Using Brain–Computer Interfaces as a Tool to Improve Athletes’ Performance.

Post-Doc in Collaboration with ——

Anatole Lécuyer, Ferran Argelaguet – Inria
Benoît Bideau, Richard Kulpa – Univ. Rennes II / ENS
Jose del R. Millán, Ricardo Chavarriaga – EPFL

Camille Jeunet

Workshop of the EPFL–Inria International Lab ——
2017–02–07
Part 0

# Background
Background
Background

Studied Cognitive Sciences @Bordeaux & @Montreal
Background

PhD in Cognitive Sciences
@Bordeaux & @Bristol/Brighton

Co-Supervised by:
F. Lotte, B. N’Kaoua, M. Hachet & S. Subramanian
Background

Post-Doc EPFL/Inria International Lab
@Rennes & @Genève
Part I

# PhD Project

Research Focus – EEG-based MI–BCIs

MI–BCI = Mental–Imagery based Brain–Computer Interface

[Wolpaw & Wolpaw (2012)]
Research Focus – EEG–based MI–BCIs
Research Focus – EEG-based MI-BCIs
Research Focus – EEG-based MI–BCIs
Research Focus – EEG–based MI–BCIs

[Wolpaw & Wolpaw (2012)]
Research Focus – EEG–based MI–BCIs
Research Focus – EEG–based MI–BCIs

[Wolpaw & Wolpaw (2012)]
Research Focus – EEG-based MI–BCIs
Research Focus – EEG-based MI-BCIs
MI-BCIs are Not Reliable Enough

[Lotte et al. (2013) – Frontiers in Neuroscience]
MI–BCIs are **Not Reliable Enough**

Sensors & Signal Processing Algorithms are Imperfect

Users do not Manage to Acquire BCI skills

[Lotte et al. (2013) – Frontiers in Neuroscience]
MI–BCIs are Not Reliable Enough

Signal Processing Algorithms are Imperfect

Users do not Manage to Acquire MI–BCI skills

[Lotte et al. (2013) – Frontiers in Neuroscience]
What are MI–BCI skills?

[Jeunet et al. (2016) – Wiley–Iste]
What are MI–BCI skills?

Generate clear MI
What are MI–BCI skills?

[Jeunet et al. (2016) – Wiley-Iste]
What are MI–BCI skills?
What are MI–BCI skills?
What are MI–BCI skills?

Stable & Distinct brain patterns

[Jeunet et al. (2016) – Wiley–Iste]
What are MI–BCI skills?

Generate clear MI
What are MI–BCI skills?

Process the feedback to improve MI

Generate clear MI

[Jeunet et al. (2016) – Wiley-Iste]
Current Training Protocols are theoretically Inappropriate.
Objective

Improving MI–BCI User–Training.
Objective

Understanding & Improving MI–BCI User–Training.

[Kübler et al. (2014) – PLoS One]
Roadmap
Roadmap

Cognitive Factors

Personality

Generate clear MI
Roadmap

- Feedback
  - Process the feedback to improve MI
- Cognitive Factors
- Personality
  - Generate clear MI
Roadmap

How Do **Cognitive Factors** Impact MI–BCI Performance?

How Does **Personality** Impact MI–BCI Performance?

How Does Standard **Feedback** Impact MI–BCI Performance?
Roadmap

- How Do **Cognitive Factors** Impact MI–BCI Performance?
- How Does **Personality** Impact MI–BCI Performance?
- How Does Standard **Feedback** Impact MI–BCI Performance?
# Roadmap

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- **How Do **Cognitive Factors** Impact MI–BCI Performance?**
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# Cognitive Factors

- **Part I - Influential Factors**

## STUDY #1

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<td># Participants</td>
<td>18</td>
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## STUDY #2

| Training Duration | 1 x 5 x 40 |  |
| # Participants | 20 |  |

[Friedrich et al., 2013 – PLOS One]
[Jeunet et al., 2015 – PLOS One]
Cognitive Factors

- Part I - Influential Factors

STUDY #1

Correlation MI–BCI Performance & Mental Rotation Scores

> $r = 0.696$ – $p < 0.005$

[Jeunet et al., 2016 – J. Neural Engineering]

