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 Chavarriage – 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

Hybrid
3D Interaction with Virtual Environments using Body and Mind

Jose del R. Millán
Ricardo Chavarriaga

Anatole Lécuyer
Ferran Argelaguet

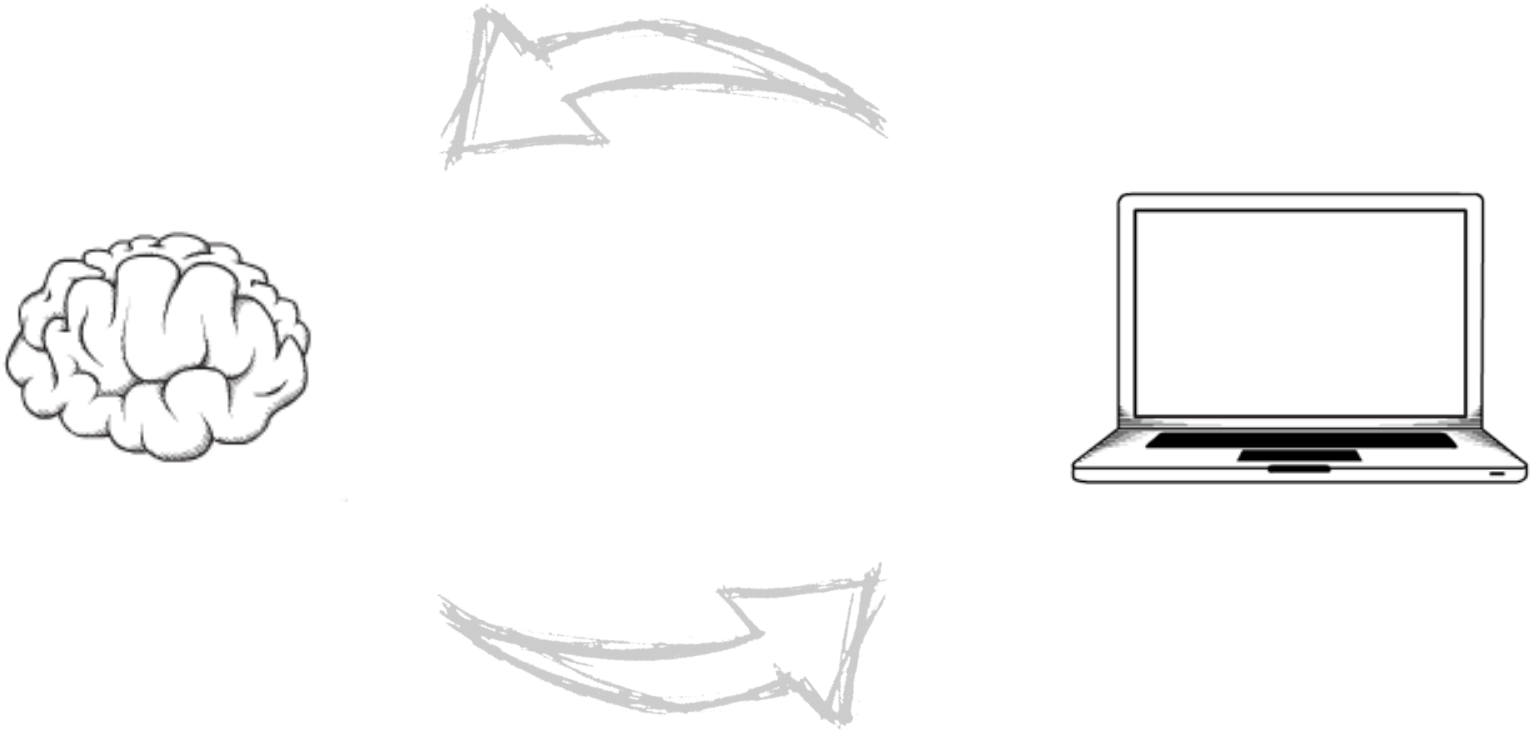
Benoît Bideau
Richard Kulpa

Part I

PhD Project

Understanding & Improving Mental-Imagery based Brain-Computer Interface User-Training: Towards a New Generation of Reliable, Efficient and Accessible BCIs.

Research Focus – EEG-based MI-BCIs



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

[Wolpaw & Wolpaw (2012)]

Research Focus – EEG-based MI-BCIs

[Wolpaw & Wolpaw (2012)]

Research Focus – EEG-based MI-BCIs

[ImmersiveTech @ EPFL “Brain Controlled Wheelchair”]

[Promotion Video of OpenViBE – Application “Use the Force”]

Research Focus – EEG-based MI-BCIs

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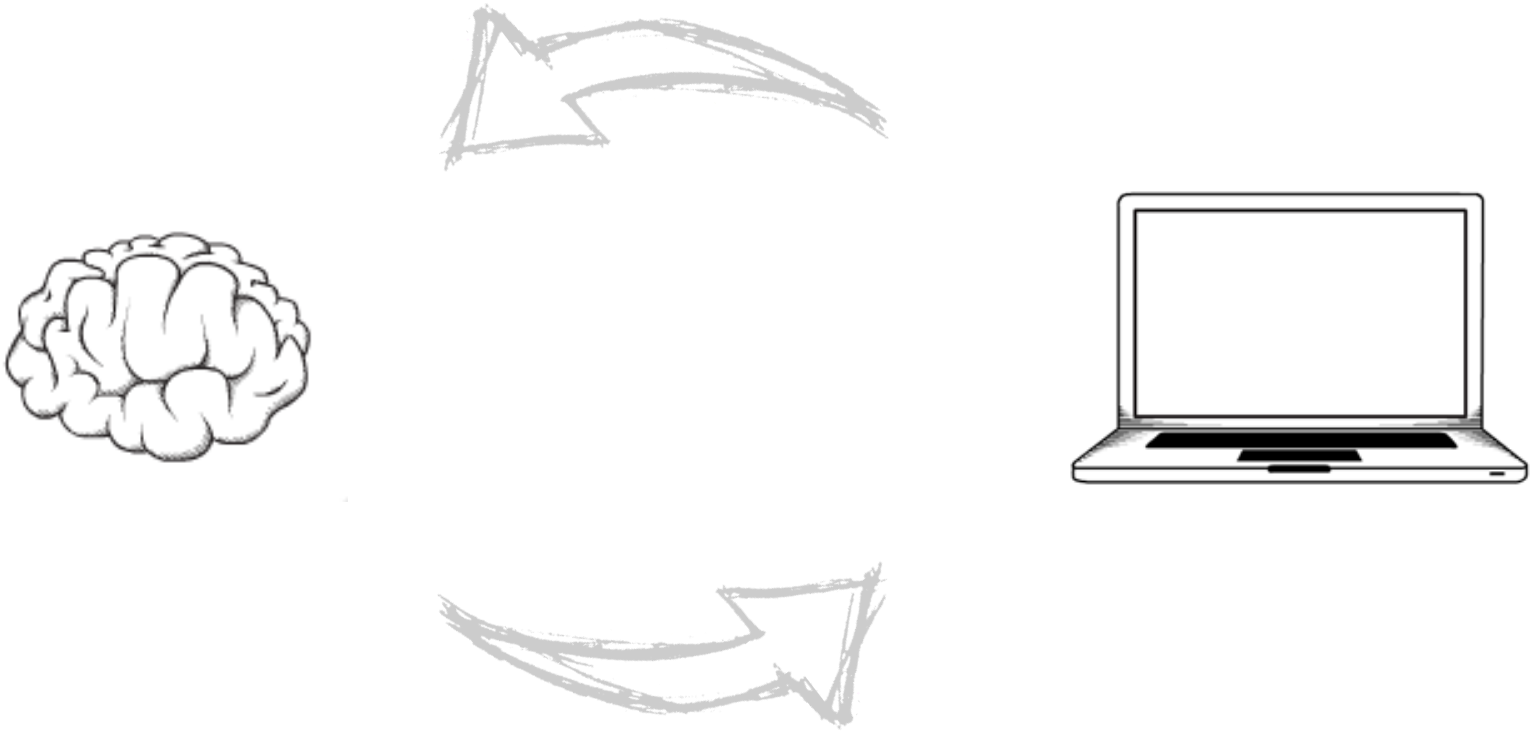
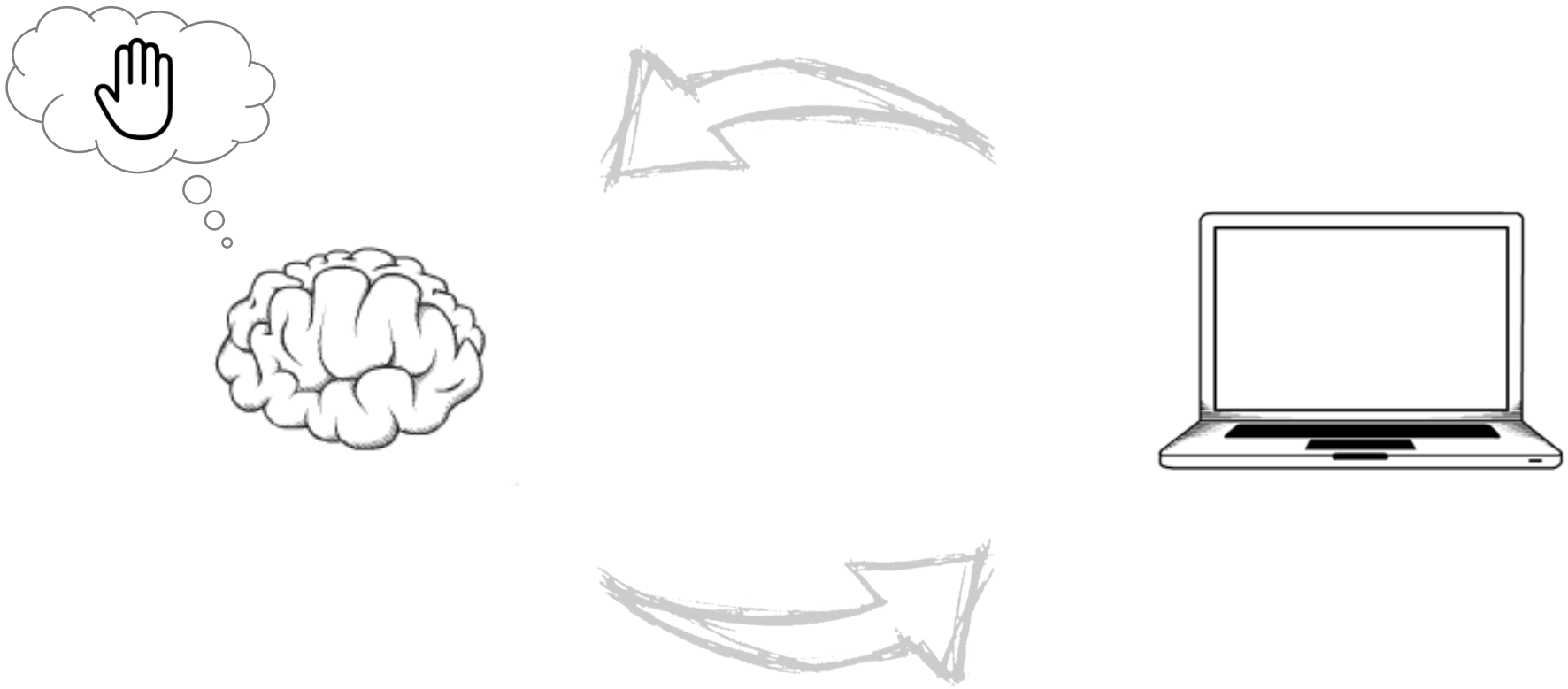


[Wolpaw & Wolpaw (2012)]

Research Focus – EEG-based MI-BCIs



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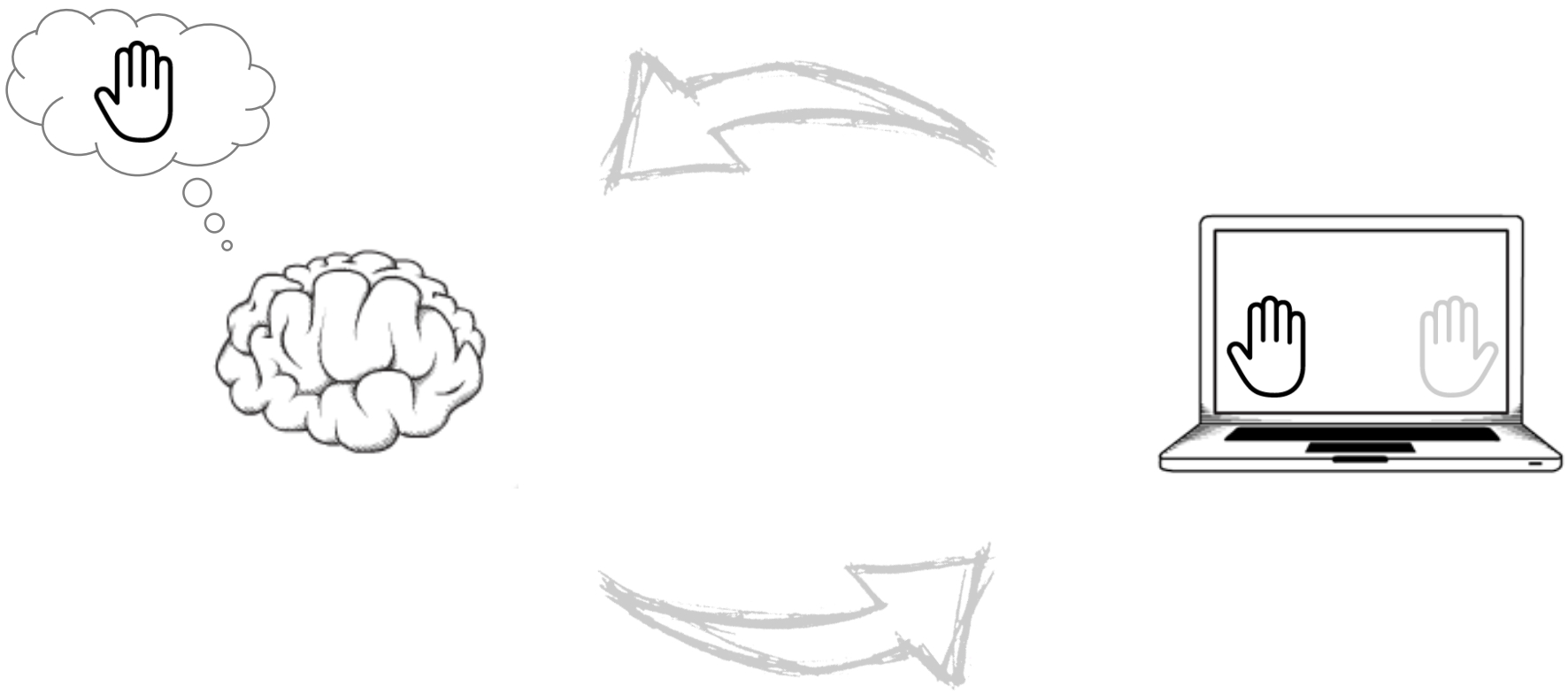
Research Focus – EEG-based MI-BCIs

[Wolpaw & Wolpaw (2012)]

Research Focus – EEG-based MI-BCIs



[Wolpaw & Wolpaw (2012)]

Research Focus – EEG-based MI-BCIs

[Wolpaw & Wolpaw (2012)]

- MI-BCIs are Not Reliable Enough

[Lotte et al. (2013) – Frontiers in Neuroscience]

MI-BCIs are Not Reliable Enough

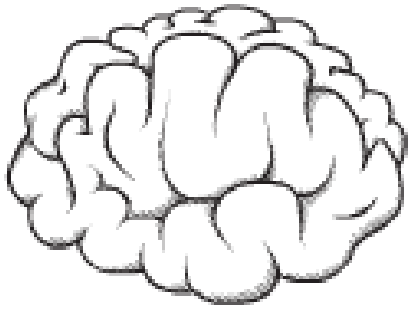
Sensors & Signal Processing Algorithms are Imperfect

