

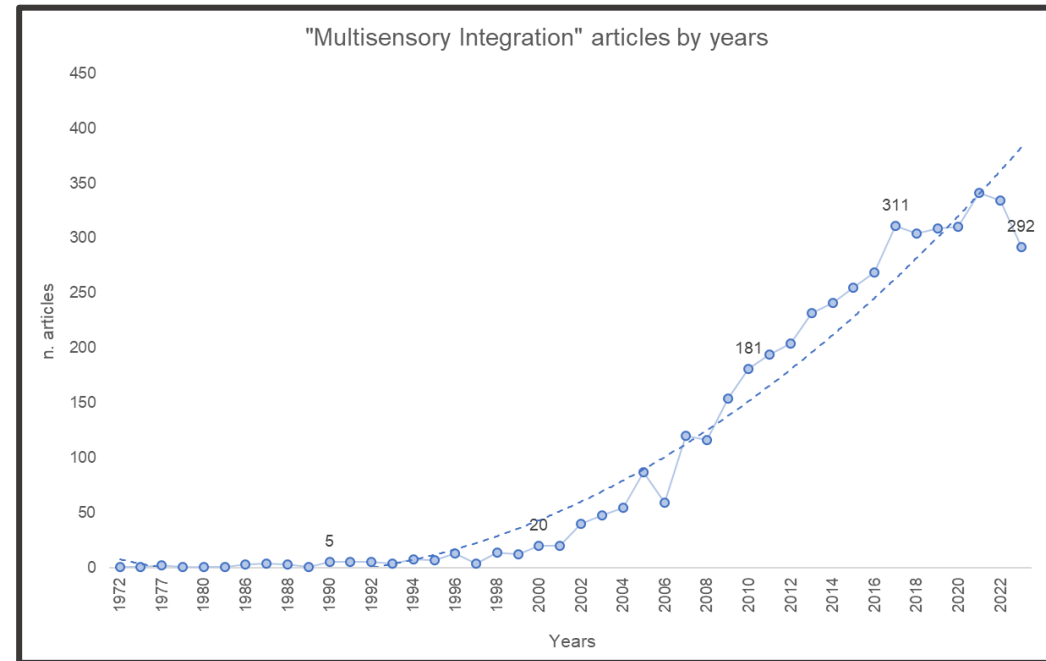
# **Multisensory integration 40 years later: three outstanding topics on the table**

Chairs: Martina Ardizzi, Francesca Ferroni

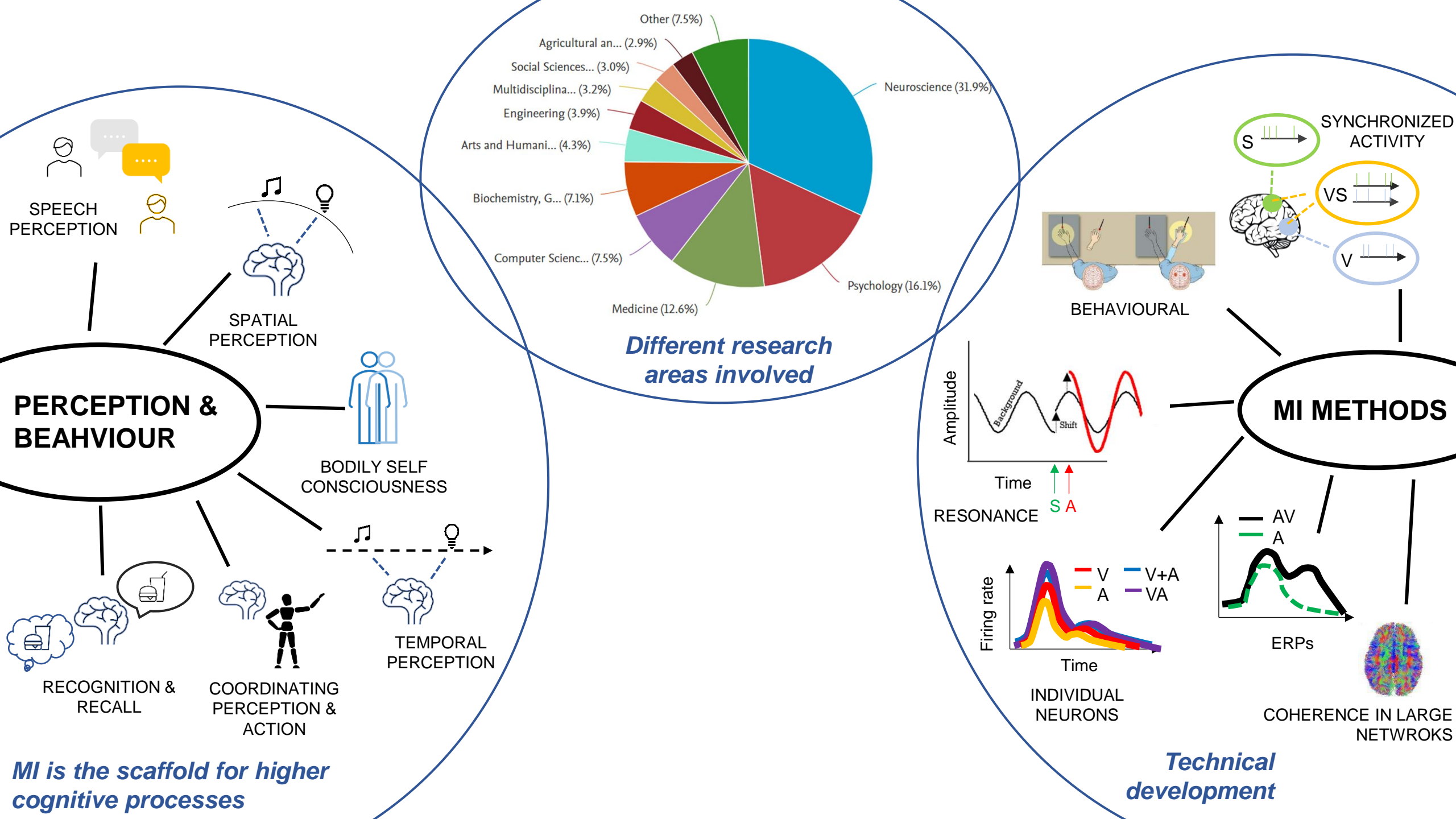
Speakers: Tommaso Bertoni, Valentina Bruno, Francesca Rastelli