STUDY #2

Correlation MI–BCI Performance & Mental Rotation Scores

> $r = 0.464$ – $p < 0.05$

[Mental Rotation test, Vandenberg, 1978]

[Jeunet et al., 2015 – PLOS One]
# Roadmap

- **Part I** – Understanding Influential Factors
- **Part II** – Improving Proposing a Solution
- **Part III** – Prospects – Ideas for Future Work

## How Do Cognitive Factors Impact MI–BCI Performance?

## How Does Personality Impact MI–BCI Performance?

## How Does Standard Feedback Impact MI–BCI Performance?
## Roadmap

- **Part I** – Understanding Influential Factors
  - How Do **Cognitive Factors** Impact MI–BCI Performance?
    - Spatial Abilities (SA)
- **Part II** – Improving Proposing a Solution
- **Part III** – Prospects – Ideas for Future Work
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| How Does Personality Impact MI–BCI Performance? |

| How Does Standard Feedback Impact MI–BCI Performance? |
Cognitive Factors

Part II – Proposing a solution

A spatial ability training improves users’ spatial abilities, which in turn has a positive impact on users’ MI-BCI performance.

[Moreau et al., 2012 – J. of Individual Differences]
[Hoyek et al., 2009 – Learning & Teaching medicine]
[Jeunet et al., 2016 – BCI Meeting]
Cognitive Factors

- Part II – *Proposing a solution*

Designing a Spatial Ability (SA) training protocols.

[Jeunet et al., 2016 – BCI Meeting]
Cognitive Factors

- Part II – *Proposing a solution*

Testing the SA training protocol: Results (N=24)

- Participants improved their mental rotation scores
- No global effect on MI–BCI performance/progression
- BUT effect of the intensity on the training on their MI–BCI progression:
Cognitive Factors

- Part II - Proposing a solution

A spatial ability training improves users’ spatial abilities, which in turn has a positive impact on users’ MI-BCI performance.

[Jeunet et al., 2016 – BCI Meeting]
Roadmap

- Part I – Understanding Influential Factors
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- Part II – Improving Proposing a Solution
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**How Do Cognitive Factors Impact MI–BCI Performance?**

- Spatial Abilities (SA)

**How Does Personality Impact MI–BCI Performance?**

**How Does Standard Feedback Impact MI–BCI Performance?**
Cognitive Factors

Part III – Prospects: Stroke Rehabilitation

Stroke Motor After-Effects

Standard Rehabilitation Motor Tasks

Motor-imagery BCI
Brain-Activity Visu. Electro-stimulation

Spatial Ability Training + BCI
Idem.

Are you doing the task?
Risk: increase Depression?

Risk: increase Depression?
# Roadmap

## Part I - Understanding Influential Factors
- **How Do Cognitive Factors Impact MI-BCI Performance?**
  - Spatial Abilities (SA)

## Part II - Improving Proposing a Solution
- **SA Training:**
- **Application: Stroke Rehabilitation?**

## Part III - Prospects - Ideas for Future Work
- **How Does Personality Impact MI-BCI Performance?**
- **How Does Standard Feedback Impact MI-BCI Performance?**
Roadmap

- Part I - Understanding Influential Factors
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Personality

Part I - Influential Factors

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[Jeunet et al., 2015 – PLOS One]
Personality

– Part I – *Influential Factors*

\[ P = \alpha_0 - \alpha_1 \times \text{Tension} + \alpha_2 \times \text{Abstractness} + \alpha_3 \times \text{Learning-Style} + \alpha_4 \times \text{Self-Reliance} \]

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<thead>
<tr>
<th>R</th>
<th>( R^2 )</th>
<th>( R^2 ) \text{ adj.}</th>
<th>Standard Error</th>
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<tr>
<td>0.925</td>
<td>0.857</td>
<td><strong>0.809</strong></td>
<td>1.919</td>
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[Jeunet et al., 2015 – PLOS One]
Roadmap

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  ▼ SA Training:
  ▼ Application: Stroke Rehabilitation?