Users do not Manage to Acquire BCI skills

[Lotte et al. (2013) – Frontiers in Neuroscience]

MI-BCIs are Not Reliable Enough

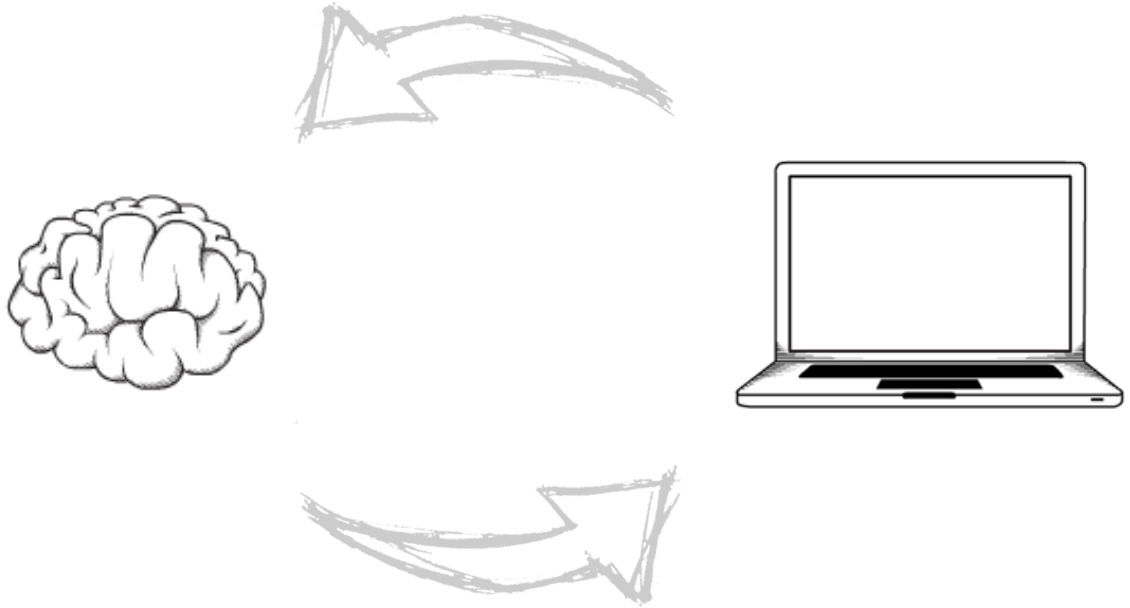
Signal Processing Algorithms are Imperfect



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]

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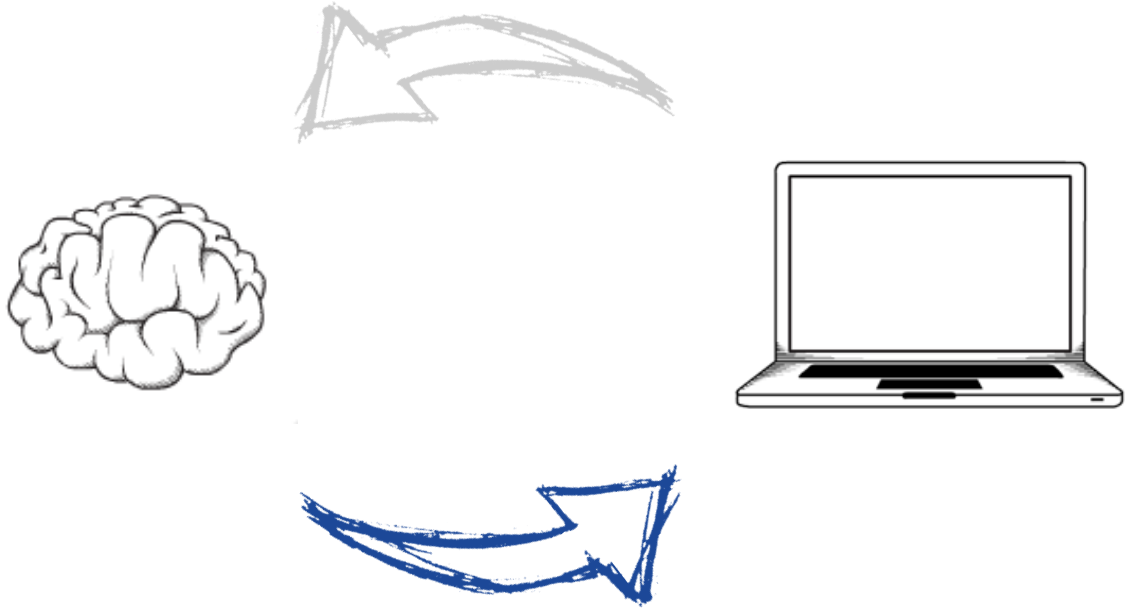
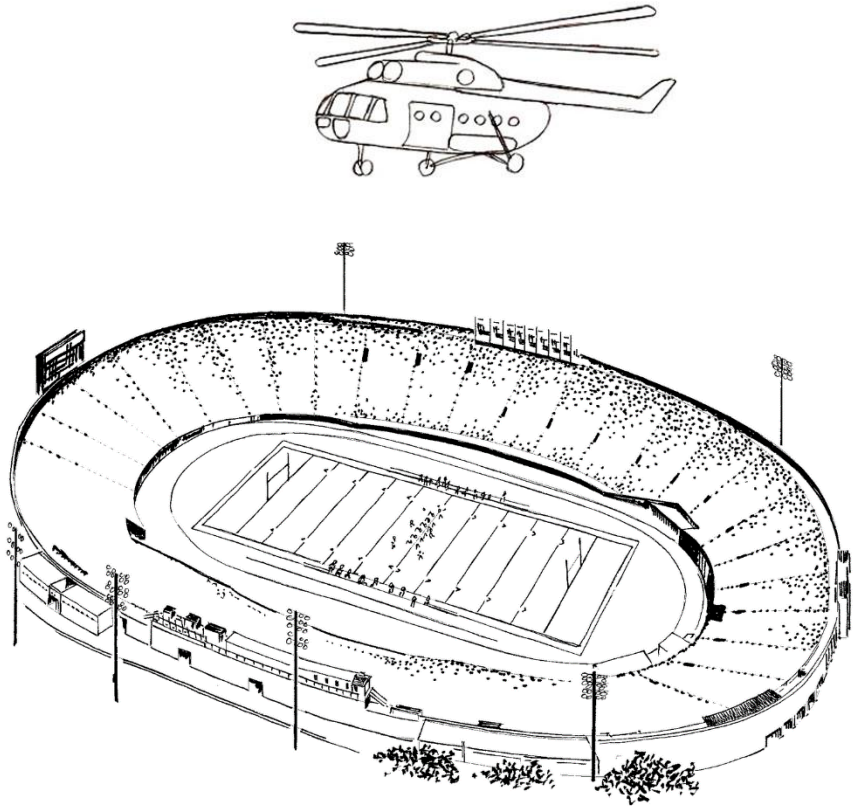


Generate clear MI

[Jeunet et al. (2016) – Wiley-Iste]

What are MI-BCI skills?



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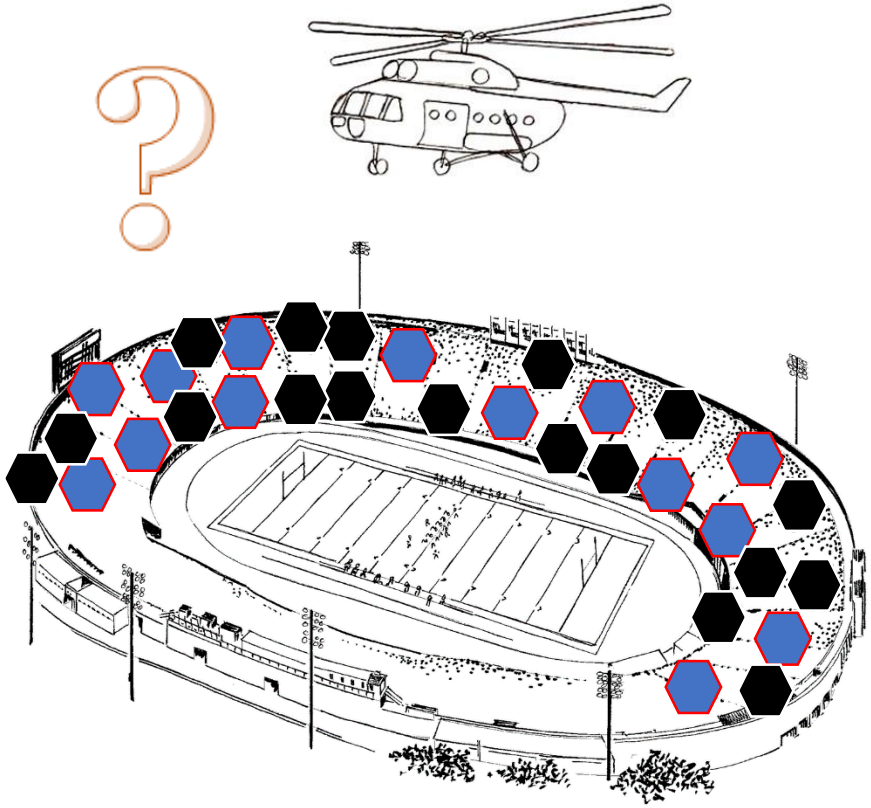

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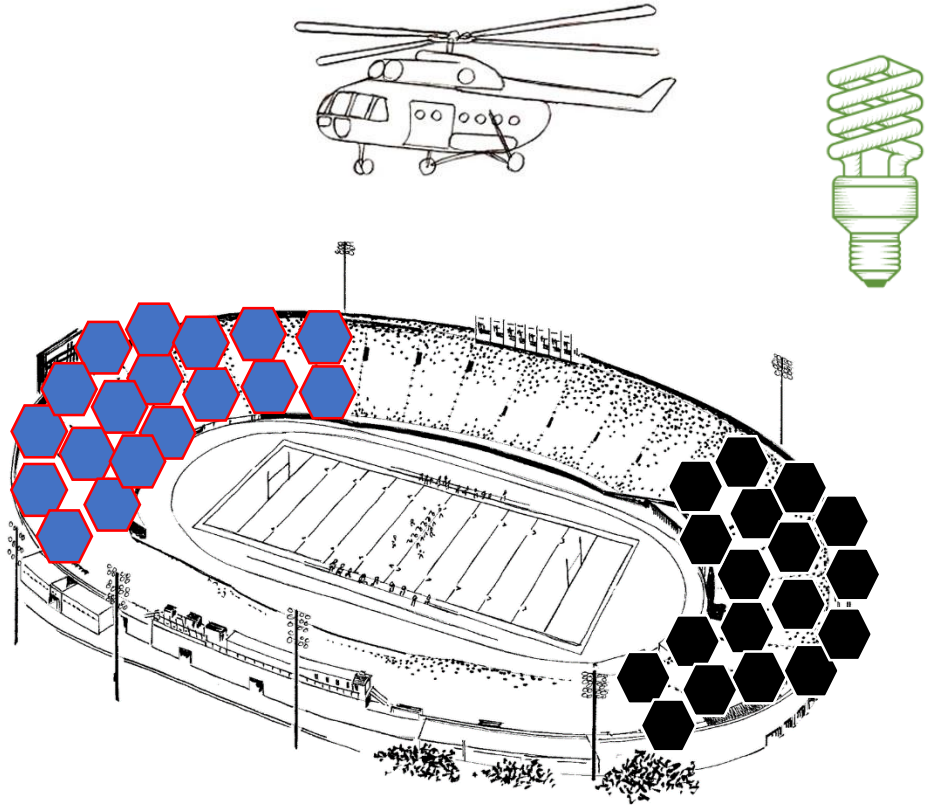

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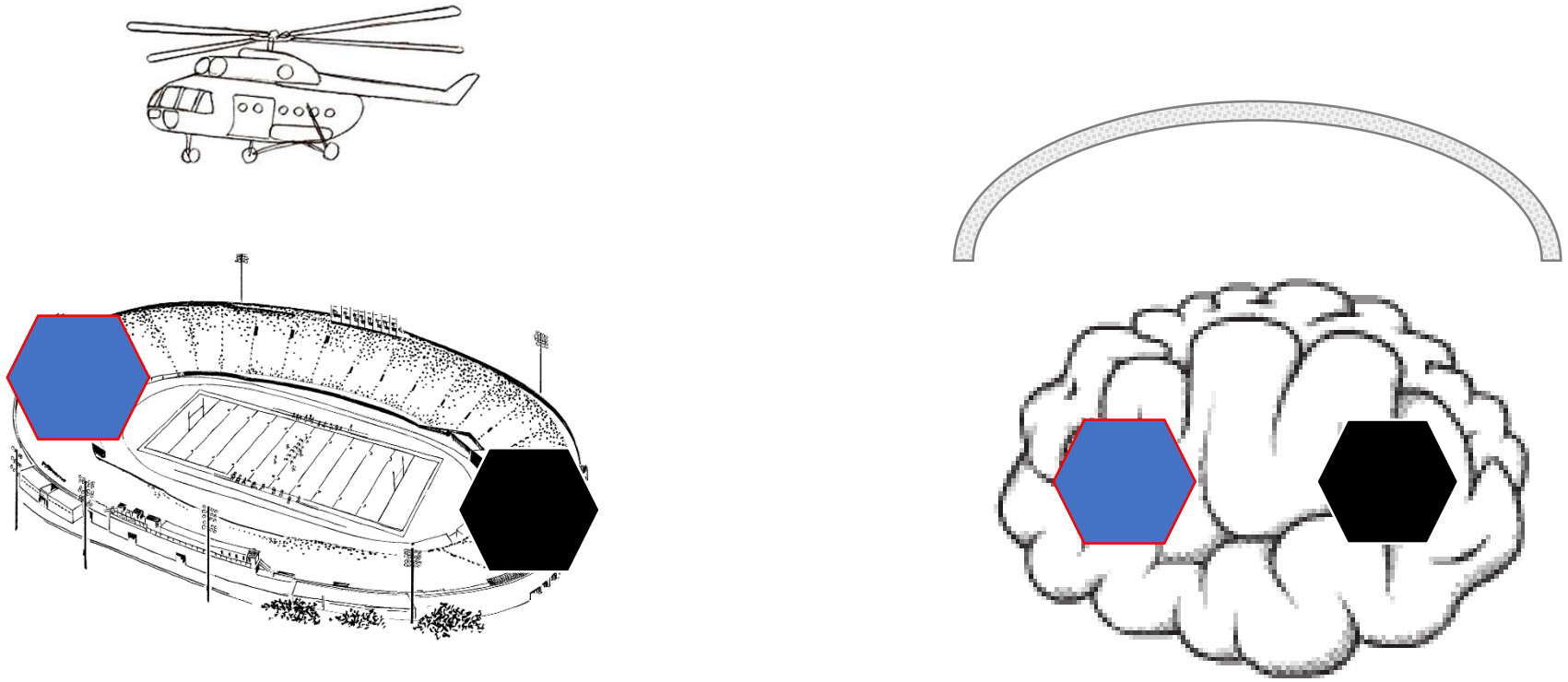
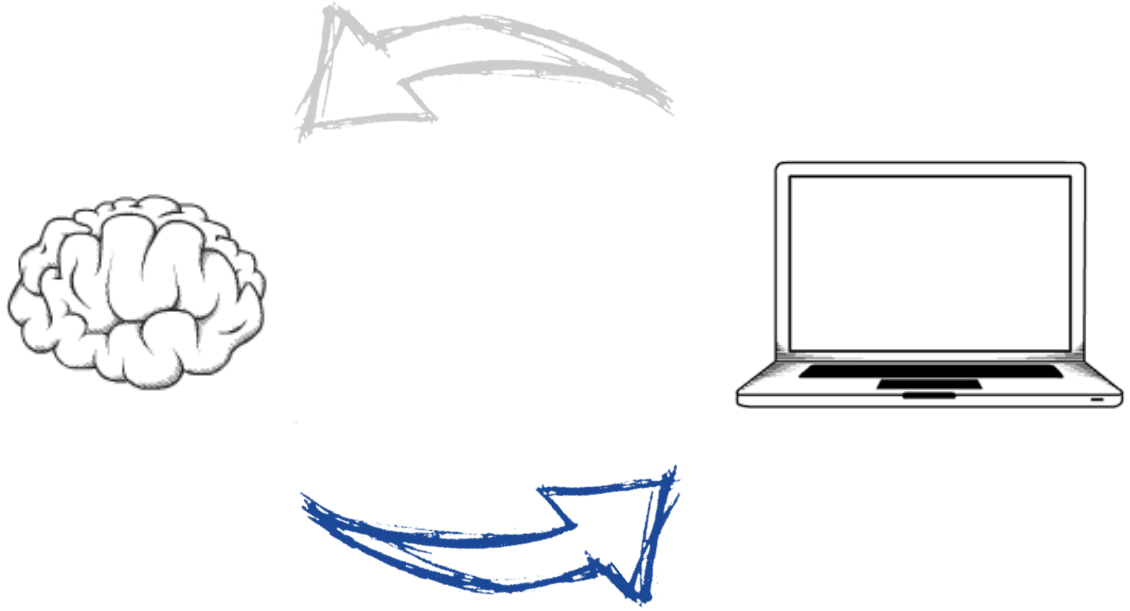


Stable & Distinct brain patterns

[Jeunet et al. (2016) – Wiley-Iste]

What are MI-BCI skills?