*9 novembre 2023, Siena*

# The rapid growth of interest in multisensory integration



4.609 documents found  
*Scopus* source



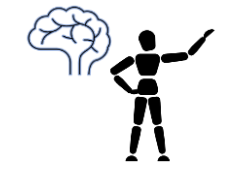
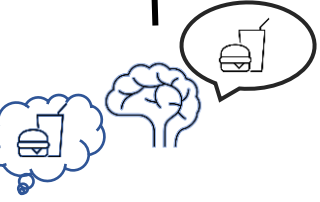
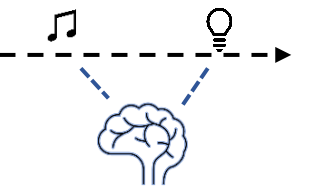
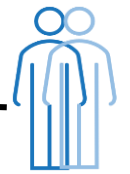
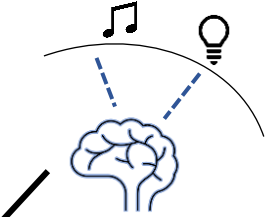
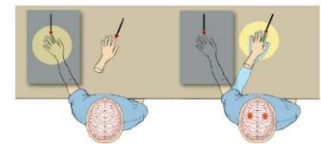
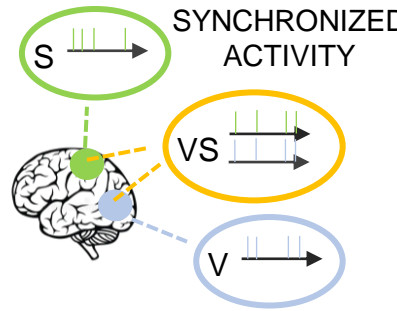
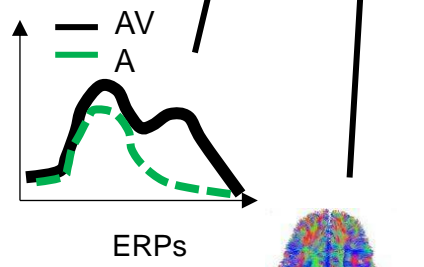
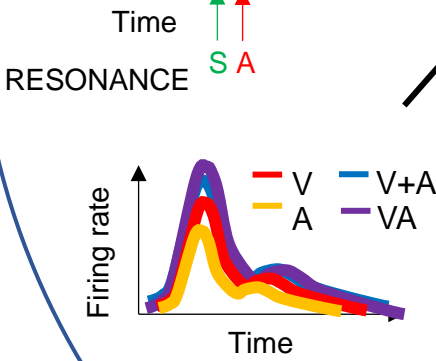
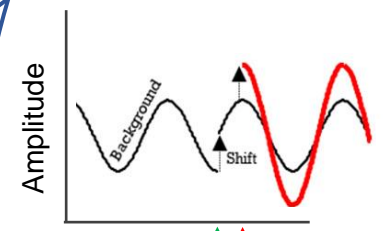
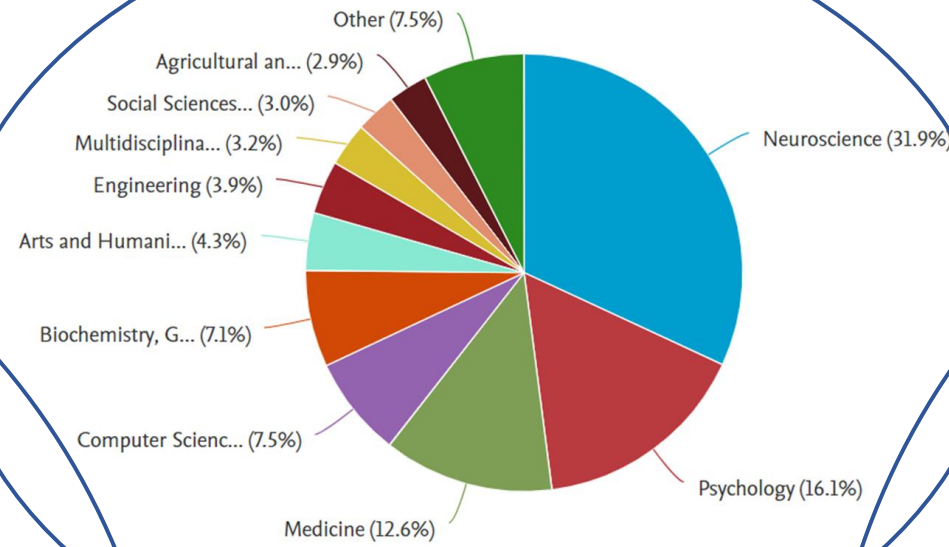
# PERCEPTION & BEHAVIOUR

# Different research areas involved

# MI METHODS

# Technical development

*MI is the scaffold for higher cognitive processes*



# THREE OUTSTANDING TOPICS... WITH THREE GLAMOUR SPEAKERS!!!



Multisensory integration in  
peripersonal space frames  
different states of  
consciousness

***Tommaso Bertoni***  
***(Losanna, Svizzera)***



The role of motor context in  
multisensory integration  
development

***Valentina Bruno***  
***(Torino, Italia)***



Multisensory integration in  
psychopathology

***Francesca Rastelli***  
***(Parma, Italia)***

*SIPF, Siena, 2023*

# **A neurophysiological marker of multisensory integration in peripersonal space indexes different states of consciousness**

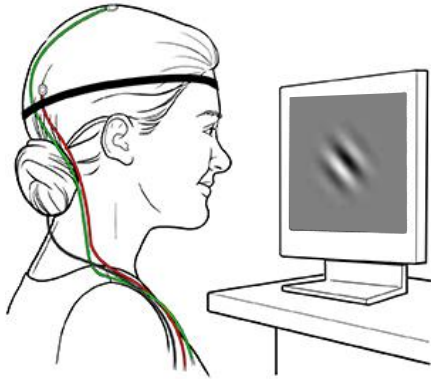
*Tommaso Bertoni*



# Bodily self-consciousness

---

What is consciousness?



Did you see that?

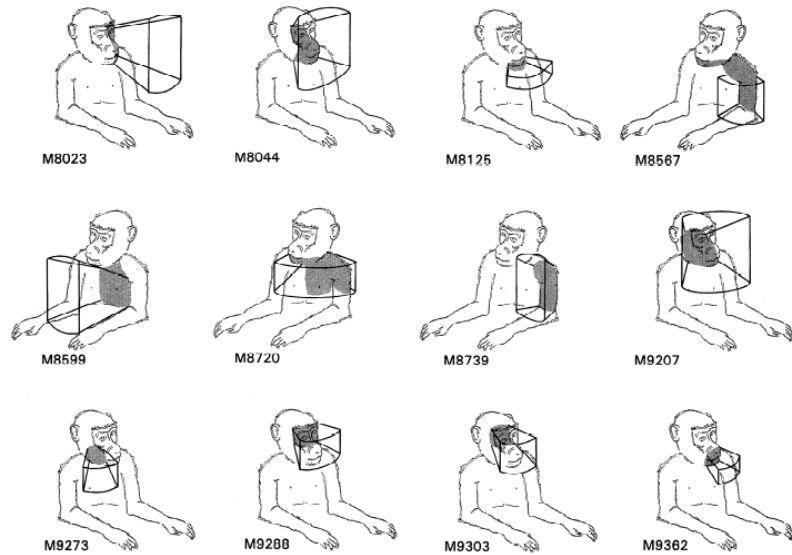
Is all really that simple?

To be aware of something implies being to some extent conscious of oneself (Aristotle)

Conscious experience is entangled with perceiving oneself and the environment, from an **embodied, first-person perspective** (Gallagher 2000, Blanke & Metzinger 2009) -> **bodily self-consciousness**

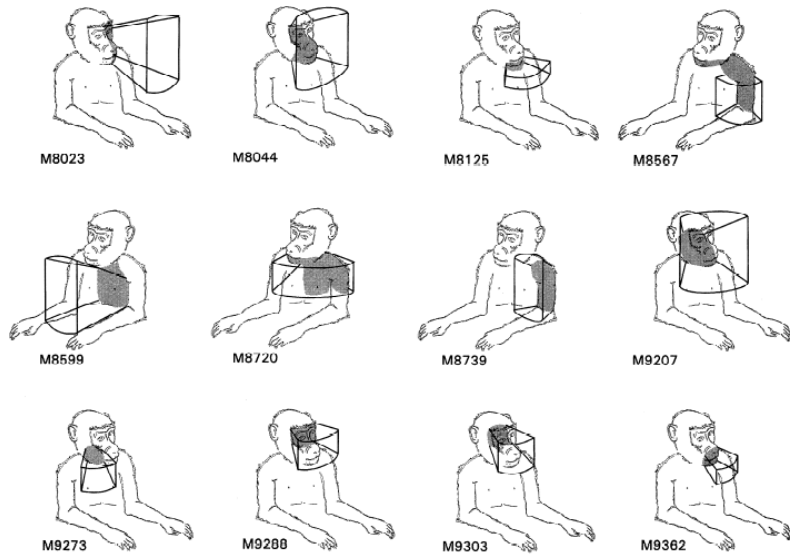
# Peripersonal space representation...

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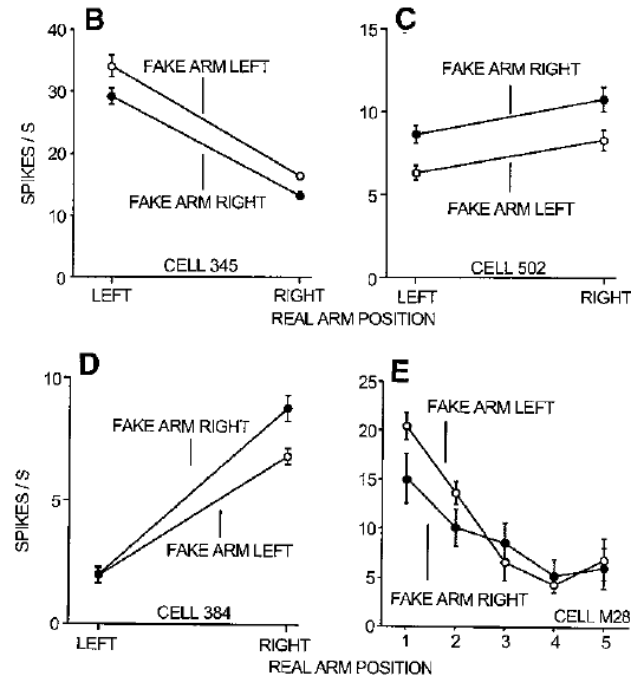


Neurons that represent peripersonal space or **PPS**, have **overlapping tactile and visual receptive fields** (Fogassi et al., 1996).