- Part II - Improving Proposing a Solution

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Léa Pillette
Boris Mansencal
Personality

Part II – Proposing a solution

\[ P = \alpha_0 - \alpha_1 \times \text{Tension} + \alpha_2 \times \text{Abstractness} + \alpha_3 \times \text{Learning-Style} + \alpha_4 \times \text{Self-Reliance} \]
Personality

- Part II – Proposing a solution

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Part II – Proposing a solution

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Need for Social Presence & Emotional Support to learn …

[Shute, 2008 – Review of Educational Research]
[Meyer & Turner, 2002 – Educational Psychologist]
Personality

- Part II – Proposing a solution

 Providing a social presence & emotional support to MI–BCI users, using a Learning Companion, during their training will improve the training process in terms of MI–BCI performance & user experience.

[N’Kambou et al., 2010 – Advances in Intelligent Tutoring Systems]
Personality

- Part II - Proposing a solution

PEANUT – Personalised Emotional Agent for Neurotechnology User-Training
Personality

– Part II – Proposing a solution

Appearance –

*Design based on …*

. The literature
. A questionnaire (N=97)
Personality

- Part II – Proposing a solution

Behaviour –
Personality

– Part II – Proposing a solution

Behaviour –

What? How? When?
Personality

– Part II – Proposing a solution

Behaviour –

What?  How?  When?

Support Effort
Empathy

Results Good
Change Strategy

[based on the literature]
Personality

– Part II – Proposing a solution

Behaviour –

What?

Support Effort

Empathy

Results Good

Change Strategy

How?

Exclamatory vs. Declarative

Personal vs. Non personal

When?

[questionnaire – N=104]

[based on the literature]

[<Pillette, Jeunet et al. – Submitted>]}
Personality

- Part II – *Proposing a solution*

Behaviour –

**What?**
- Support Effort
- Empathy
- Results Good
- Change Strategy

**How?**
- Exclamatory vs. Declarative
- Personal vs. Non personal

**When?**
- [rule tree]

[questionnaire – N=104]

[based on the literature]

*Pillette, Jeunet et al. – Submitted*
Providing a social presence & emotional support to MI–BCI users during their training will improve the training process in terms of MI–BCI performance & user experience.

[Kübler et al. (2014) – PLoS One]
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    - Spatial Abilities (SA)
  - SA Training:
  - Application: Stroke Rehabilitation?

- **Part II** – Improving Proposing a Solution
  - How Does Personality Impact MI–BCI Performance?
    - Tension, self-reliance, abstractedness, learning style.

- **Part III** – Prospects – Ideas for Future Work

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Léa Pillette

Boris Mansencal
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Personality

– Part III – Prospects: Cognitive Support

PEANUT & TEEGI

Roadmap

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- How Does Standard Feedback Impact MI-BCI Performance?
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- **Part I** - Understanding Influential Factors
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**How Do Cognitive Factors Impact MI–BCI Performance?**

**How Does **Personality** Impact MI–BCI Performance?**

**How Does Standard Feedback Impact MI–BCI Performance?**
Roadmap

- Part I - Understanding Influential Factors
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How Do Cognitive Factors Impact MI–BCI Performance?

How Does Personality Impact MI–BCI Performance?

How Does Standard Feedback Impact MI–BCI Performance?

Emilie Jahanpour
Alison Cellard
Feedback

– Part I – Influential Factors
Feedback

- Part I – Influential Factors

Around 17% of the participants did not manage to learn.
Feedback

Part I – Influential Factors

Performance obtained at the motor tasks per participant & per run.

[Jeunet et al. (2016) – J. Neural Engineering]
How Does Standard Feedback Impact MI-BCI Performance?

How Does Personality Impact MI-BCI Performance?

- Tension, self-reliance, abstractedness, learning style.

- Learning Companion: PEANUT:

- Improvement: Cognitive Support

How Do Cognitive Factors Impact MI-BCI Performance?

- Spatial Abilities (SA)

- SA Training:

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Roadmap

- Part I: Understanding Influential Factors
- Part II: Improving Proposing a Solution
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- **Part III** – Prospects – Ideas for Future Work
  - **Improvement:** Cognitive Support

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**How Does Standard Feedback Impact MI–BCI Performance?**

- Feedback requires many cognitive resources to be processed.
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**Chi Tinh Vi**
Daniel Spelmezan
Feedback

- Part II – Proposing a solution

Tactile feedback requires less cognitive resources than an equivalent visual feedback in a BCI context (i.e., where the visual channel is overtaxed), thus resulting in a better acquisition of MI–BCI skills & better performances at side tasks.
Proposed Vibrotactile Glove

We present a glove with vibrotactile actuators which gives users continuous tactile feedback at the palm.
Feedback

- Part II – Proposing a solution

Tactile feedback requires less cognitive resources than an equivalent visual feedback in a BCI context (i.e., where the visual channel is overtaxed), thus resulting in a better acquisition of MI–BCI skills & better performances at side tasks.