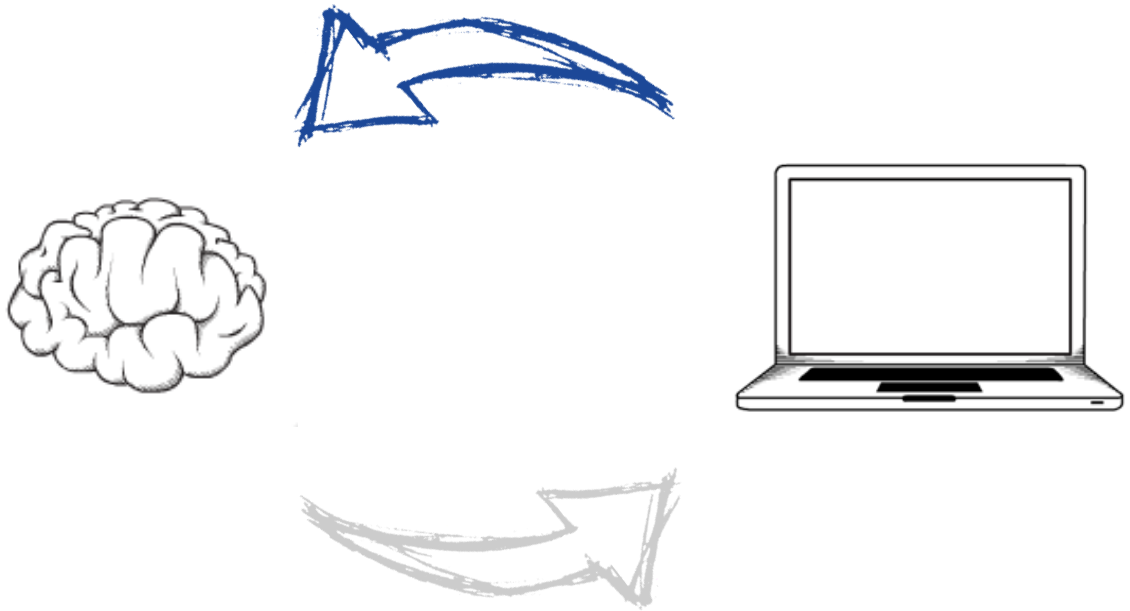


Generate clear MI

[Jeunet et al. (2016) – Wiley-Iste]

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.

[Lotte et al. (2013) – Frontiers in Neuroscience]

Objective

Improving

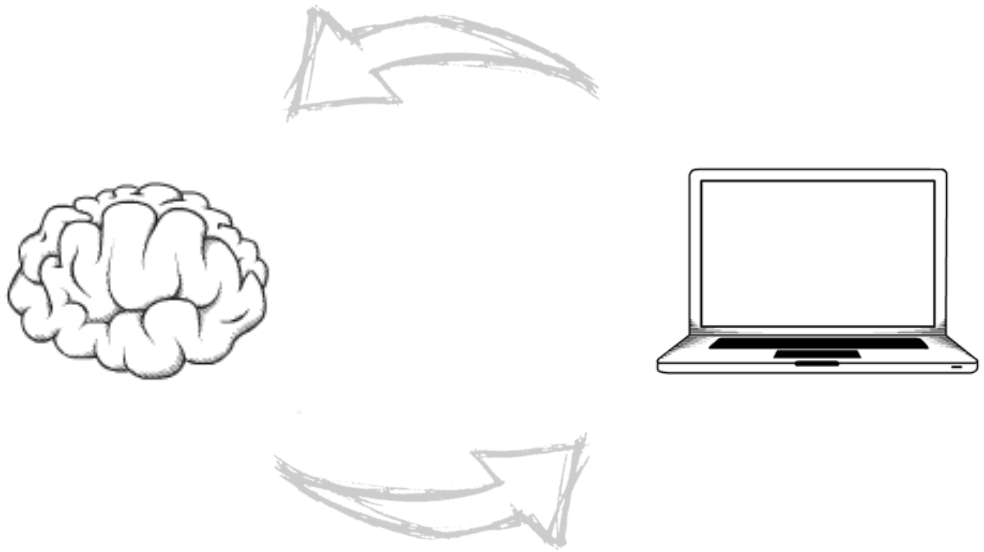
MI-BCI **User-Training**.

Objective

Understanding & Improving MI–BCI **User–Training**.

[Kübler et al. (2014) – PLoS One]

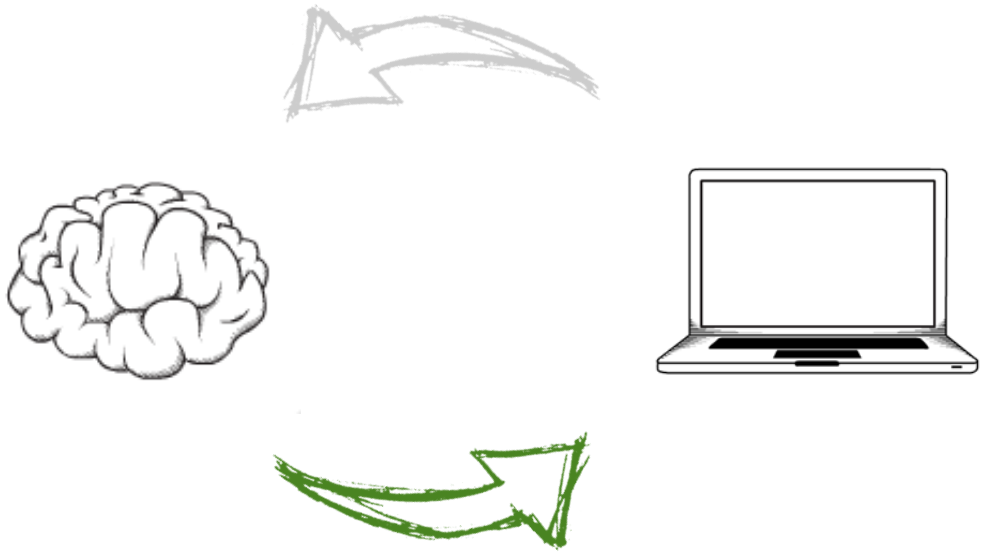
Roadmap



Roadmap

Cognitive Factors

Personality



Generate clear MI

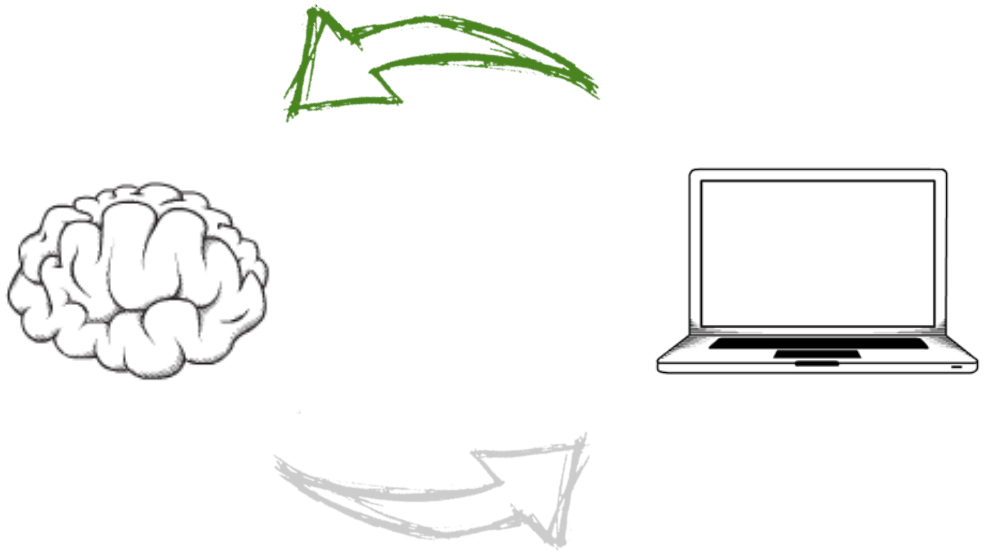
Roadmap

Feedback

Cognitive Factors

Personality

Process the feedback to improve MI



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

	How Do Cognitive Factors Impact MI-BCI Performance?	How Does Personality Impact MI-BCI Performance?	How Does Standard Feedback Impact MI-BCI Performance?
– Part I – Understanding Influential Factors			
– Part II – Improving Proposing a Solution			
– Part III – Prospects – Ideas for Future Work			

Roadmap

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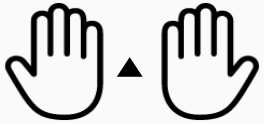
Cognitive Factors

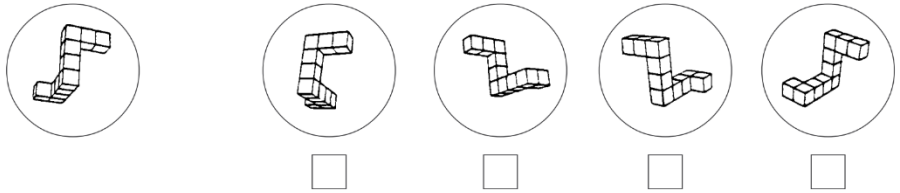
– Part I – *Influential Factors*

	STUDY #1	STUDY #2
Training tasks		
Training Duration	**6** sessions x **5** runs x **45** trials	**1** session x **5** runs x **40** trials
# Participants	 **X 18**	 **X 20**

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

Cognitive Factors

– Part I – *Influential Factors*



[Mental Rotation test, Vandenberg, 1978]

STUDY #1

Correlation MI–BCI Performance
& Mental Rotation Scores
>> $r = 0.696$ – $p < 0.005$

STUDY #2

Correlation MI–BCI Performance
& Mental Rotation Scores
>> $r = 0.464$ – $p < 0.05$

[Jeunet et al., 2015 – PLOS One]

[Jeunet et al. (2016) – J. Neural Engineering]

Roadmap

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Roadmap

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

Roadmap

Suzy Teillet

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

Cognitive Factors

– Part II – *Proposing a solution*

H // 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:

[Teillet, Jeunet et al., 2016 – SMC2016]

Cognitive Factors

– Part II – *Proposing a solution*

H // 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

How Do Cognitive Factors Impact MI-BCI Performance?

How Does Personality Impact MI-BCI Performance?

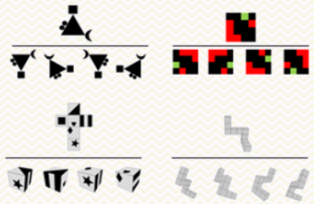
How Does Standard Feedback Impact MI-BCI Performance?

– Part I –
Understanding
Influential Factors

- Spatial Abilities (SA)

– Part II –
Improving
Proposing a Solution

- SA Training:



– Part III –
Prospects –
Ideas for Future Work

Roadmap

	How Do Cognitive Factors Impact MI-BCI Performance?	How Does Personality Impact MI-BCI Performance?	How Does Standard Feedback Impact MI-BCI Performance?
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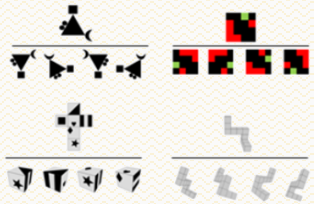
– Part II – Improving Proposing a Solution	SA Training: 		
– Part III – Prospects – Ideas for Future Work			

Cognitive Factors

– Part III – *Prospects: Stroke Rehabilitation*

Stroke
Motor After-Effects

→

Standard Rehabilitation
Motor Tasks

→

. Are you doing the task?
. Risk: increase Depression?

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

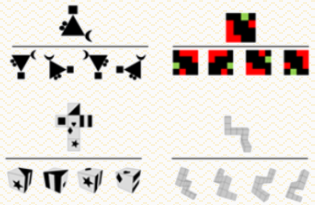
→

. Risk: increase Depression?

Spatial Ability Training + BCI
Idem.

→

Roadmap

	How Do Cognitive Factors Impact MI-BCI Performance?	How Does Personality Impact MI-BCI Performance?	How Does Standard Feedback Impact MI-BCI Performance?
– Part I – Understanding Influential Factors	▼Spatial Abilities (SA)		
– Part II – Improving Proposing a Solution	▼SA Training: 		
– Part III – Prospects – Ideas for Future Work	▼Application: Stroke Rehabilitation?		

Roadmap

How Do Cognitive Factors Impact MI-BCI Performance?

How Does Personality Impact MI-BCI Performance?

How Does Standard Feedback Impact MI-BCI Performance?

– Part I –
Understanding
Influential Factors

- Spatial Abilities (SA)

– Part II –
Improving
Proposing a Solution

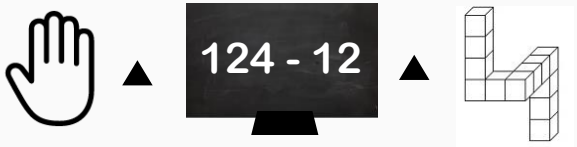
- SA Training:

– Part III –
Prospects –
Ideas for Future Work

- Application: Stroke Rehabilitation?

Personality

– Part I – *Influential Factors*

	STUDY
Training tasks	
Training Duration	**6** sessions x **5** runs x **45** trials
# Participants	 **X 18**

[Jeunet et al., 2015 – PLOS One]

Personality

– Part I – *Influential Factors*

$$P = \alpha_0 - \alpha_1 * \text{Tension} + \alpha_2 * \text{Abstractness} + \alpha_3 * \text{Learning-Style} + \alpha_4 * \text{Self-Reliance}$$

R	R^2	R^2 adj.	Standard Error
0.925	0.857	0.809	1.919

[Jeunet et al., 2015 – PLOS One]

Roadmap

How Do Cognitive Factors Impact MI-BCI Performance?

How Does Personality Impact MI-BCI Performance?

How Does Standard Feedback Impact MI-BCI Performance?

– Part I –
Understanding
Influential Factors

- Spatial Abilities (SA)

– Part II –
Improving
Proposing a Solution

- SA Training:

– Part III –
Prospects –
Ideas for Future Work

- Application: Stroke Rehabilitation?

Roadmap

	How Do Cognitive Factors Impact MI-BCI Performance?	How Does Personality Impact MI-BCI Performance?	How Does Standard Feedback Impact MI-BCI Performance?
– Part I – Understanding Influential Factors	Spatial Abilities (SA)	Tension, self-reliance, abstractedness, learning style.	
– Part II – Improving Proposing a Solution	SA Training: 		
– Part III – Prospects – Ideas for Future Work	Application: Stroke Rehabilitation?		