# Peripersonal space representation...



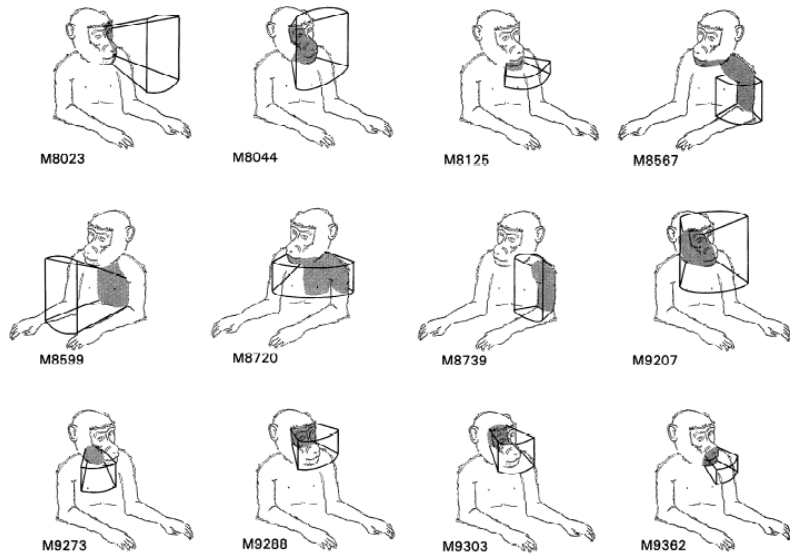
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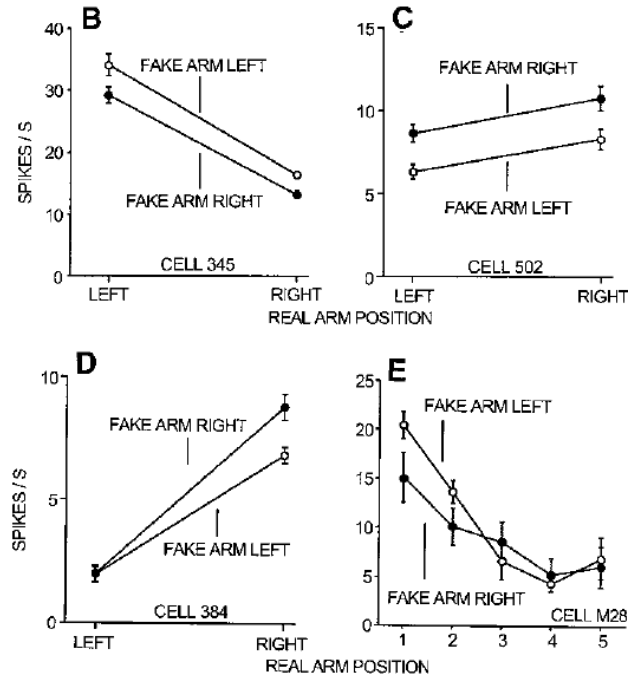
Their receptive fields can **anchor to fake limbs** after visuotactile stimulation (Graziano, 2000)



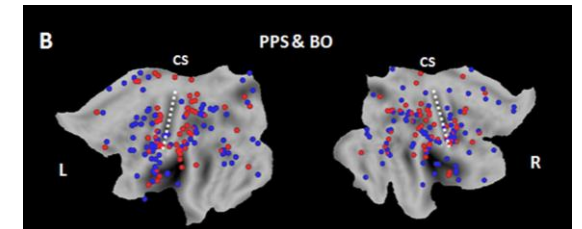
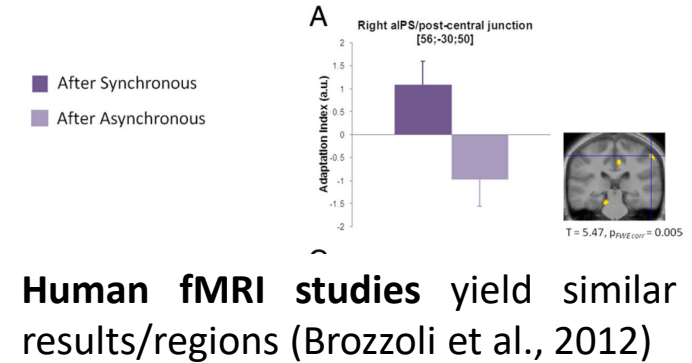
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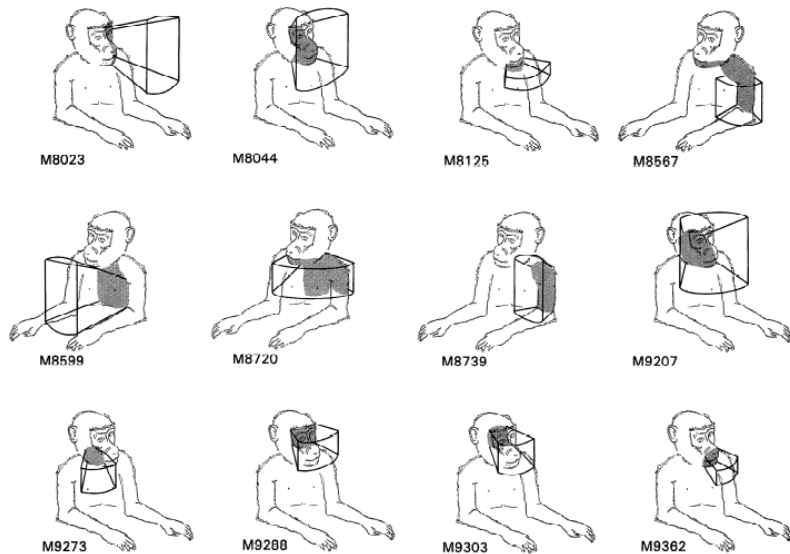


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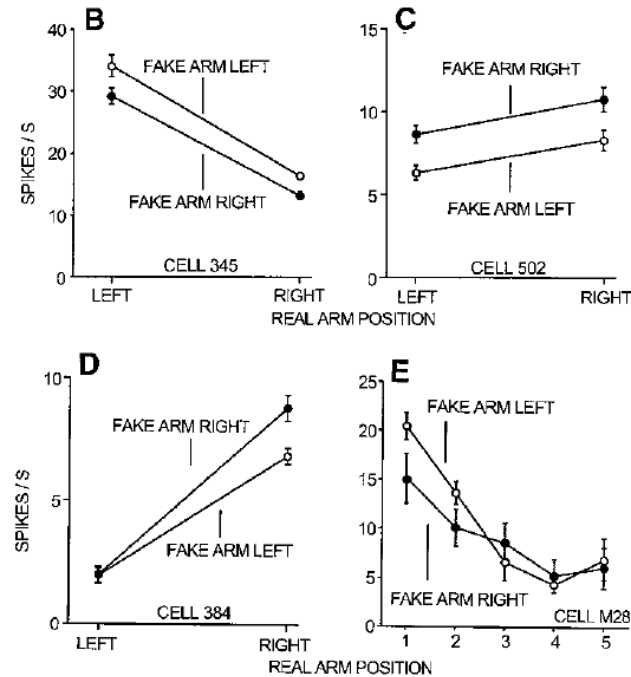
**PPS and body ownership networks show overlap** at the intraparietal sulcus (Grivaz et al., 2017)