[ Jeunet et al. (2015) – Interact ]
How Does Standard Feedback Impact MI–BCI Performance?

Feedback requires many cognitive resources to be processed.

How Does Personality Impact MI–BCI Performance?

Tension, self-reliance, abstractedness, learning style.

How Do Cognitive Factors Impact MI–BCI Performance?

Spatial Abilities (SA)

SA Training:

Application: Stroke Rehabilitation?

Improvement: Cognitive Support

Roadmap

Part I – Understanding Influential Factors

Part II – Improving Proposing a Solution

Part III – Prospects – Ideas for Future Work

Chi Tahn Vi

Daniel Spelmezan
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### Improving Proposing a Solution

- Part II - Improving Proposing a Solution
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    - Feedback requires many cognitive resources to be processed.
    - Tactile Feedback:

### Prospects - Ideas for Future Work

- Part III - Prospects - Ideas for Future Work
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  - How Does Standard Feedback Impact MI–BCI Performance?
    - Feedback requires much cognitive resources to be processed
      - Tactile Feedback:
Feedback

– Part III – Prospects: Why is tactile feedback efficient?

H1 //
It requires fewer cognitive resources to be processed.

H2 //
Vibrations on the hands trigger the motor cortex.

H3 //
Tactile feedback is associated with a better sense of agency.

[ Jeunet et al. (2016) – Progress in Brain Research ]
Roadmap

- Part I – Understanding Influential Factors
  - How Do Cognitive Factors Impact MI–BCI Performance?
    - Spatial Abilities (SA)
- Part II – Improving Proposing a Solution
  - How Does Personality Impact MI–BCI Performance?
    - Tension, self-reliance, abstractedness, learning style
    - Learning Companion: PEANUT
  - Application: Stroke Rehabilitation?
  - Improvement: Cognitive Support
- Part III – Prospects – Ideas for Future Work
  - How Does Standard Feedback Impact MI–BCI Performance?
    - Feedback requires much cognitive resources to be processed
    - Tactile Feedback
How Does Standard Feedback Impact MI–BCI Performance?

- Feedback requires many cognitive resources to be processed.

- Tactile Feedback:
  - Neurophysiological correlates of tactile feedback efficiency

How Does Personality Impact MI–BCI Performance?

- Tension, self-reliance, abstractedness, learning style.

- Learning Companion: PEANUT:
  - Improvement: Cognitive Support

How Do Cognitive Factors Impact MI–BCI Performance?

- Spatial Abilities (SA)
  - SA Training:

- Application: Stroke Rehabilitation?

- Improvement: Cognitive Support

Roadmap

- Part I – Understanding Influential Factors
- Part II – Improving Proposing a Solution
- Part III – Prospects – Ideas for Future Work
## Roadmap

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<td>How Do <strong>Cognitive Factors</strong> Impact MI–BCI Performance?</td>
<td>How Does <strong>Personality</strong> Impact MI–BCI Performance?</td>
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<tr>
<td>▼ SA Training: <img src="image1.png" alt="Image" /></td>
<td>▼ Learning Companion: PEANUT: <img src="image2.png" alt="Image" /></td>
<td>▼ Tactile Feedback: <img src="image3.png" alt="Image" /></td>
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</tbody>
</table>

**How Do Cognitive Factors Impact MI–BCI Performance?**

- Spatial Abilities (SA)

**How Does Personality Impact MI–BCI Performance?**

- Tension, self-reliance, abstractedness, learning style.