Roadmap

Léa Pillette

Boris Mansencal

– 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?

- Spatial Abilities (SA)
- SA Training:

- Application: Stroke Rehabilitation?

How Does Personality Impact MI-BCI Performance?

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

How Does Standard Feedback Impact MI-BCI Performance?

Personality

– Part II – *Proposing a solution*

$$P = \alpha_0 - \alpha_1 * \text{Tension} + \alpha_2 * \text{Abstractness} + \alpha_3 * \text{Learning-Style} + \alpha_4 * \text{Self-Reliance}$$

Personality

– Part II – *Proposing a solution*

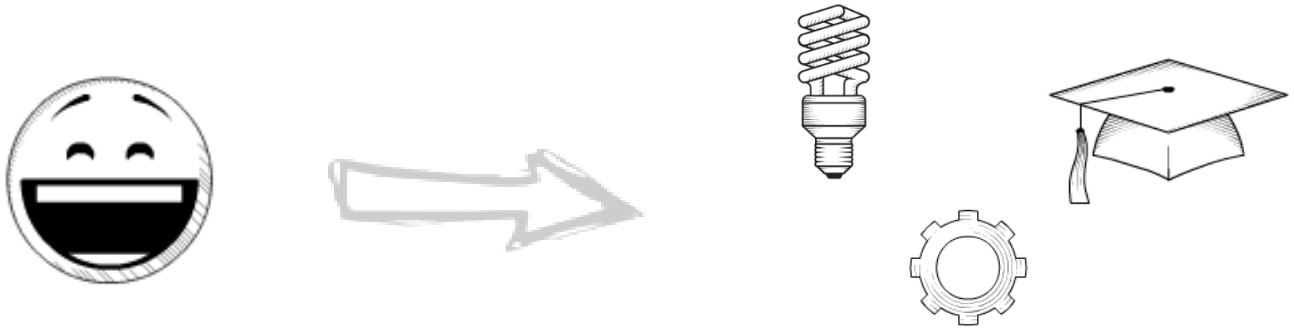
$$P = \alpha_0 - \alpha_1 * \text{Tension} + \alpha_2 * \text{Abstractness} + \alpha_3 * \text{Learning-Style} + \alpha_4 * \text{Self-Reliance}$$

Personality

– Part II – *Proposing a solution*

$$P = \alpha_0 - \alpha_1 * \text{Tension} + \alpha_2 * \text{Abstractness} + \alpha_3 * \text{Learning-Style} + \alpha_4 * \text{Self-Reliance}$$

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*

H // 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

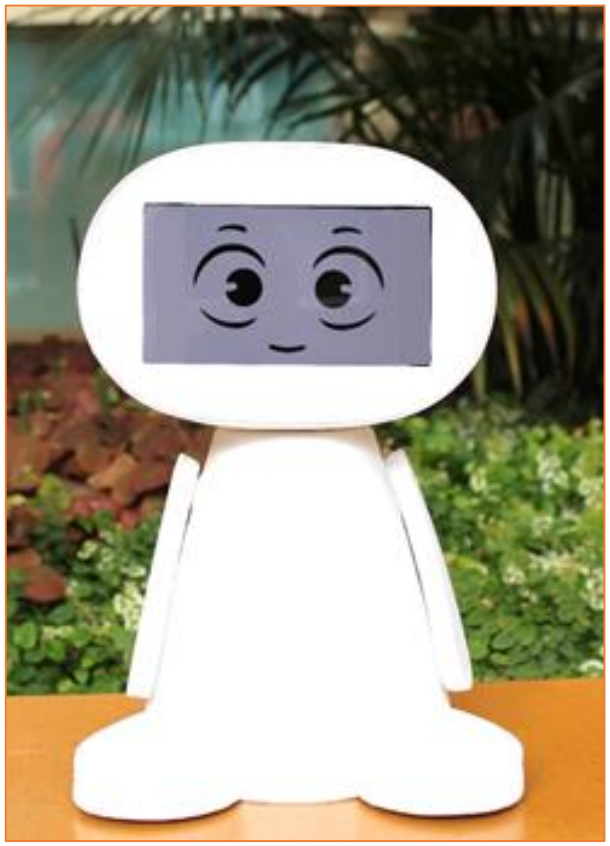
▼ Personality

– Part II – *Proposing a solution*

Appearance –

Design based on …

. The literature
. A questionnaire (N=97)



[Um et al. (2012à – J. Educ. Psy.]
[Hornecker (2011) – Interactions]
[Pillette, Jeunet et al. – Submitted]

Personality

– Part II – *Proposing a solution*

Behaviour –

[Pillette, Jeunet et al. – Submitted]

Personality

– Part II – *Proposing a solution*

Behaviour –

What? *How?* *When?*

[Pillette, Jeunet et al. – Submitted]

Personality

– Part II – *Proposing a solution*

Behaviour –

What? *How?* *When?*

Support Effort

Empathy

Results Good

Change Strategy

[based on the literature]

[Pillette, Jeunet et al. – Submitted]

Personality

– Part II – *Proposing a solution*

Behaviour –

What?

Support Effort

Empathy

Results Good

Change Strategy

[based on the literature]

How?

! Exclamatory vs. Declarative .

-

it Personal vs. Non personal you

[questionnaire – N=104]

When?

[Pillette, Jeunet et al. – Submitted]

Personality

– Part II – *Proposing a solution*

Behaviour –

What?

Support Effort

Empathy

Results Good

Change Strategy

[based on the literature]

How?

!

Exclamatory

vs.

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•

Personal

vs.

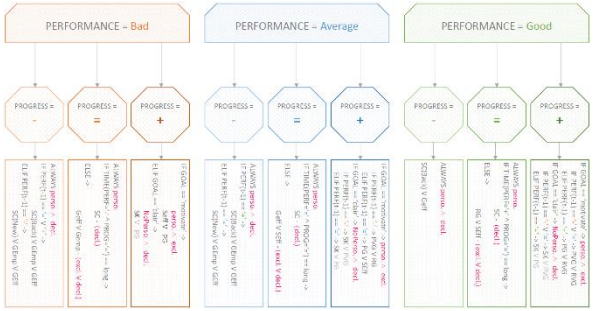
Non personal

it

you

[questionnaire – N=104]

When?



[rule tree]

[Pillette, Jeunet et al. – Submitted]

Personality

– Part II – *Proposing a solution*

H // 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]

Roadmap

Léa Pillette

Boris Mansencal

– 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?

- Spatial Abilities (SA)
- SA Training:

- Application: Stroke Rehabilitation?

How Does Personality Impact MI-BCI Performance?

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

How Does Standard Feedback Impact MI-BCI Performance?

Roadmap

Léa Pillette

Boris Mansencal

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- SA Training:

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How Does Personality Impact MI-BCI Performance?

- Tension, self-reliance, abstractedness, learning style.
- Learning Companion: PEANUT

How Does Standard Feedback Impact MI-BCI Performance?

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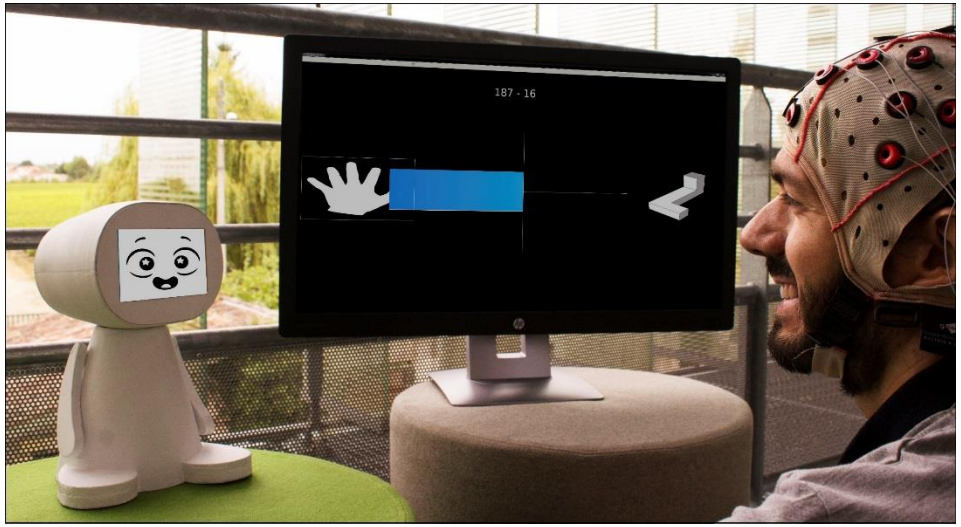
– Part II – Improving Proposing a Solution	SA Training: 	Learning Companion: PEANUT 	
– Part III – Prospects – Ideas for Future Work	Application: Stroke Rehabilitation?		

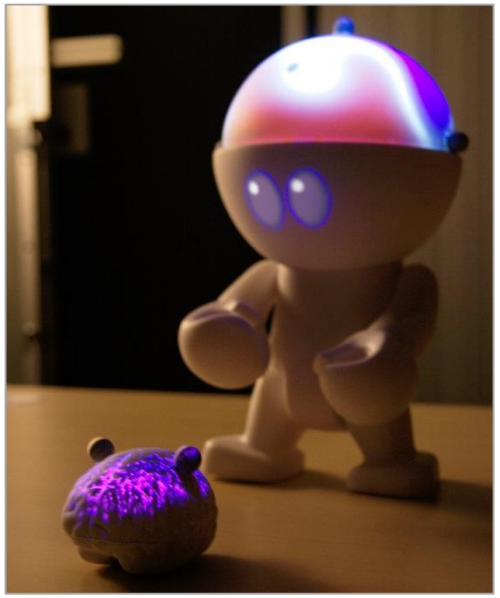
Personality

– Part III – *Prospects: Cognitive Support*



PEANUT

&



TEEGI

[Frey, Gervais, et al. (2014) – UIST]

Roadmap

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

Roadmap

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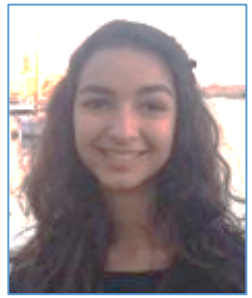
Roadmap

Alison Cellard

Emilie Jahanpour



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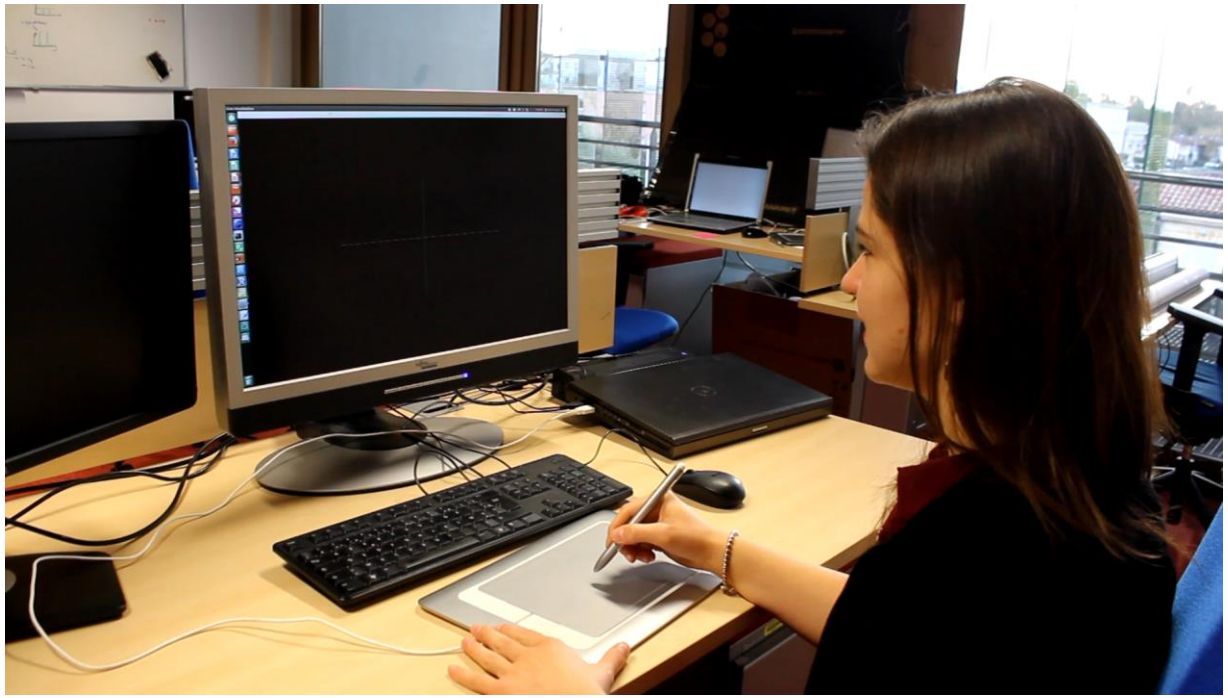
Feedback

– Part I – *Influential Factors*



[Pfurtscheller & Neuper (2001) – Proc. IEEE]

[Jeunet et al. (2014) – Graz BCI Conference]

[Jeunet et al. (2016) – J. Neural Engineering]

Feedback

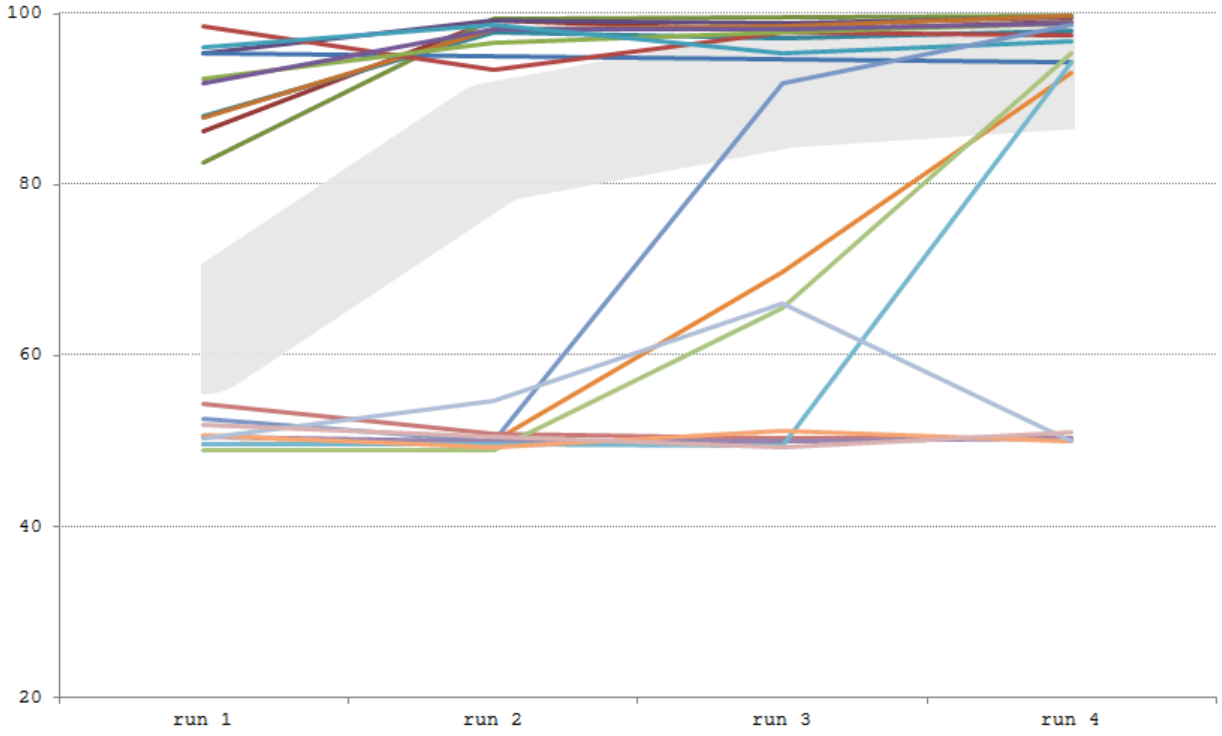
– Part I – *Influential Factors*

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

[Pfurtscheller & Neuper (2001) – Proc. IEEE]
[Jeunet et al. (2014) – Graz BCI Conference]
[Jeunet et al. (2016) – J. Neural Engineering]

Feedback

– Part I – *Influential Factors*



N=53

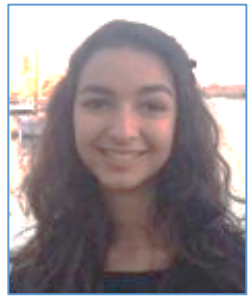
Performance obtained at the motor tasks per participant & per run.