# Peripersonal space representation...

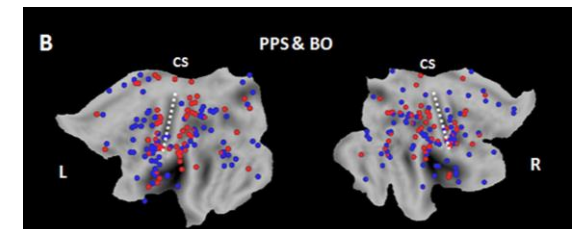
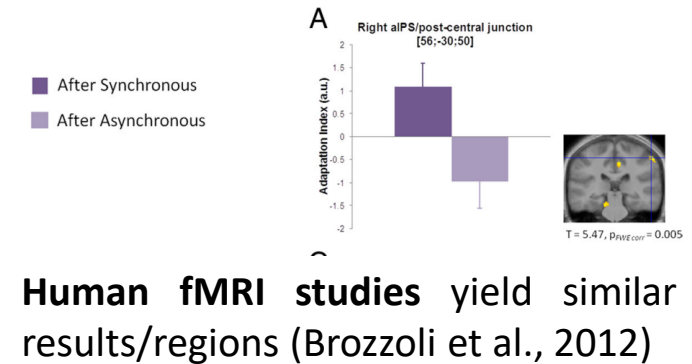


Neurons that represent peripersonal space or **PPS**, have **overlapping tactile and visual receptive fields** (Fogassi et al., 1996).

The «**PPS system**», i.e., the capability to **create a body centered, multisensory representation of space**, has something to do with our capability to experience the world from an embodied, first person perspective



Their receptive fields can **anchor to fake limbs** after visuotactile stimulation (Graziano, 2000)



**PPS and body ownership networks** show **overlap** at the intraparietal sulcus (Grivaz et al., 2017)

...as a hallmark of consciousness?

---

What happens to PPS representation when consciousness fades?

...as a hallmark of consciousness?

---

What happens to PPS representation when consciousness fades?



**Experiment 1:** During deep sleep



**F. Siclari**



**J. Cataldi**

# ...as a hallmark of consciousness?

What happens to PPS representation when consciousness fades?



**Experiment 1:** During deep sleep



**F. Siclari**



**J. Cataldi**



**Experiment 2:** In patients with disorders of consciousness (DOC)



**K. Diserens**



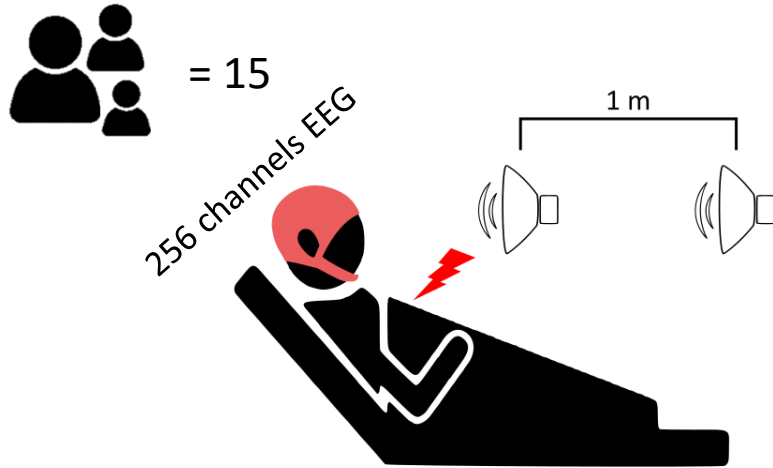
**J.P. Noel**



**G. Ricci**

# Experiment 1 – PPS and consciousness in wakefulness and sleep

## Wakefulness session



5 stimulation conditions,  
randomized every 4s

Tactile (T)

Near Auditory  
(AN)

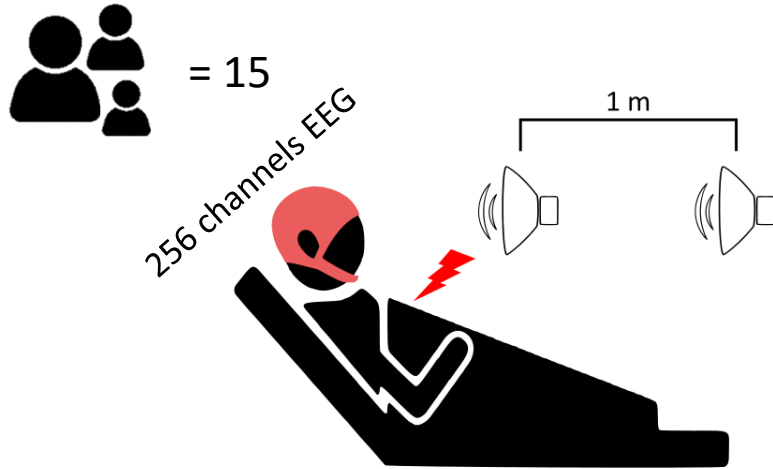
Far Auditory  
(AF)

Near  
Audiotactile  
(ANT)

Far  
Audiotactile  
(AFT)

# Experiment 1 – PPS and consciousness in wakefulness and sleep

## Wakefulness session



5 stimulation conditions, randomized every 4s

Tactile (T)

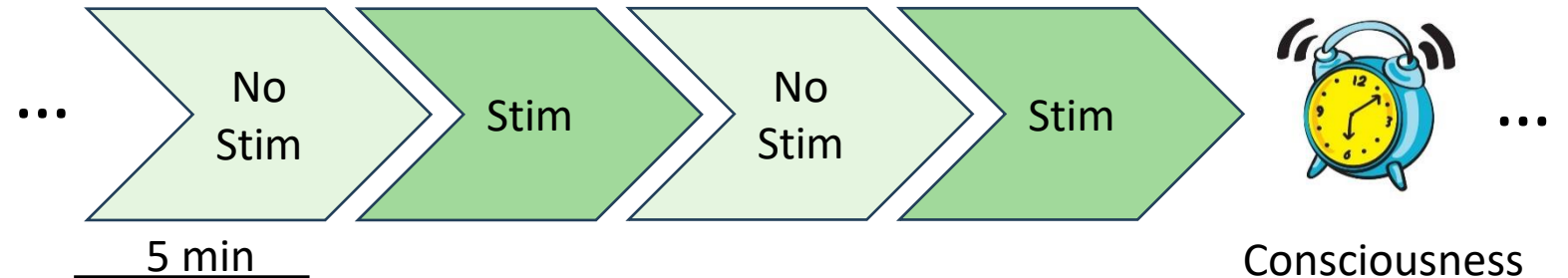
Near Auditory (AN)

Far Auditory (AF)

Near Audiotactile (ANT)

Far Audiotactile (AFT)

## Sleep session



Consciousness questionnaire (x6)

# High- $\beta$ power provides an EEG index of PPS representation

---

**Wakefulness session** as «ground truth» for PPS representation in conscious states

How to «detect» PPS representation? PPS is...

- **Space dependent**
- **Multisensory**
- **Body-centered**

→ PPS index = (AFT-ANT) – (AF-AN)