**How Does Standard Feedback Impact MI–BCI Performance?**

- Feedback requires many cognitive resources to be processed.
Discussion – Limits

- Need for...
  - New measures of performance
  - A multi-factorial approach of user-training
  - A Model of the skills to be acquired
PERFORMANCE: Classification Accuracy
PERFORMANCE: Classification Accuracy

Mental Rotation score

Spatial Abilities

PERFORMANCE: Classification Accuracy
Spatial Abilities

- Spatial Training
  - Kinaesthetic Imagination Score
  - Mental Rotation Score
  - Visual-Motor Imagination Score

- Abstractness
- Visual-Motor Coordination
- Active Learning
- Spatial Abilities

Mu

PERFORMANCE: Classification Accuracy
PERFORMANCE: Classification Accuracy

// User–Technology Relationship

Self Reliance
Computer Anxiety
Self–Efficacy
Mastery Confidence
Perceived difficulty
Sense of Agency
Tension / Anxiety
Worry about perf.

// Spatial Abilities

Video Games
Spatial Ability Training
Cognitive Support

Kinaesthetic Imagination Score
Mental Rotation score
Visual–Motor Imagination Score

Abstracted ness
Visual–Motor Coordination
Active Learning

Spatial Abilities

Mu
PERFORMANCE: Classification Accuracy

User–Technology Relationship

- Positively Biased Feedback
- Transparent Mapping
- Priority, Consistency & Exclusivity Principles
- Social Presence & Emotional Support
- Computer Anxiety
- Mastery Confidence
- Perceived difficulty
- Sense of Agency
- Tension / Anxiety
- Worry about perf.
- Self Reliance
- Self-Efficacy

Spatial Abilities

- Video Games
- Spatial Ability Training
- Cognitive Support
- Kinaesthetic Imagination Score
- Mental Rotation score
- Visual–Motor Imagination Score
- Abstracted ness
- Visual–Motor Coordination
- Active Learning
- Spatial Abilities
- Mu
- Spatial Abilities

Positive Bias

Video Games

Cognitive Support

Kinaesthetic Imagination

Mental Rotation

Visual–Motor Imagination

Abstractedness

Visual–Motor Coordination

Active Learning

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COGNITIVE MODEL OF MI–BCI TASKS

Perceived difficulty

Sense of Agency

Mastery Confidence

Computer Anxiety

Worry about perf.

Tension / Anxiety

Self Reliance

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Gamma

Attentional Abilities

Focused Attention

Motivation

Tiredness

Mood

PERFORMANCE: Classification Accuracy
# Post-Doc Project

Using Brain–Computer Interfaces as a Tool to Improve Athletes’ Performance.
Object of the Project EEG & Sport

Brain–Computer Interfaces for the Analysis and Training of Athletes’ Performance.
Object of the Project EEG & Sport

Brain–Computer Interfaces for the Analysis and Training of Athletes’ Performance.
Object of the Project EEG & Sport

Brain–Computer Interfaces for the Analysis and Training of Athletes’ Performance.

[Biomechanics] [Physiology]
Object of the Project EEG & Sport

Brain–Computer Interfaces for the Analysis and Training of Athletes’ Performance.

- Biomechanics
- Physiology
- Social
- Cognitive
- Psychological
- Neurophysiological
Object of the Project EEG & Sport

Brain–Computer Interfaces for the Analysis and Training of Athletes’ Performance.
First Study

OBJECT –
Evaluate the effect of competition on performance & on neurophysiological activity.

METHODS –
Virtual Reality Environment Training vs. Competition

[ Pereira et al. – Submitted ]
First Study

RESULTS –
First Study

RESULTS –

Difference between Training & Competition

B) $\mu$ power difference

$r^2 = 69\% \; p = 0.015$
Objectives of the Post-Doc

Use EEG as a Tool to Improve Athletes’ Performance…

- To find markers of performance
- Study their relationship with the performance
- Train the athletes based on these markers
- Test the training on different sports & professionals
Objectives of the Post-Doc

Use EEG as a Tool to Improve Athletes’ Performance...

[Covert Attention Neurofeedback Training]
Objectives of the Post-Doc

Use EEG as a Tool to Improve Athletes’ Performance

[Covert Attention Neurofeedback Training]

[Ecological Motor–Imagery Training]
THANK YOU!

Using Brain–Computer Interfaces as a Tool to Improve Athletes’ Performance.

Post-Doc in Collaboration with ——
Anatole Lécuyer, Ferran Argelaguet – Inria
Benoît Bideau, Richard Kulpa – Univ. Rennes II / ENS
Jose del R. Millán, Ricardo Chavarriaga – EPFL

Camille Jeunet

Workshop of the EPFL–Inria International Lab ——
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