[Jeunet et al. (2016) – J. Neural Engineering]

Roadmap

Alison Cellard

Emilie Jahanpour



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Roadmap

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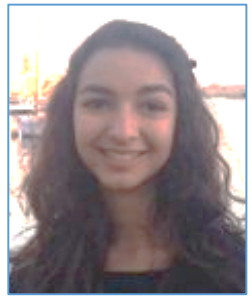

– Part I –
Understanding
Influential Factors

– Part II –
Improving
Proposing a Solution

– Part III –
Prospects –
Ideas for Future Work

How Do Cognitive Factors Impact MI-BCI Performance?

- Spatial Abilities (SA)
- SA Training:

- Application: Stroke Rehabilitation?

How Does Personality Impact MI-BCI Performance?

- Tension, self-reliance, abstractedness, learning style.
- Learning Companion: PEANUT:

- Improvement: Cognitive Support

How Does Standard Feedback Impact MI-BCI Performance?

- Feedback requires many cognitive resources to be processed.

Roadmap

Chi Tanh Vi

Daniel Spelmezan

– 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?

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▾ Feedback

– Part II – *Proposing a solution*

H // **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]

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*

H // 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]

Roadmap

Chi Tanh Vi

Daniel Spelmezan

– Part I –
Understanding
Influential Factors

– Part II –
Improving
Proposing a Solution

– Part III –
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Ideas for Future Work

How Do Cognitive Factors Impact MI-BCI Performance?

- Spatial Abilities (SA)
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Roadmap

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Daniel Spelmezan

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How Does Standard Feedback Impact MI-BCI Performance?

- Feedback requires many cognitive resources to be processed.
- Tactile Feedback:

Roadmap

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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.

[Gallagher (2000) – Trends in Cognitive Sciences]

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

Roadmap

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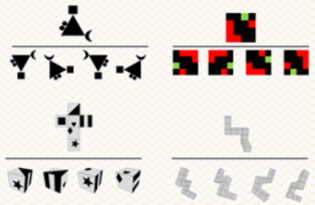
– Part II – Improving Proposing a Solution	▼SA Training: 	▼Learning Companion: PEANUT: 	▼Tactile Feedback: 
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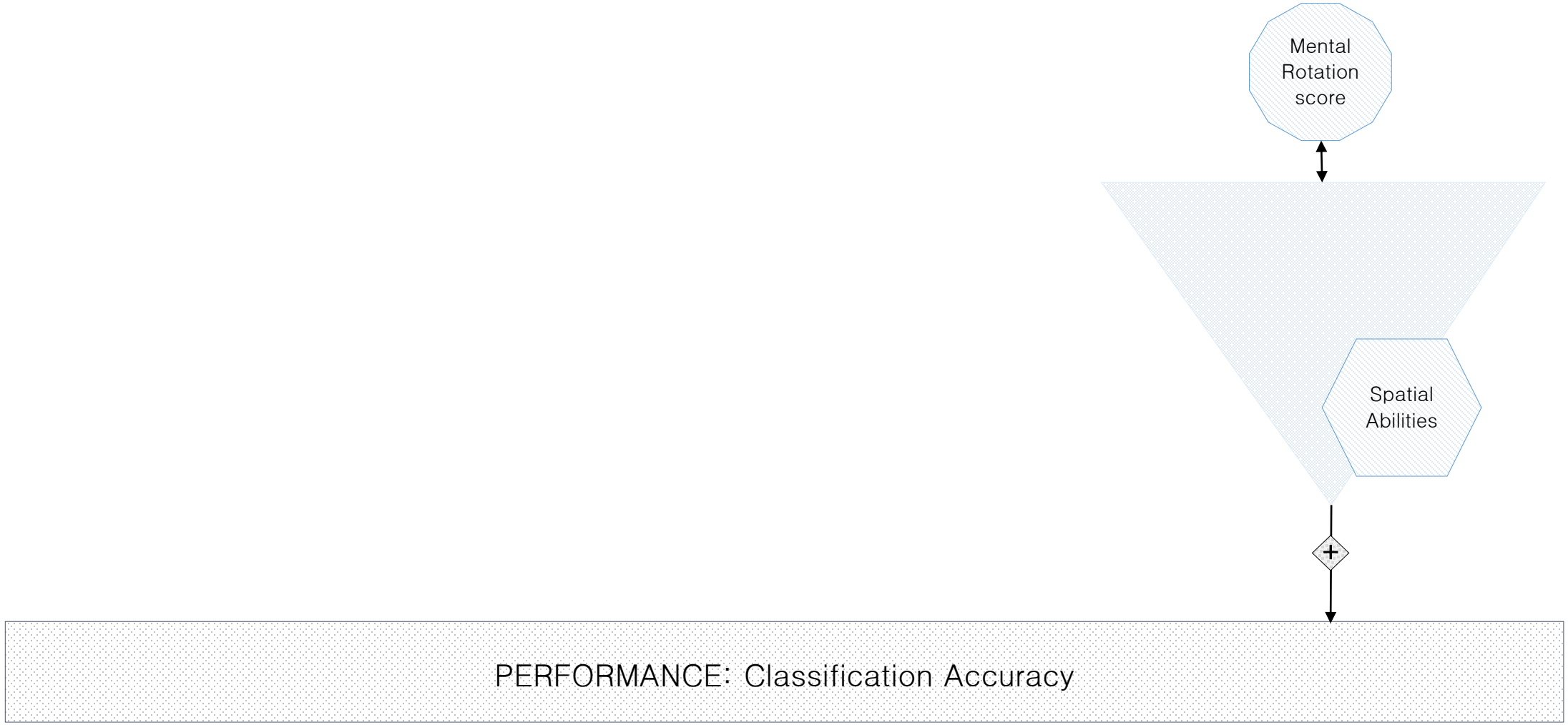
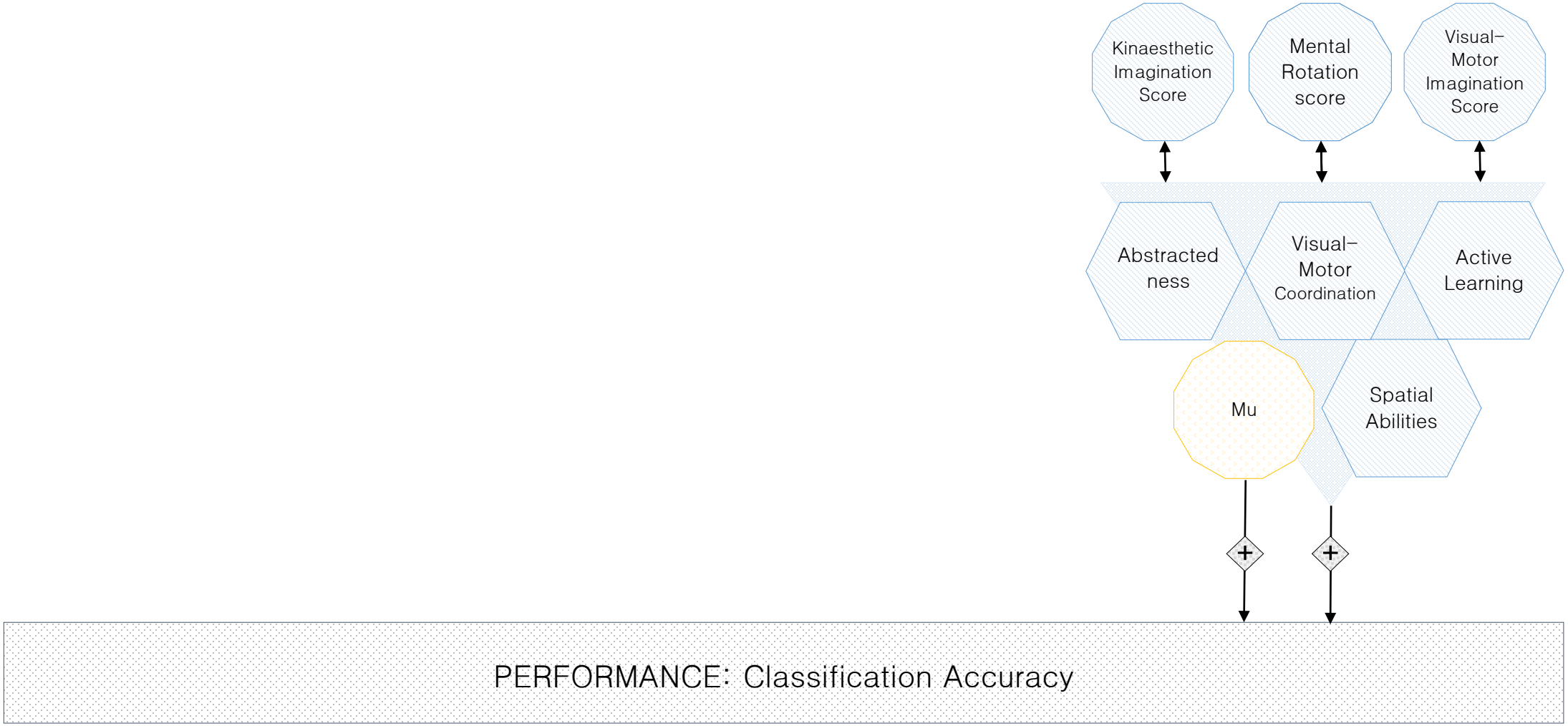
Discussion – Limits

- Need for…
  - New measures of performance
  - A multi-factorial approach of user-training
  - A Model of the skills to be acquired

PERFORMANCE: Classification Accuracy


Mental Rotation score
Spatial Abilities
+
PERFORMANCE: Classification Accuracy

/ Spatial Abilities



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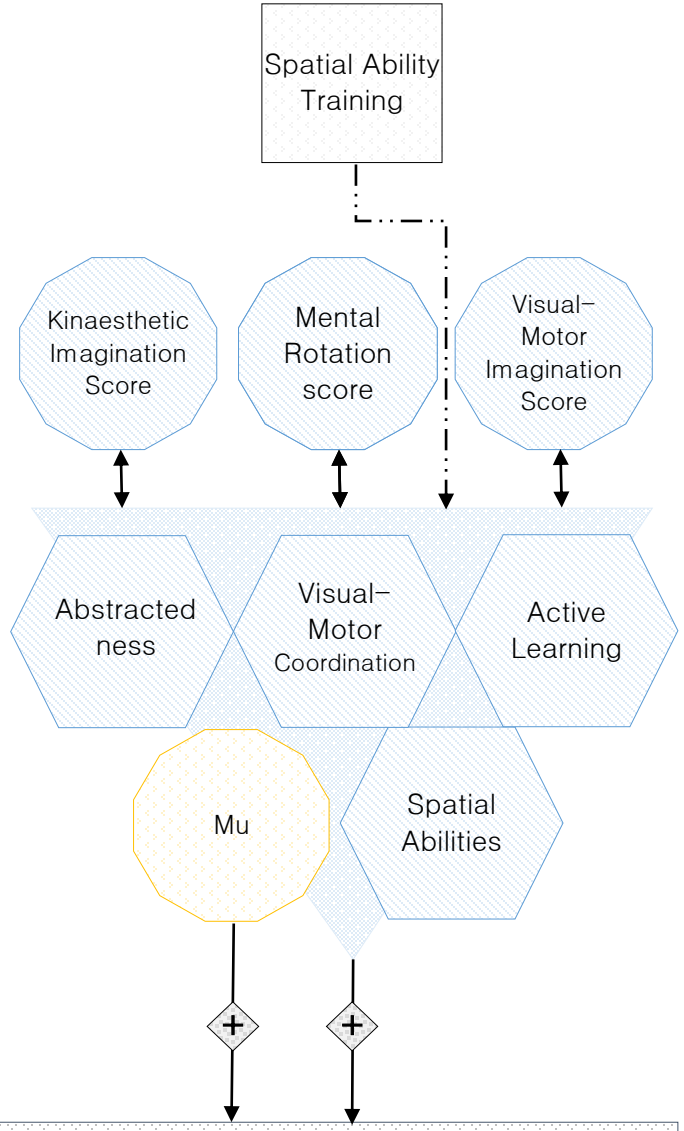

PERFORMANCE: Classification Accuracy

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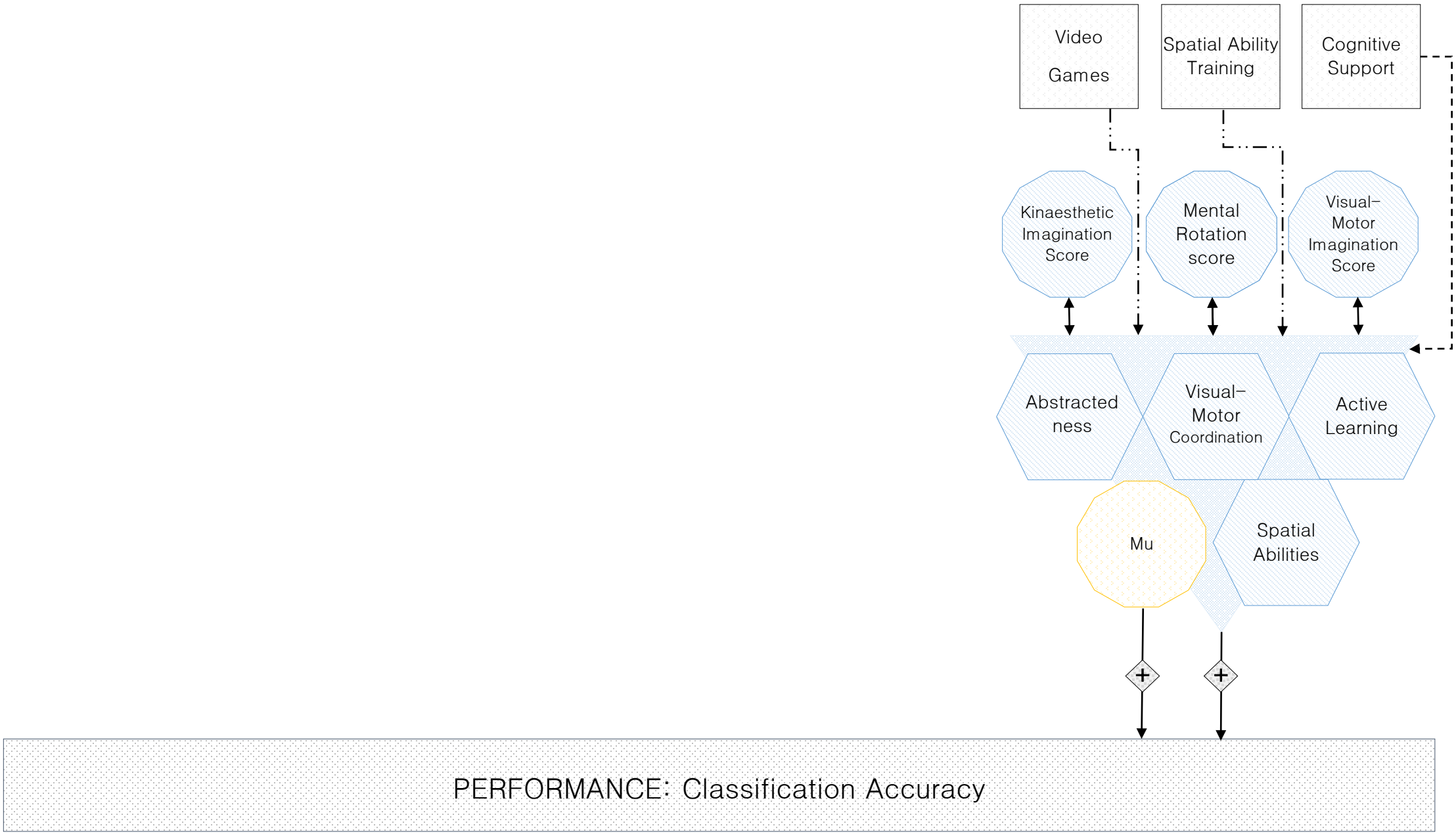