Multisensory  
near-far  
discrimination

Should be >

Unisensory  
near-far  
discrimination



# High- $\beta$ power provides an EEG index of PPS representation

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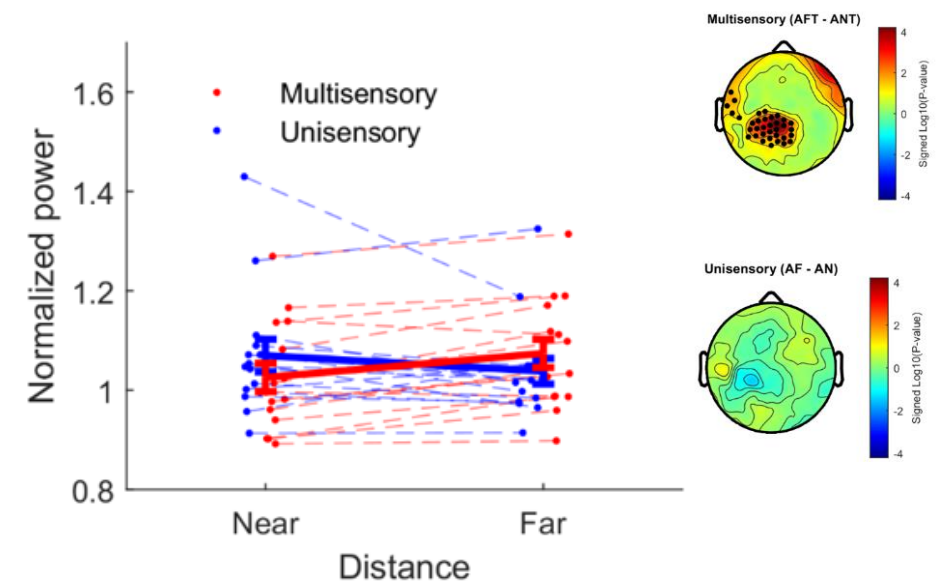
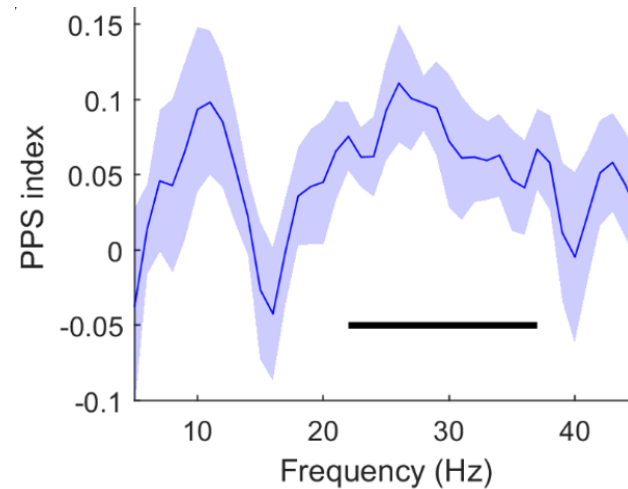
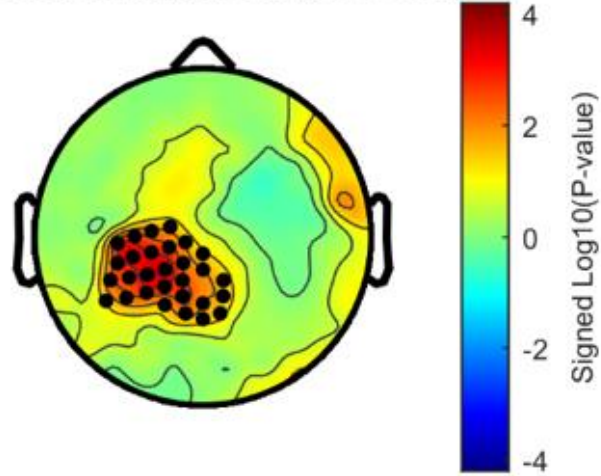
Should be >

Unisensory  
near-far  
discrimination

# High- $\beta$ power provides an EEG index of PPS representation

Wakefulness session as «ground truth» for PPS representation in conscious states

PPS index, high beta (20-30 Hz)

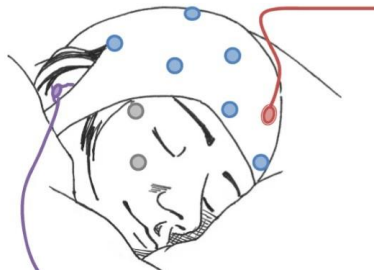


Significant **centro-parietal cluster** in the **high beta** band

Greater desynchronization for multisensory near stimuli (PPS-like)  
**Sensorimotor system activation?**

# Awakening protocol – behavioural results

---



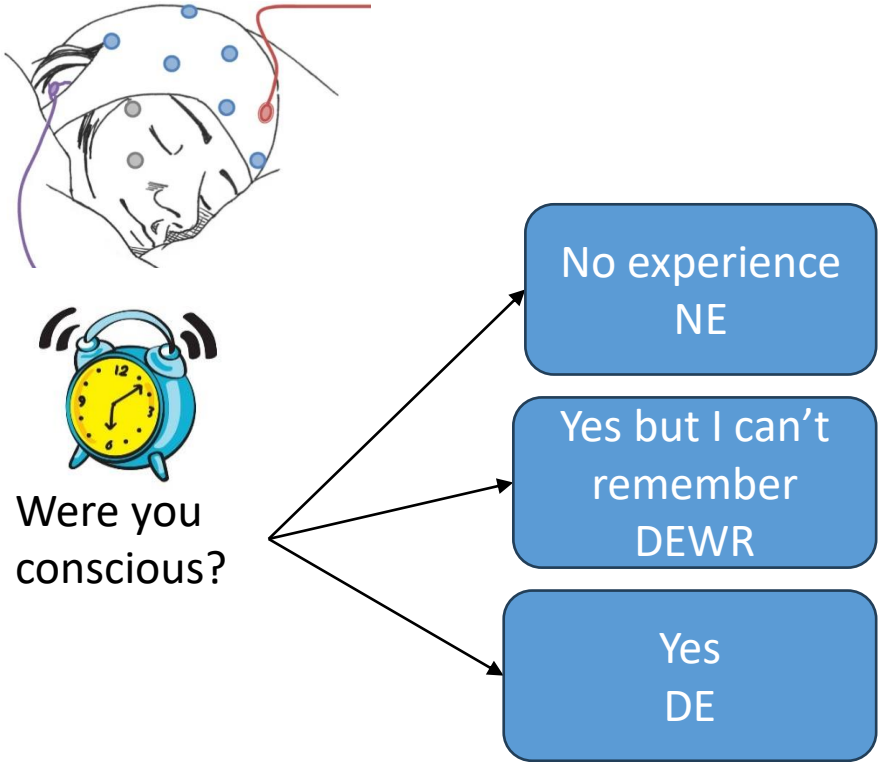
Were you  
conscious?

No experience  
NE

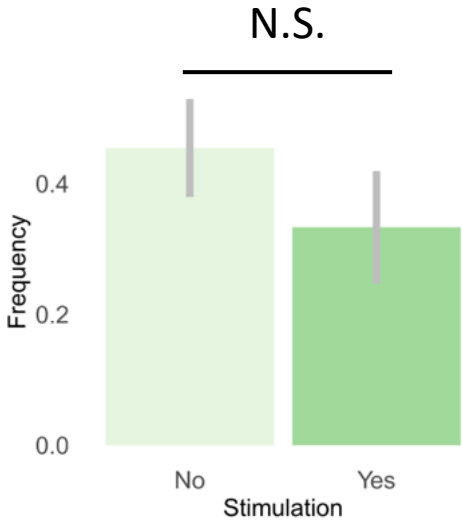
Yes but I can't  
remember  
DEWR

Yes  
DE

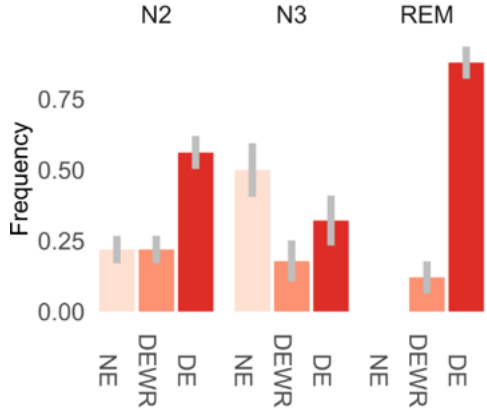
# Awakening protocol – behavioural results



Was the dream similar to the stimuli?

