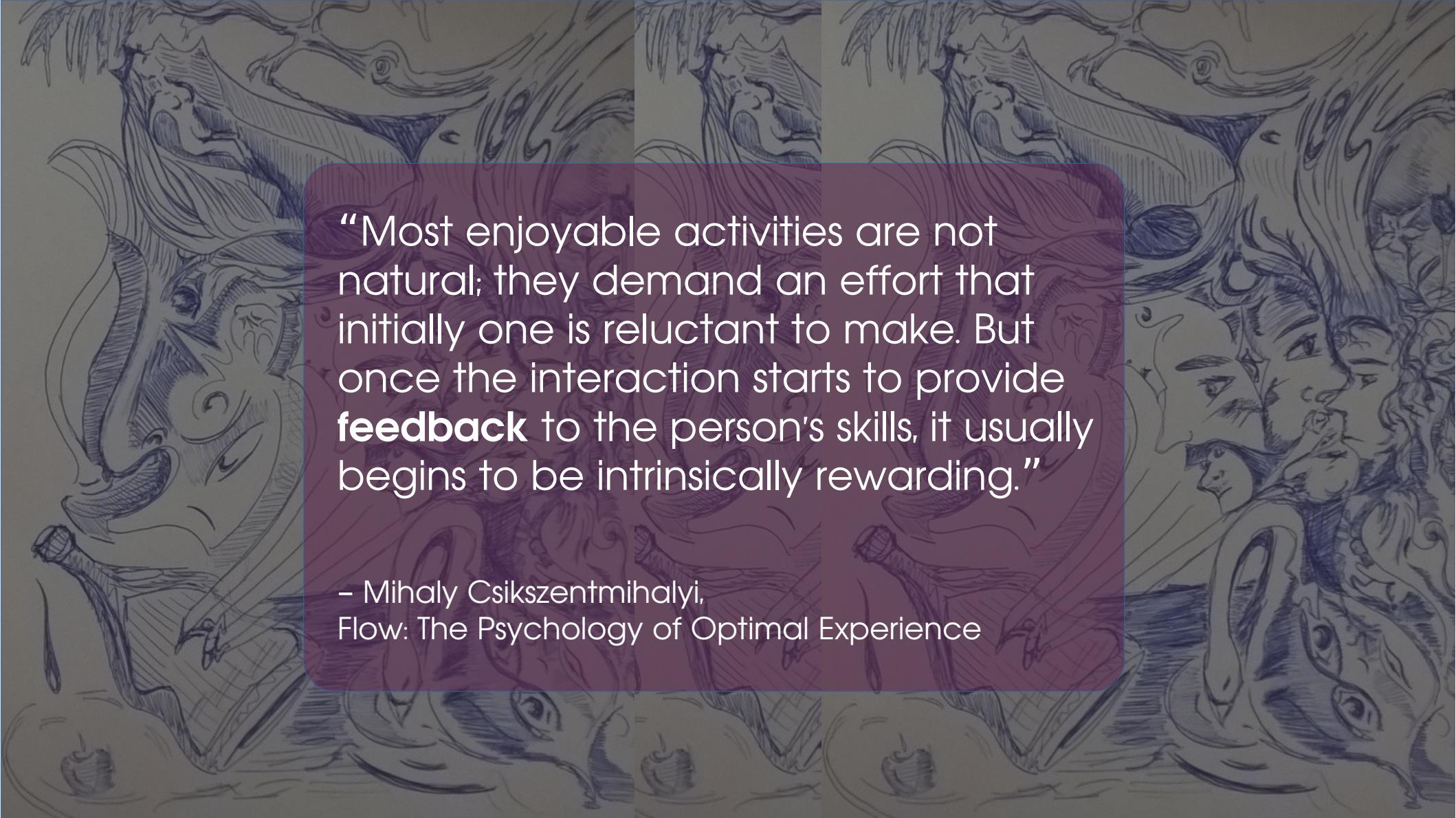
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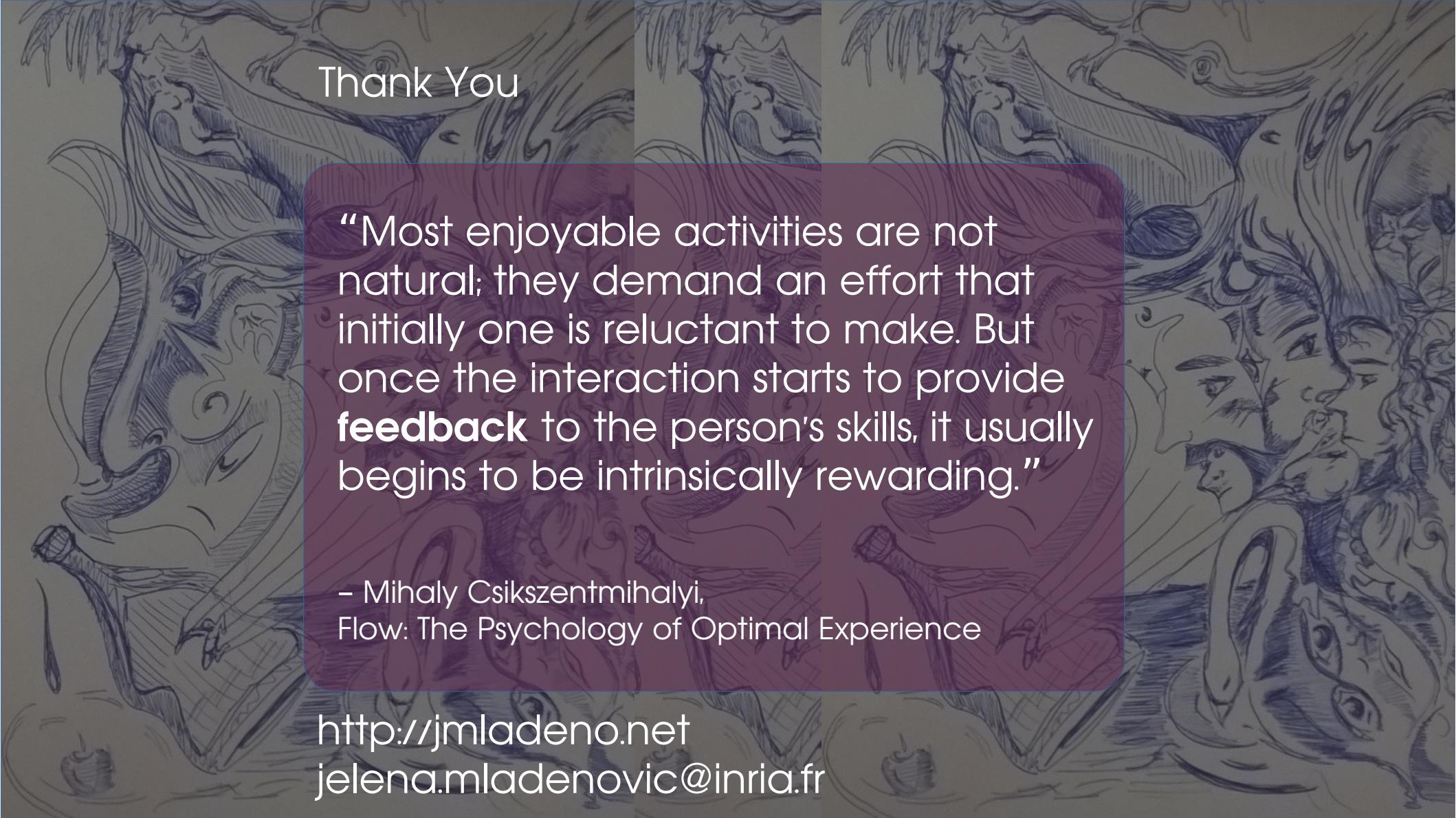
Summary

- Evolution of feedback in BCI regarding educational theories
- Flow theory -- the next step
- Adaptive and immersive feedback as means to reach flow in BCI and increase performance



“Most enjoyable activities are not natural; they demand an effort that initially one is reluctant to make. But once the interaction starts to provide **feedback** to the person’s skills, it usually begins to be intrinsically rewarding.”

– Mihaly Csikszentmihalyi,
Flow: The Psychology of Optimal Experience



Thank You

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Flow: The Psychology of Optimal Experience

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Appendix:

Methods and Materials

- 32 electrodes Brain Product;
- 2 class Motor Imagery BCI;
- CSP spatial filter;
- Probabilistic SVM classifier output modified in real-time providing biased feedback,
- 3 music songs
- Tux Racer, open source video game, being controlled by a virtual joystick connected to openvibe

NB. classifier accuracy presents user performance

Appendix:

Problem:

Not balanced groups. Non-adaptive group more advanced from the beginning than the adaptive group.

No corr between online perf and flow because of the diff of environments in train and test (graz and tux)