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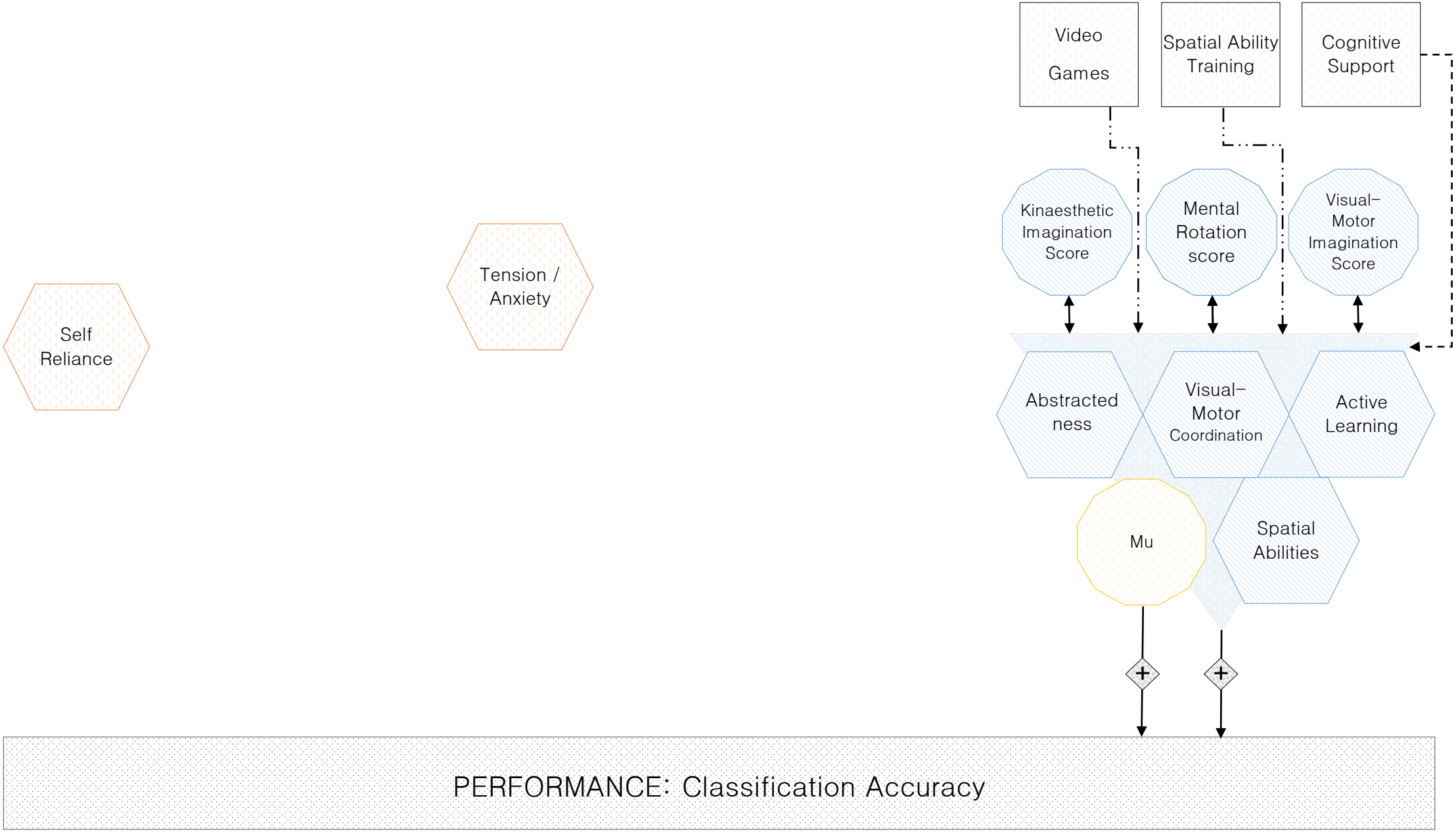
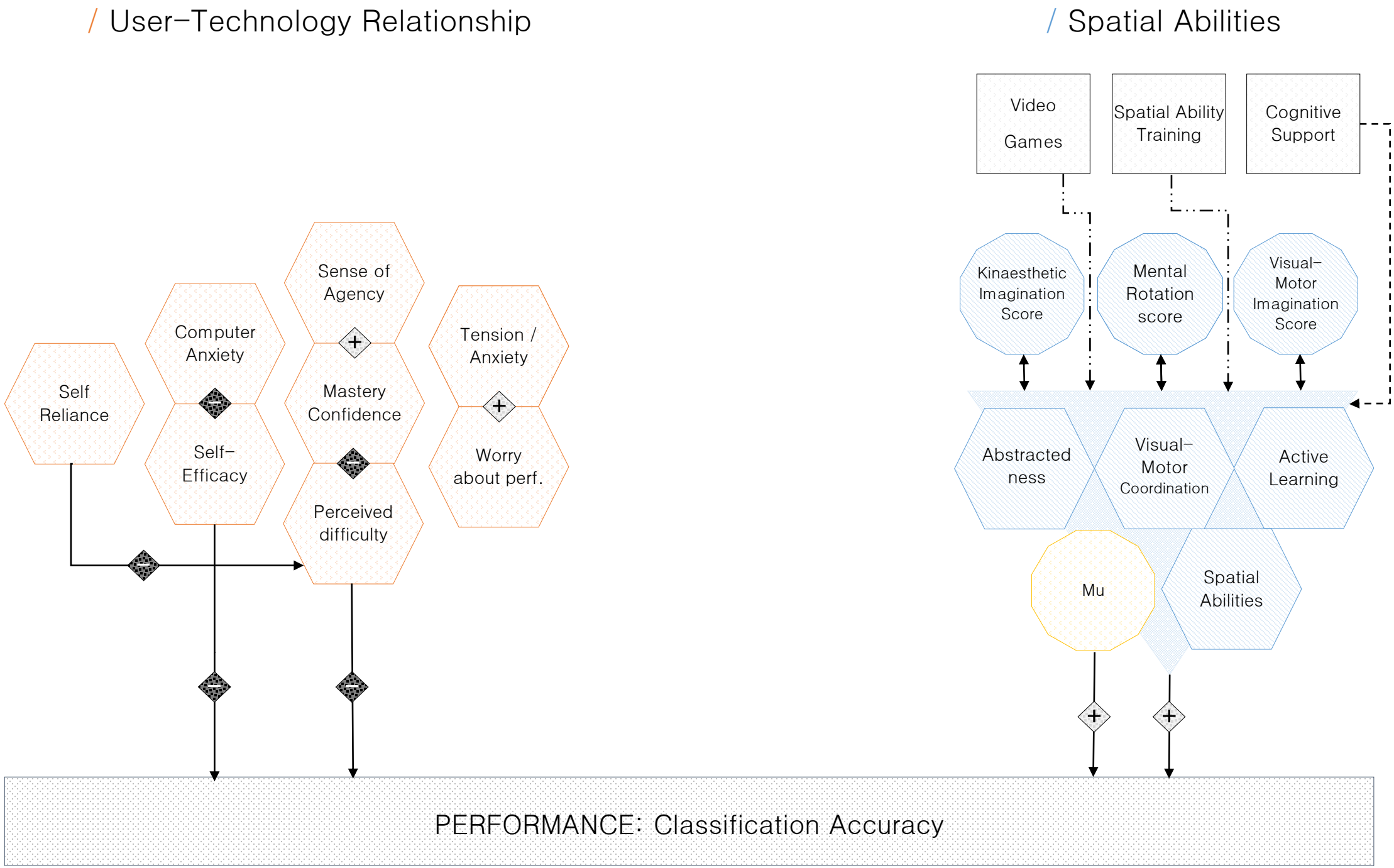
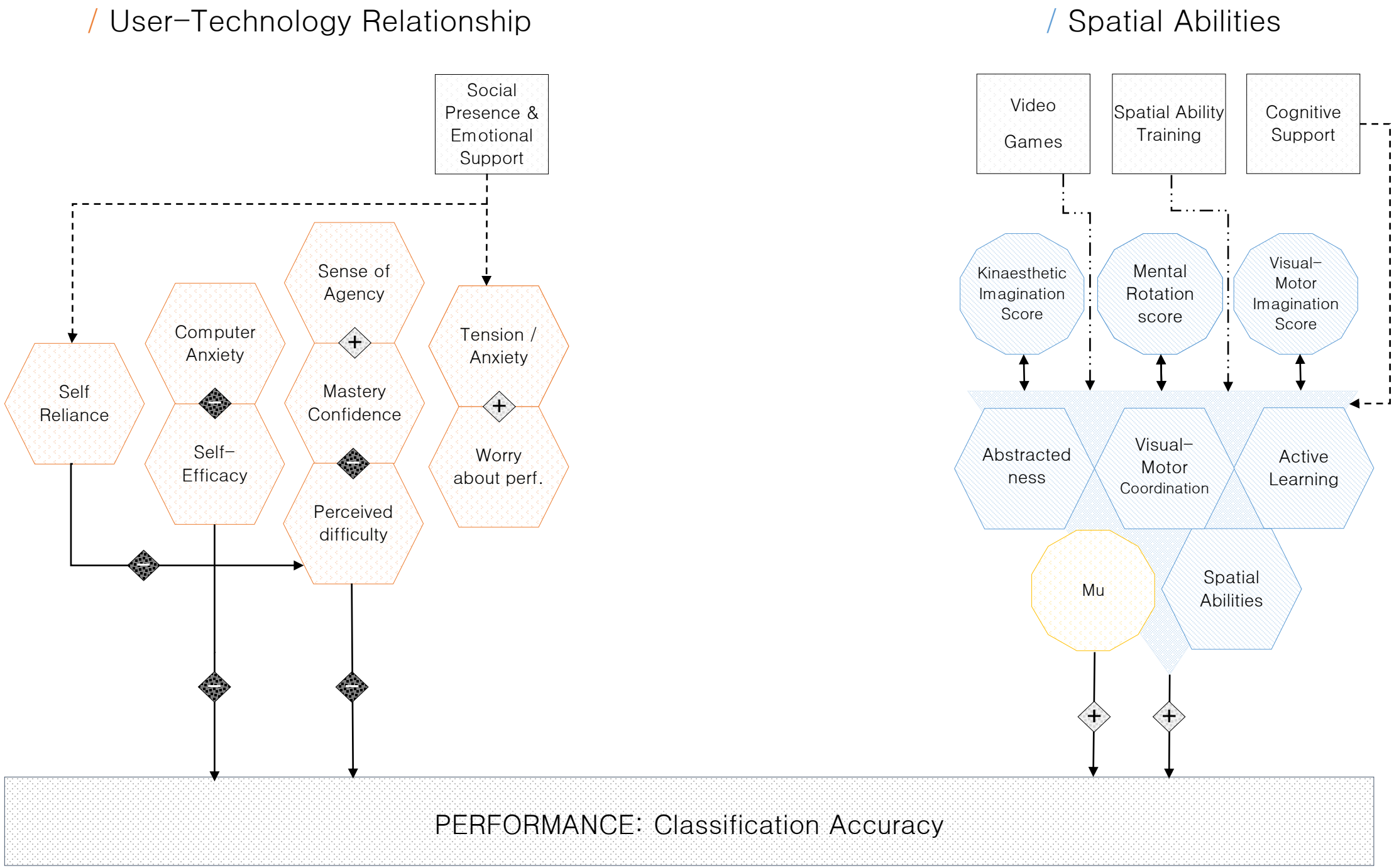