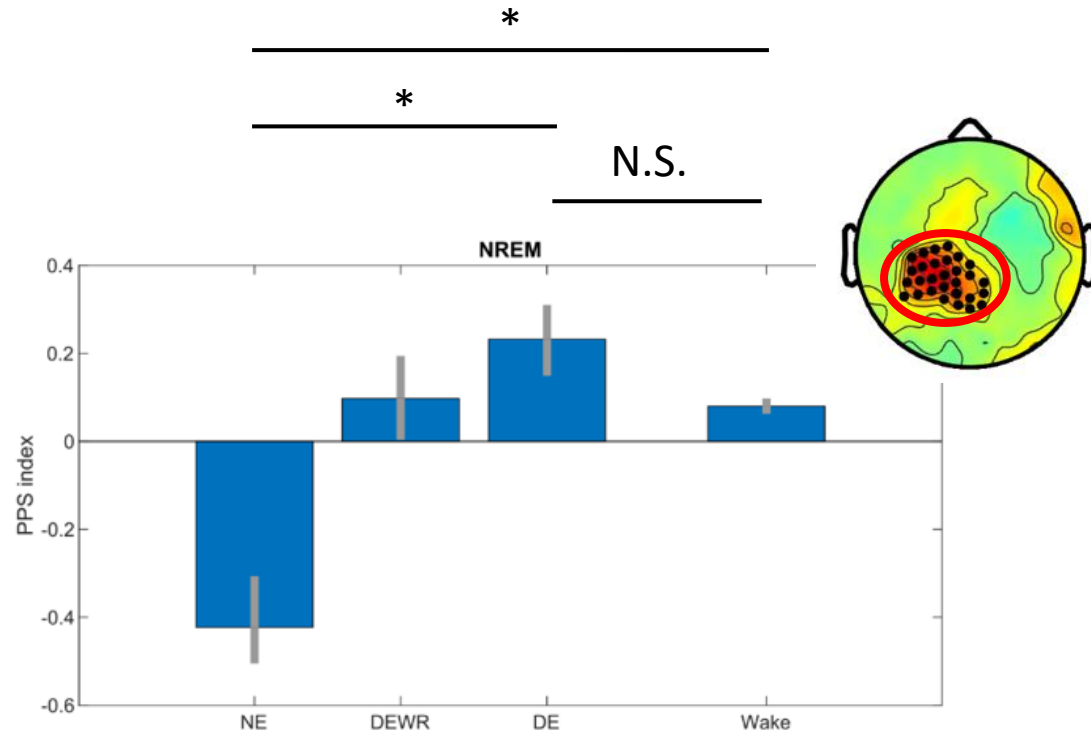


Stimulation not incorporated in dreams



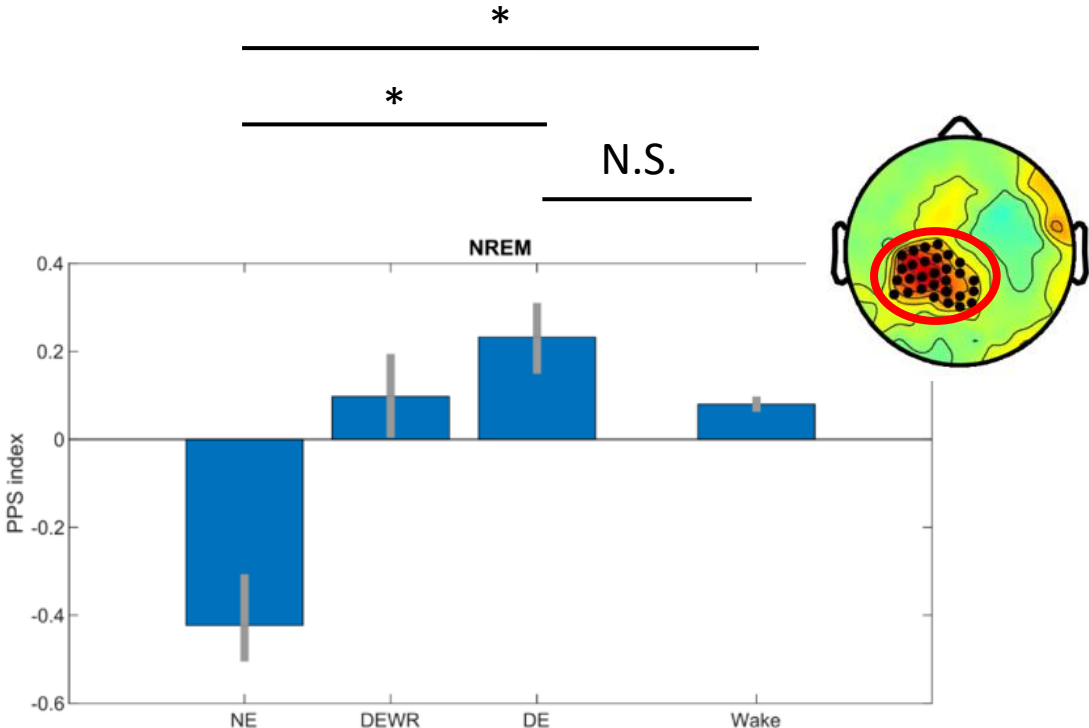
NE is more common in N3, absent in REM

# The High- $\beta$ PPS index differentiates conscious from unconscious sleep

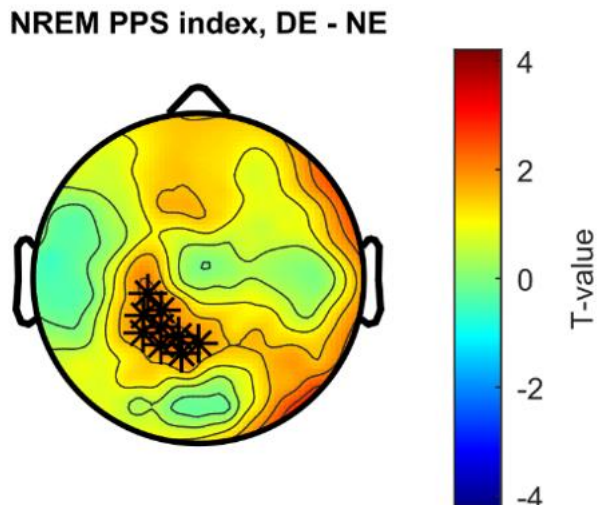


PPS index conscious dreaming sleep is similar to wakefulness and different from deep unconscious sleep

# The High- $\beta$ PPS index differentiates conscious from unconscious sleep



PPS index conscious dreaming sleep is similar to wakefulness and different from deep unconscious sleep



DE vs. NE comparison topography resembles the cluster where PPS is represented in healthy awake participants

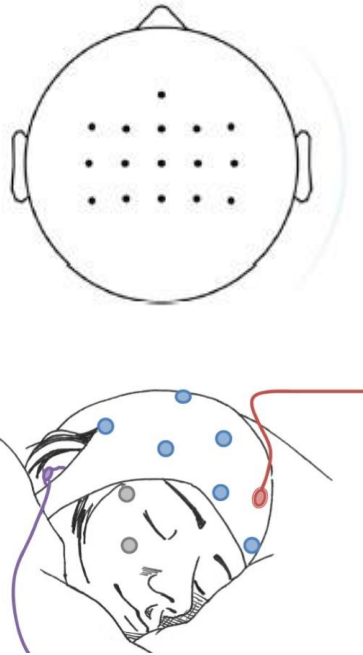
# Recap

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- The high- $\beta$  PPS index is a marker of covert consciousness
- Covert consciousness is a potential predictor of clinical outcome in disorders of consciousness patients
- Can we use the high- $\beta$  PPS index to predict clinical outcome in these patients?

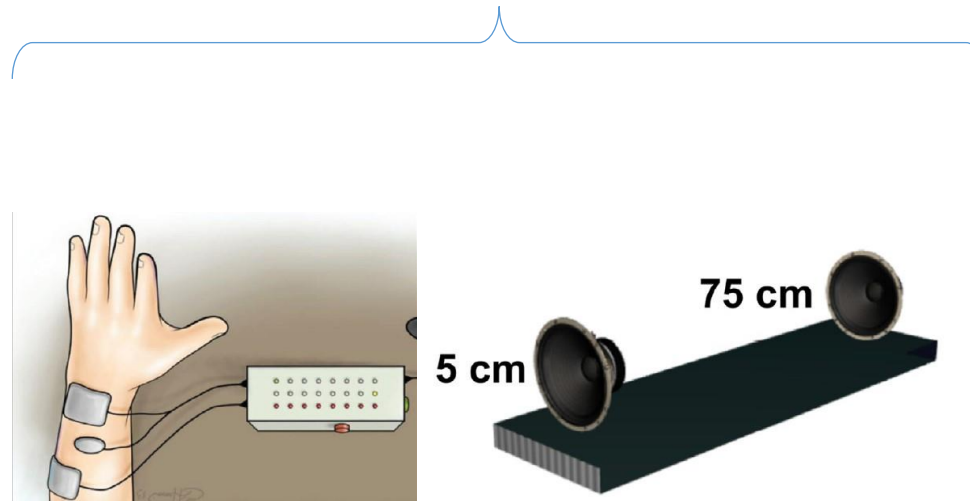
# Experiment 2 – PPS and consciousness in DOC patients

DOC/CMD patients – 16 electrodes



EEG recording

PPS audio-tactile paradigm



Tactile (T)

Near Auditory  
(AN)

Far Auditory  
(AF)

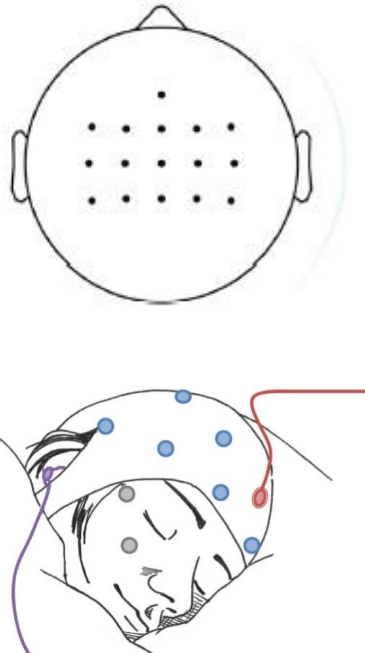
Near  
Audiotactile  
(ANT)

Far  
Audiotactile  
(AFT)



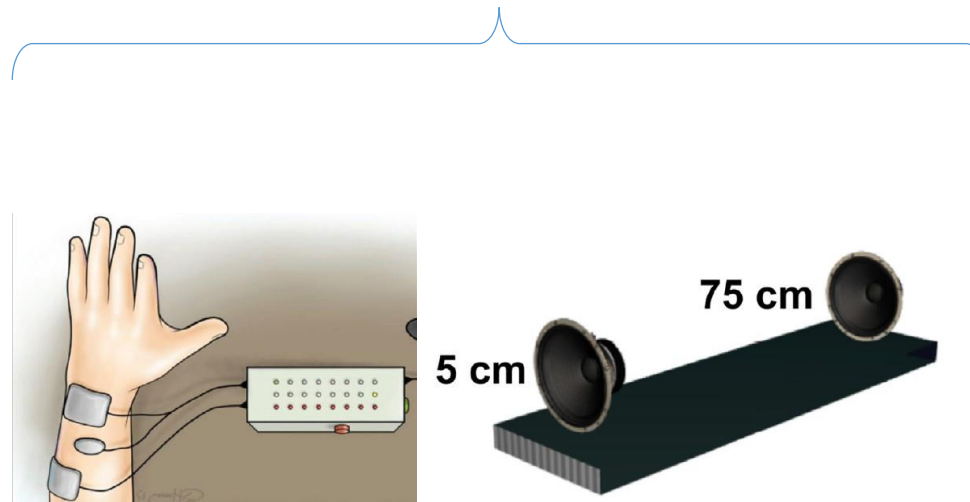
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EEG recording

PPS audio-tactile paradigm



Tactile (T)

Near Auditory (AN)

Far Auditory (AF)

Near Audiotactile (ANT)

Far Audiotactile (AFT)

 = 45

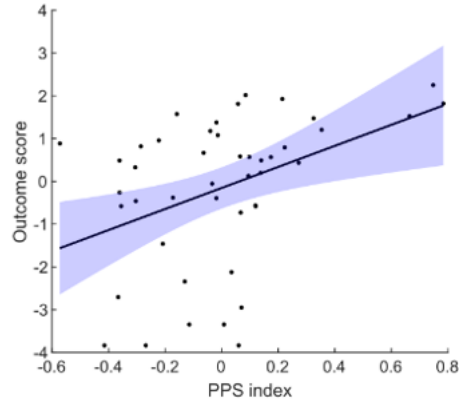
Acute neurorehabilitation admission



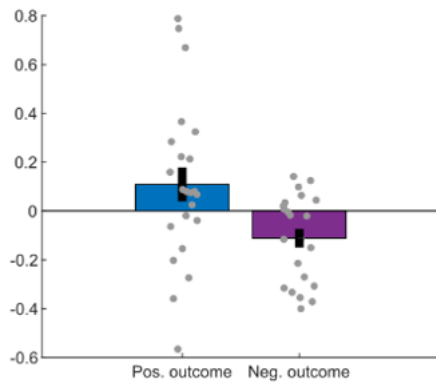
29±7 days

Discharge and clinical outcome evaluation

# The High- $\beta$ PPS index predicts clinical outcome in DOC patients

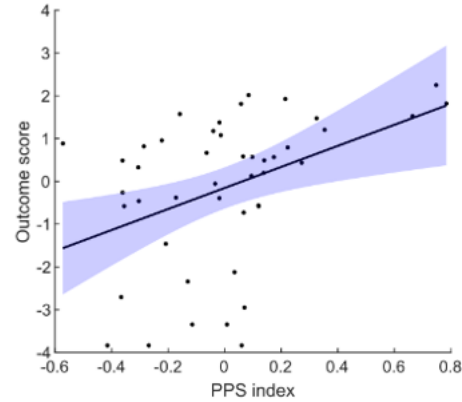


PPS index correlates with long-term clinical outcome

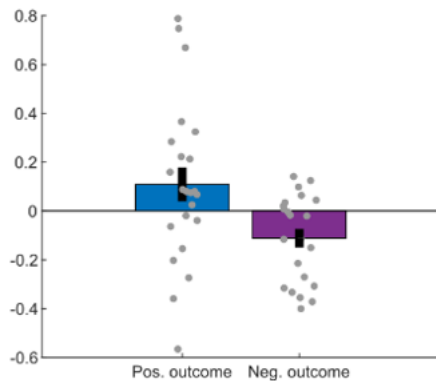


Higher PPS index is linked with more chances of recovery

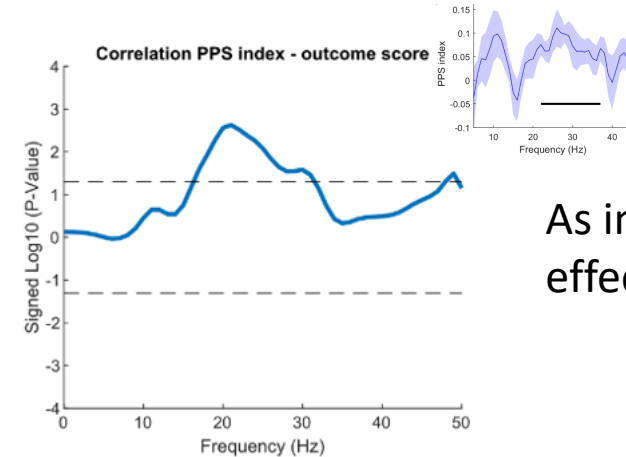
# The High- $\beta$ PPS index predicts clinical outcome in DOC patients



PPS index correlates with long-term clinical outcome



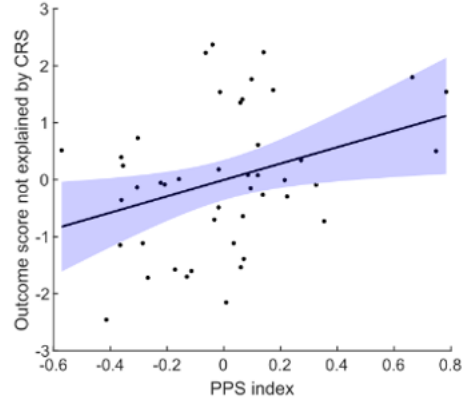
Higher PPS index is linked with more chances of recovery



As in healthy participants, the effect peaks in the beta band

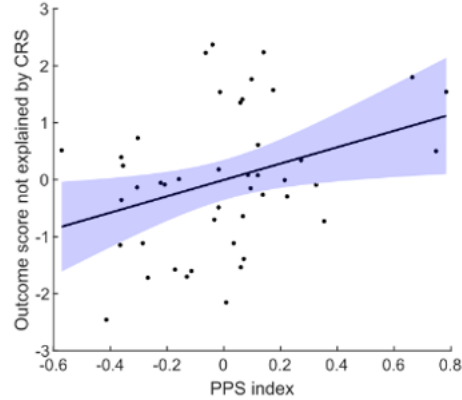
# The High- $\beta$ PPS index improves predictions from clinical evaluations