/ User–Technology Relationship
/ Spatial Abilities
Self Reliance
Computer Anxiety
Self–Efficacy
Sense of Agency
Mastery Confidence
Perceived difficulty
Tension / Anxiety
Worry about perf.
Video Games
Spatial Ability Training
Cognitive Support
Kinaesthetic Imagination Score
Mental Rotation score
Visual–Motor Imagination Score
Abstractedness
Visual–Motor Coordination
Active Learning
Mu
Spatial Abilities
PERFORMANCE: Classification Accuracy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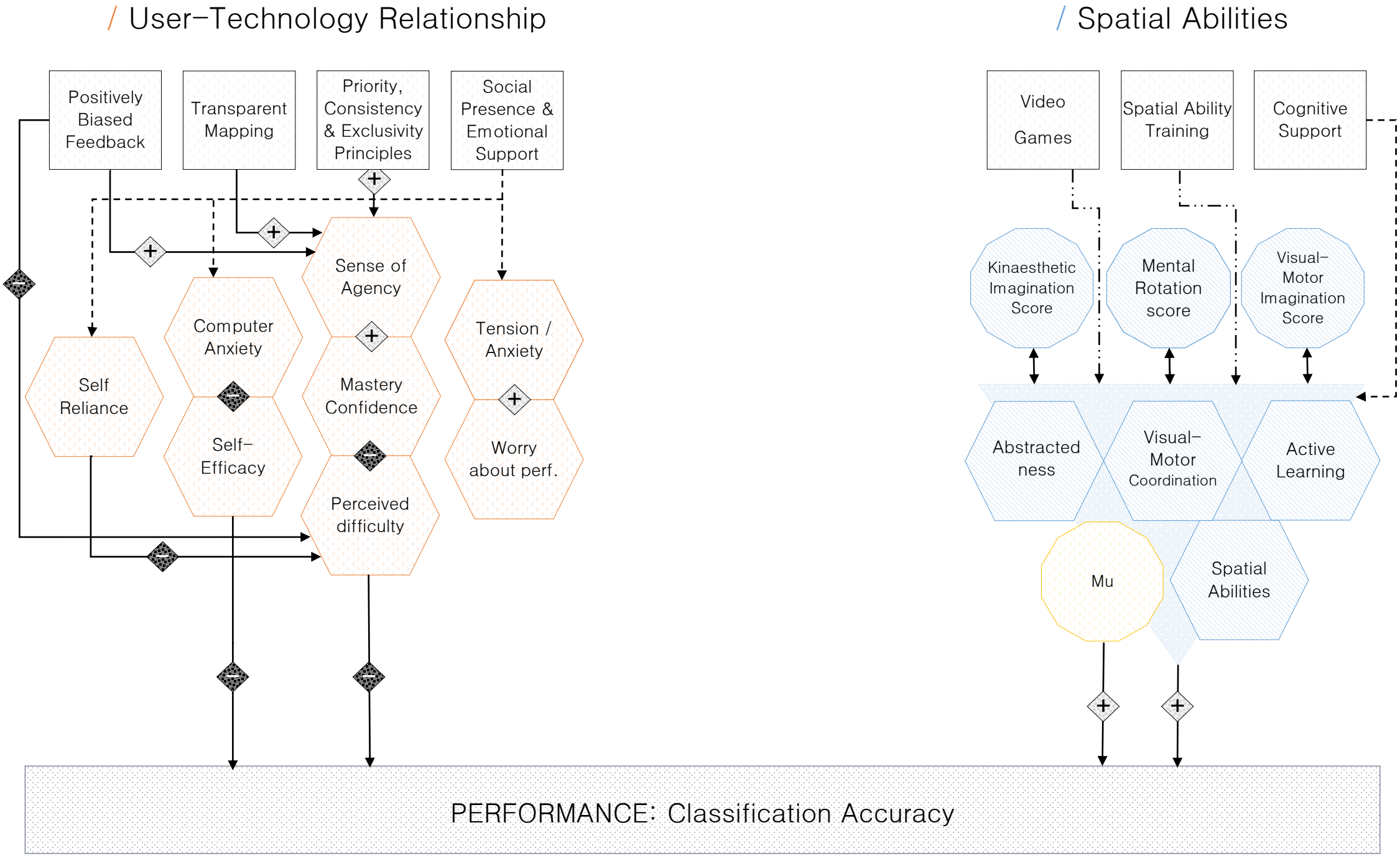
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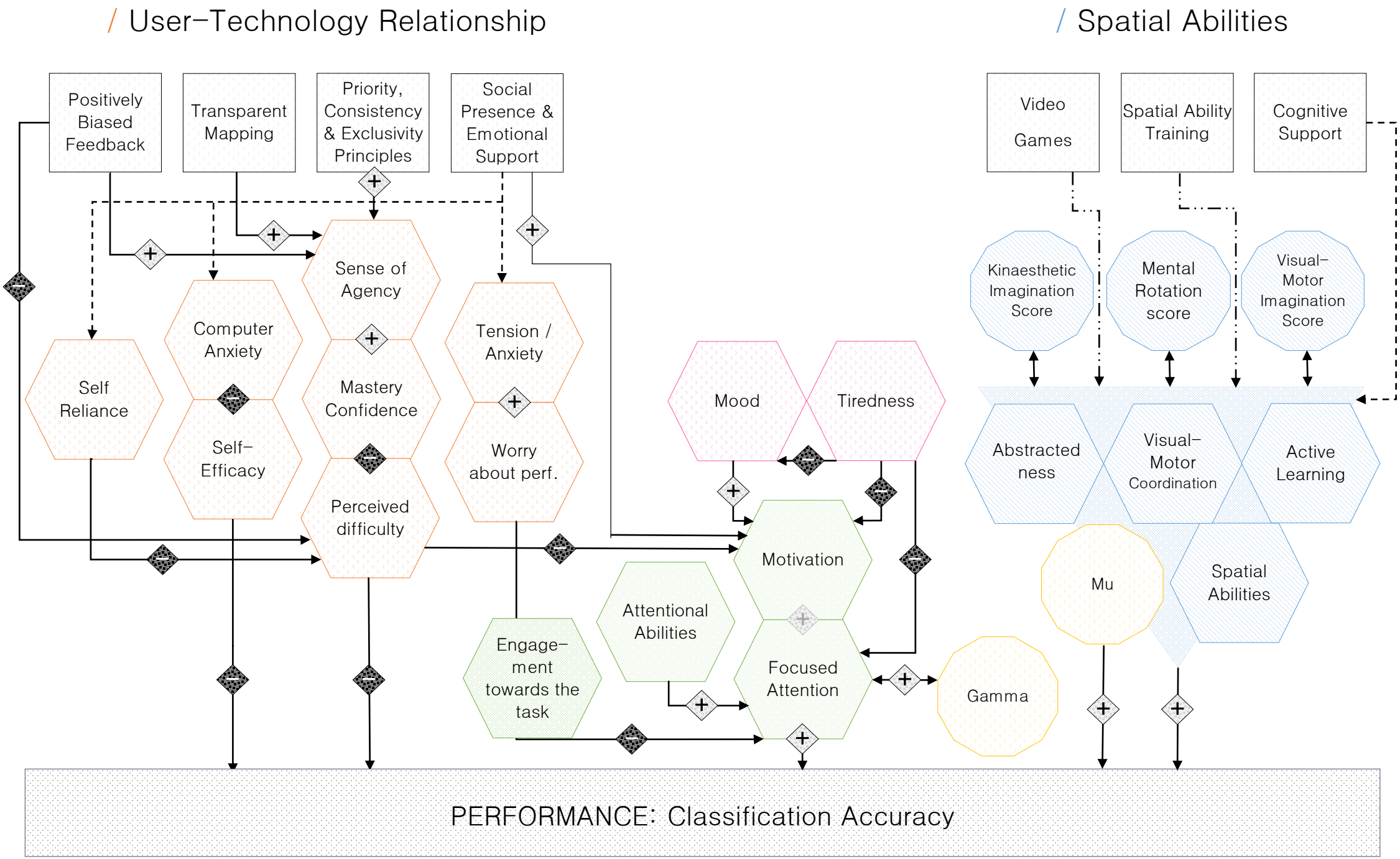
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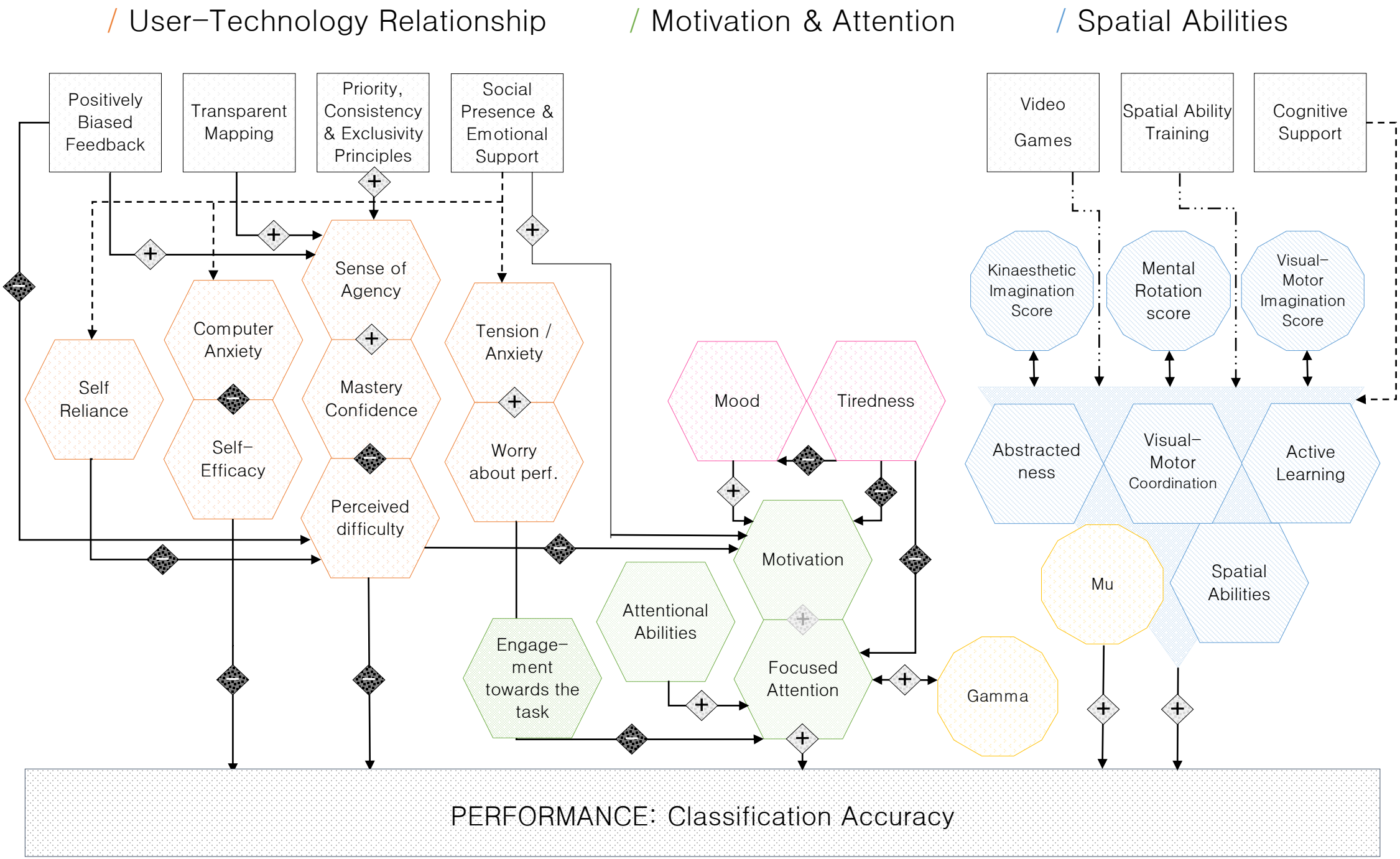
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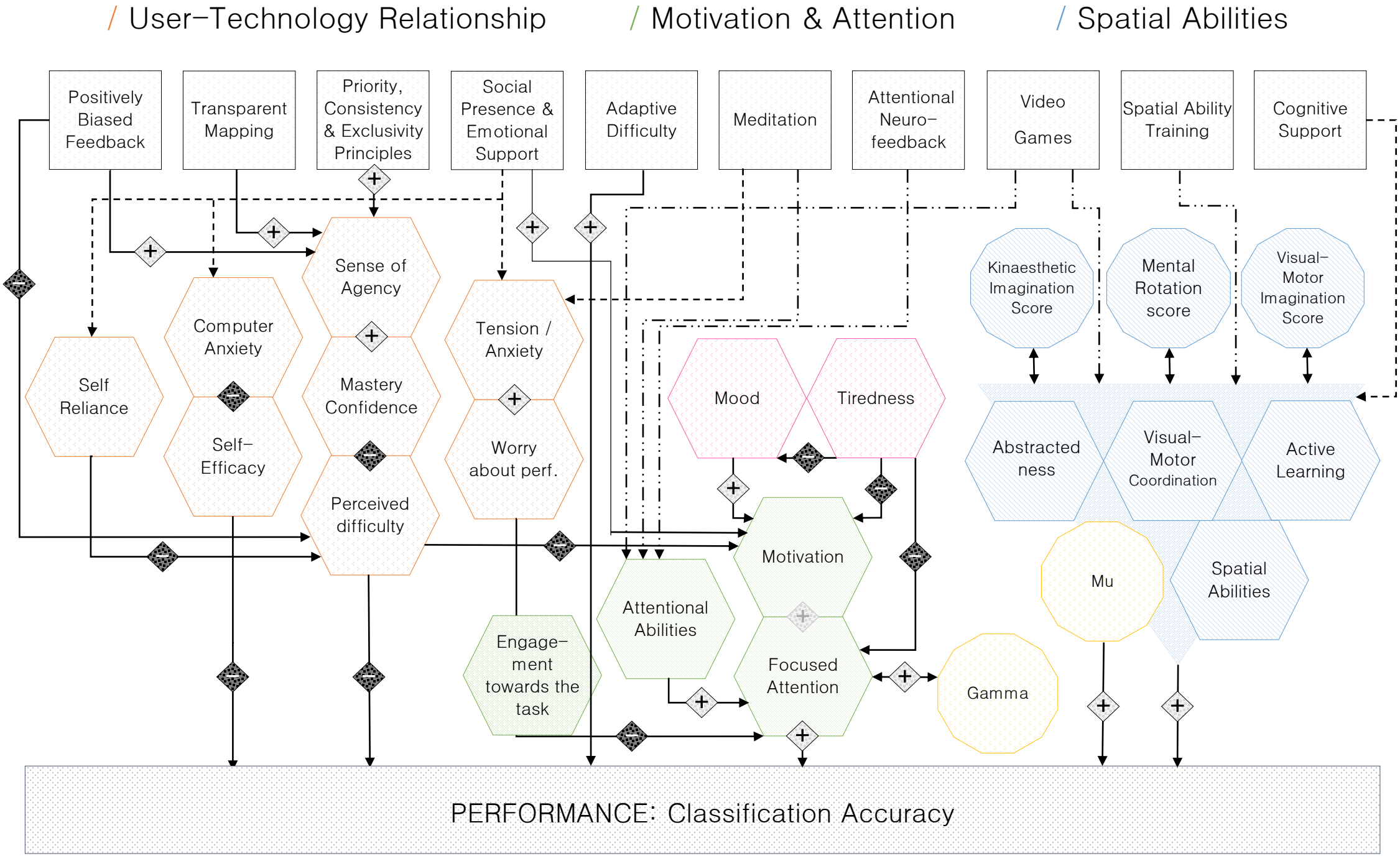
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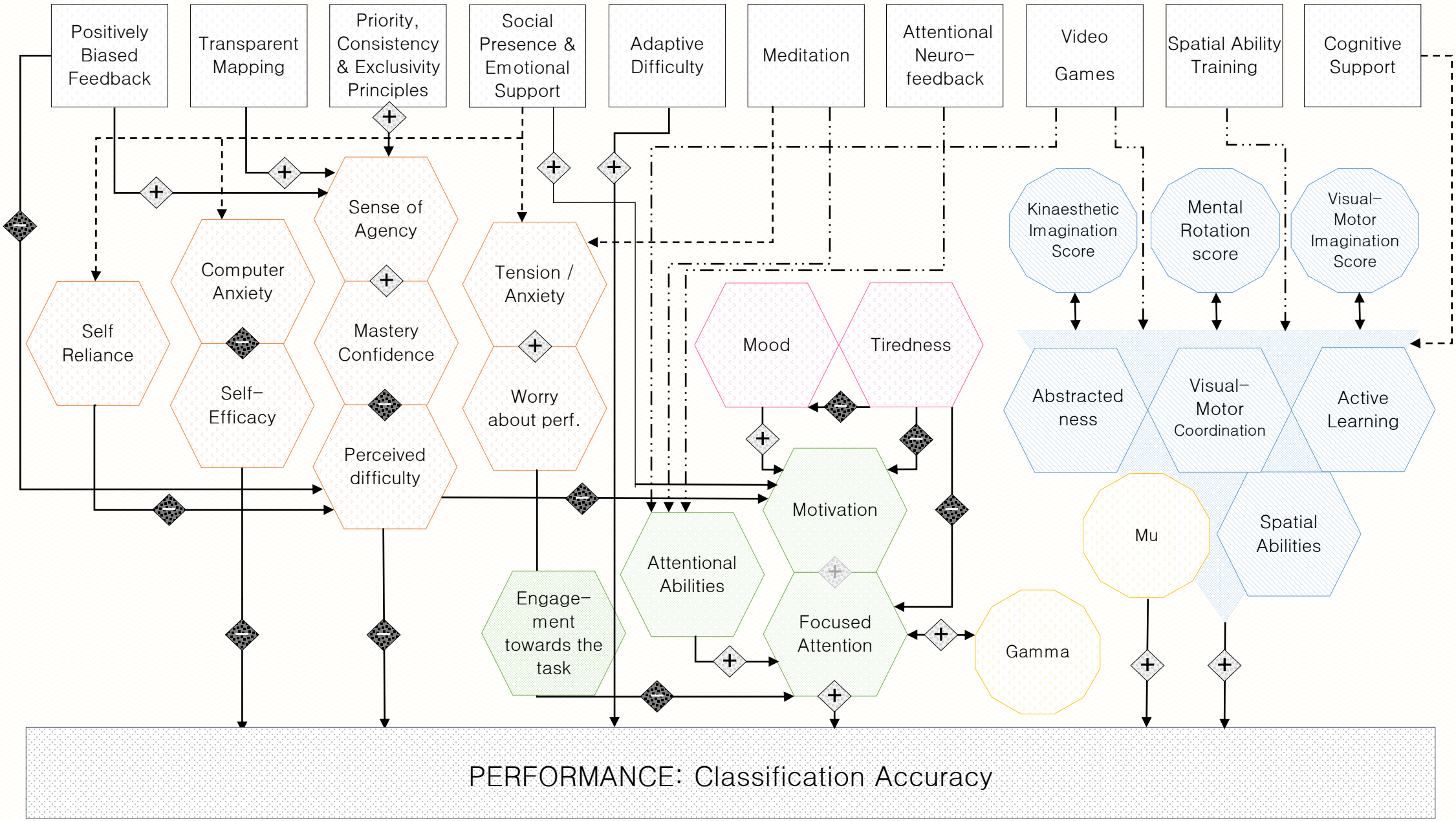
PERFORMANCE: Classification Accuracy

COGNITIVE MODEL OF MI-BCI TASKS



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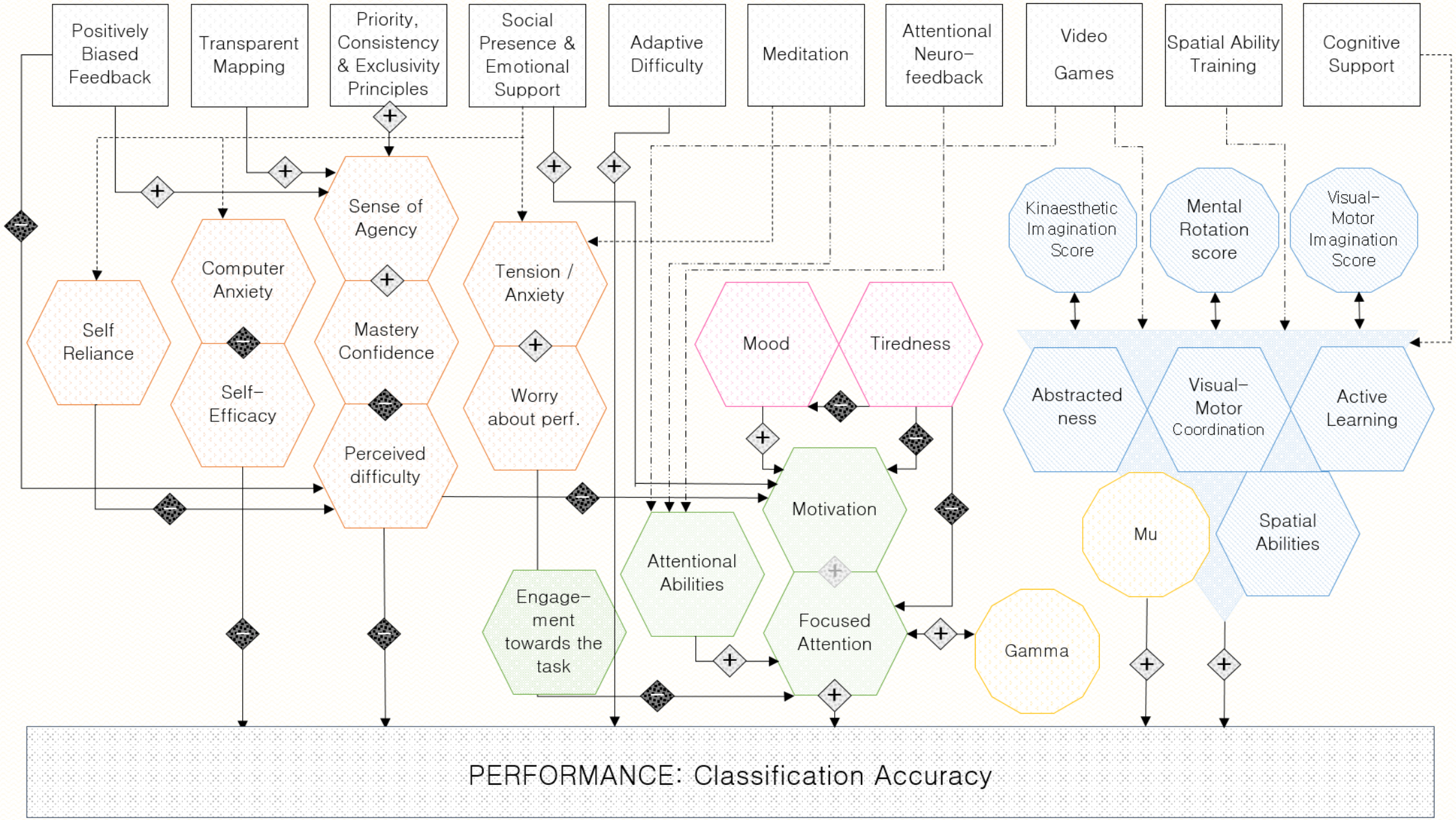

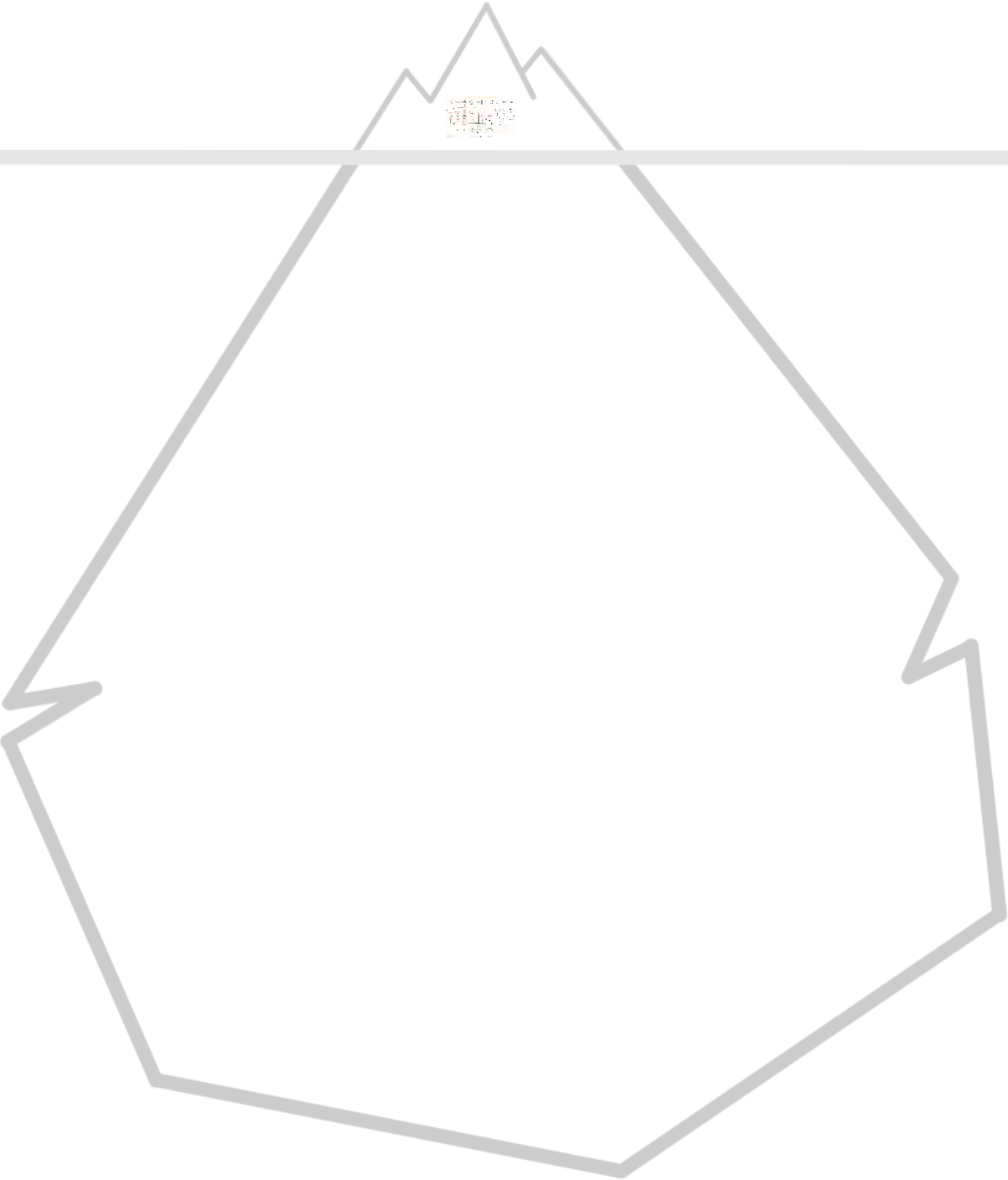

Part II

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.

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Brain-Computer Interfaces for the Analysis and Training of Athletes' Performance.

[Biomechanics]

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

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[Biomechanics]

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[Social]

[Cognitive]

[Psychological]

[Neurophysiological]

Object of the Project EEG & Sport

Brain-Computer Interfaces for the Analysis and Training of Athletes' Performance.

[Biomechanics]

[Physiology]

[Mental State]

[Social]

[Cognitive]

[Psychological]

[Neurophysiological]

First Study

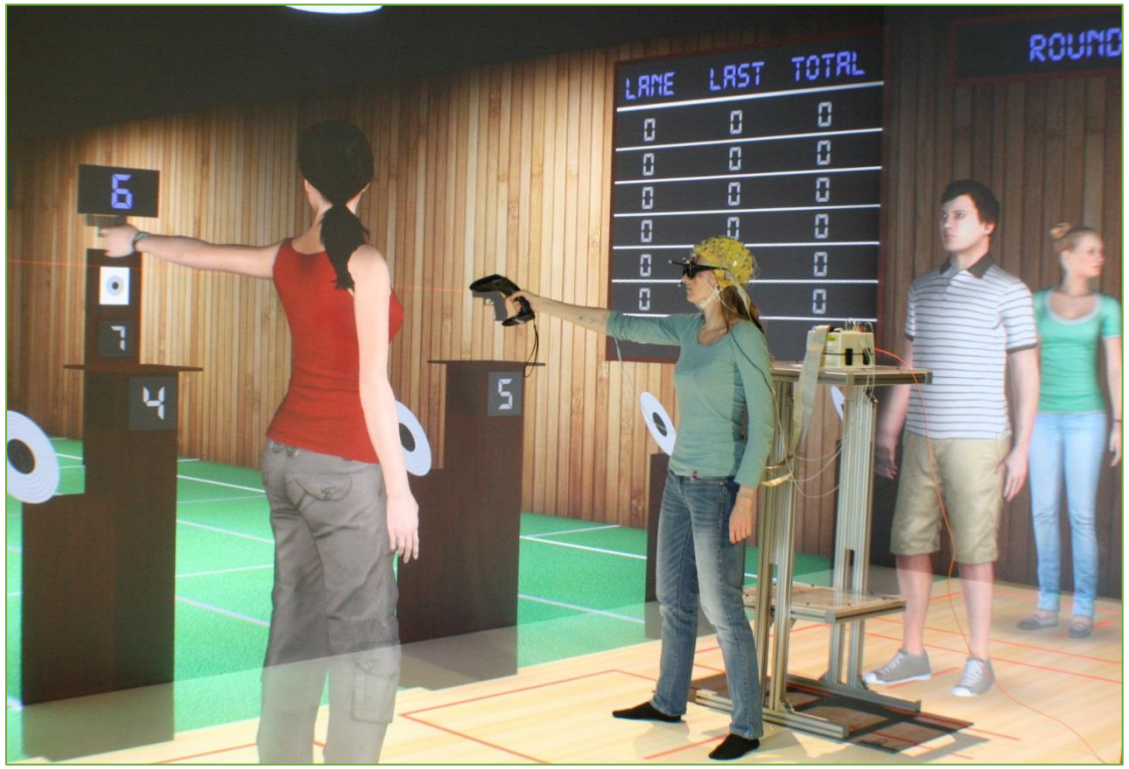
OBJECT –

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

METHODS –

Virtual Reality Environment

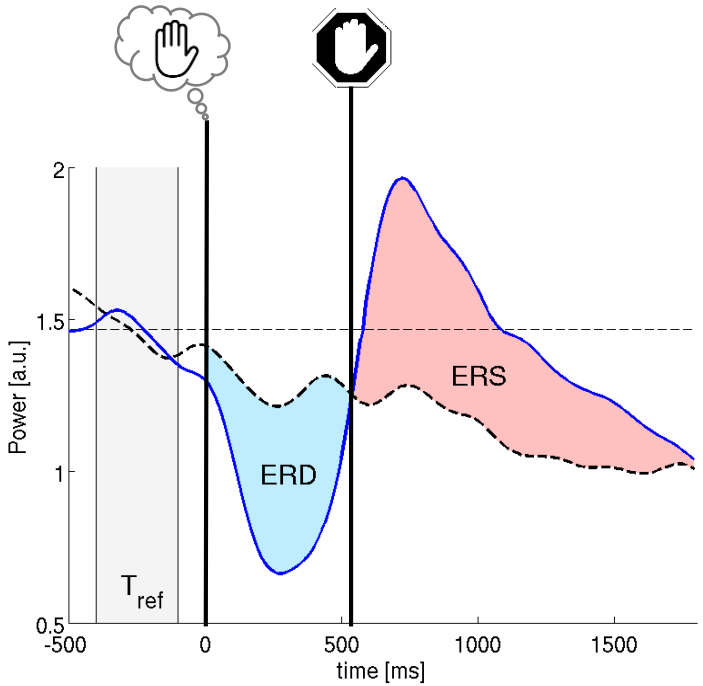
Training vs. Competition



[Pereira et al. – Submitted]

First Study

RESULTS –

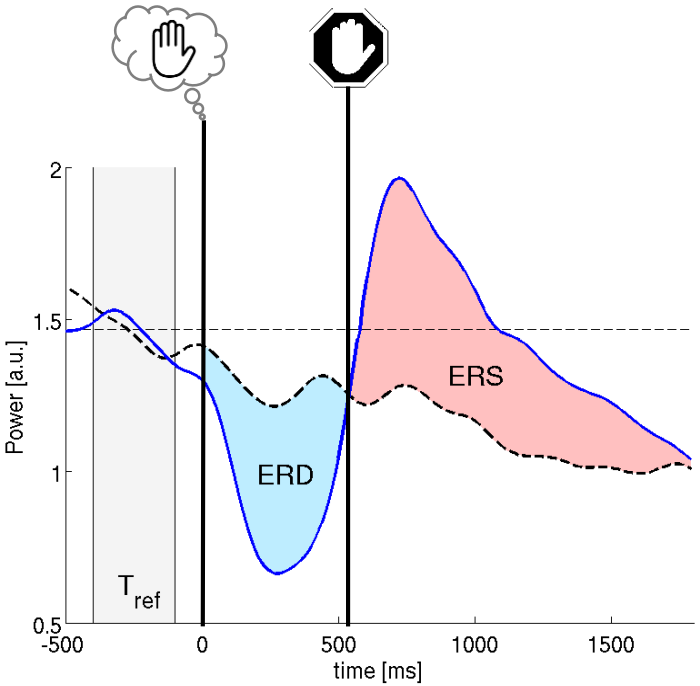


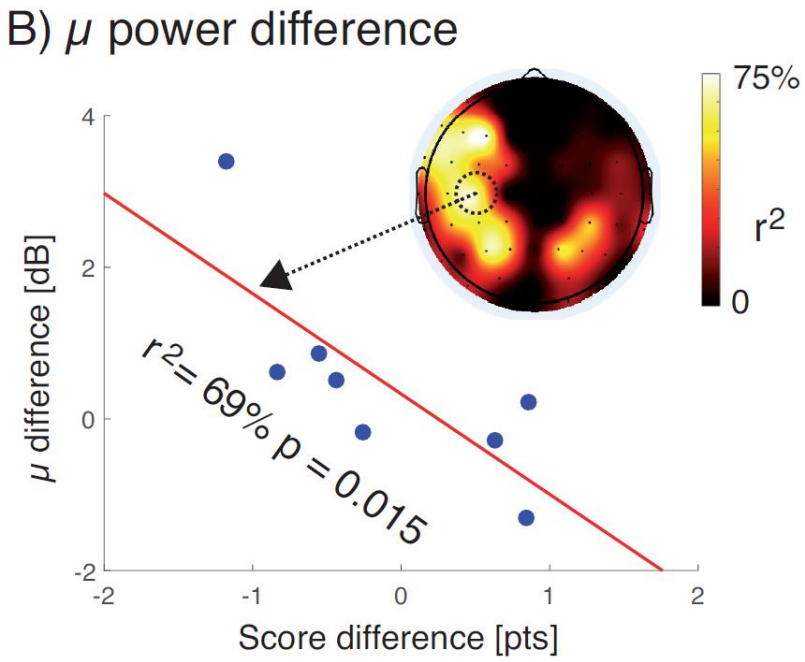
[Pfurtscheller & Lopes da Silva (1999) – Clinical Neurophysiology]

First Study

RESULTS –

Difference between Training & Competition





[Pereira et al. – Submitted]

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!

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Inria INVENTORS FOR THE DIGITAL WORLD

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 Chavarriage – EPFL

Camille Jeunet

Workshop of the
EPFL–Inria International Lab --
2017-02-07