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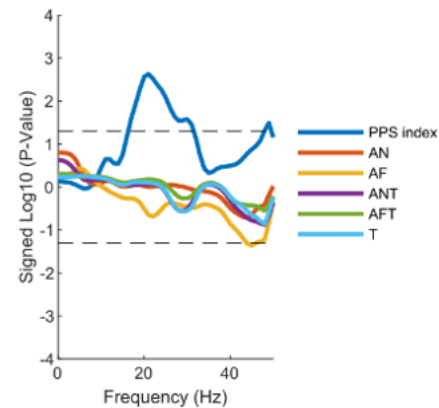
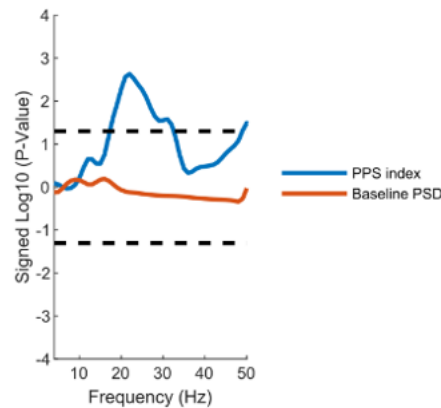


PPS index correlates with variability in the outcome that is not explained by clinical scales based on behaviour (overt consciousness)

# The High- $\beta$ PPS index improves predictions from clinical evaluations



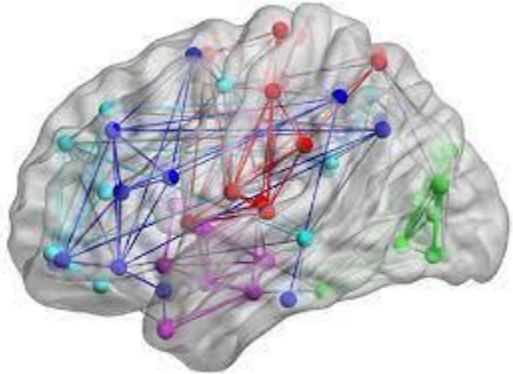
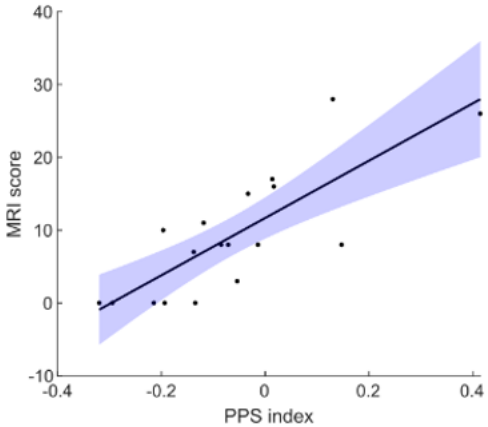
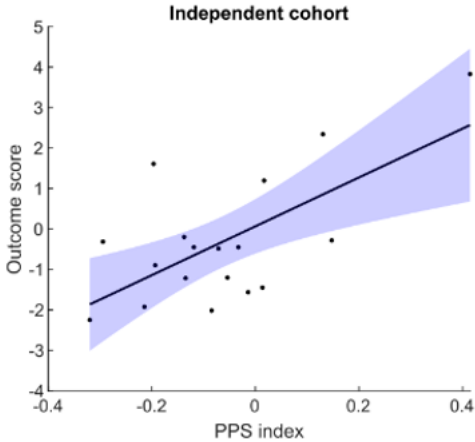
PPS index correlates with variability in the outcome that is not explained by clinical scales based on behaviour (overt consciousness)



Indexes based on simpler features of EEG responses do not provide meaningful outcome predictions

# The High- $\beta$ PPS index correlates with an MRI index of network integrity

 = 18



Can we identify brain hubs that are responsible for the disintegration of PPS representation (and consciousness)? Analysis ongoing...



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NeuroImage: Clinical

journal homepage: [www.elsevier.com/locate/ynicl](http://www.elsevier.com/locate/ynicl)



# Conclusions

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- Space-dependent high- $\beta$  power patterns index PPS representation
- The High- $\beta$  PPS index can detect covert consciousness during sleep
- Possibly by detecting covert consciousness in DOC patients, the PPS index predicts clinical outcome
- What are the underlying mechanisms in terms of brain function?

# Thank you!

G. Ricci



F. Siclari



J. Cataldi



J.P. Noel

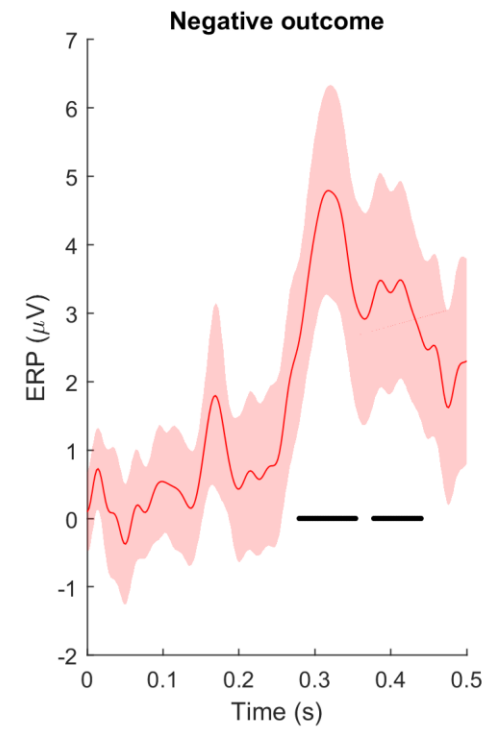
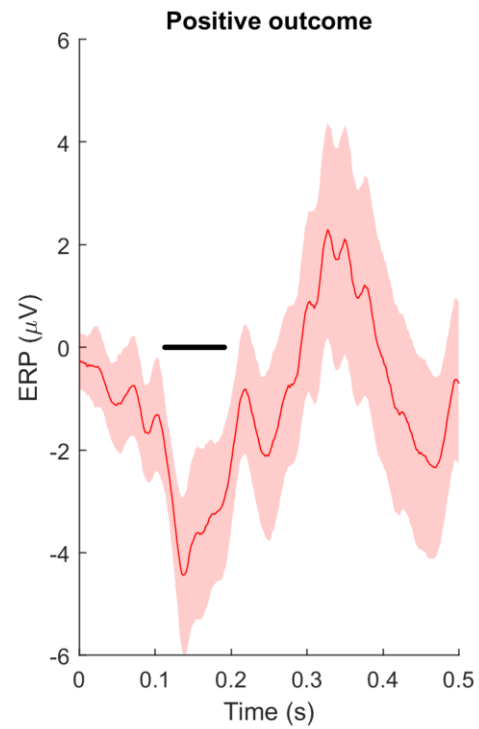
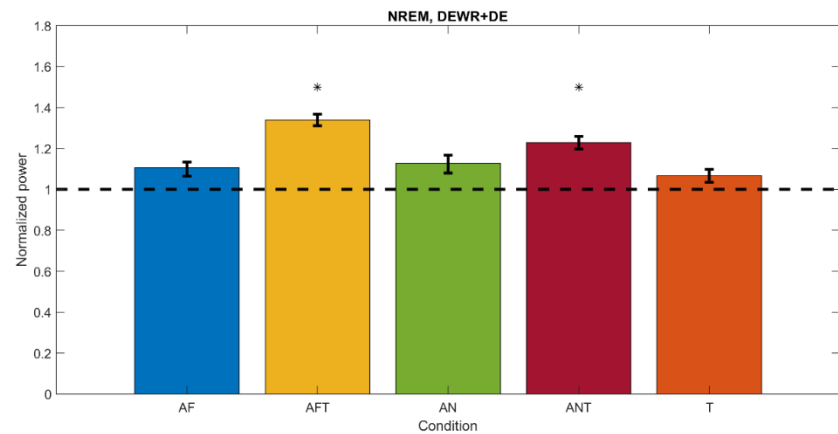
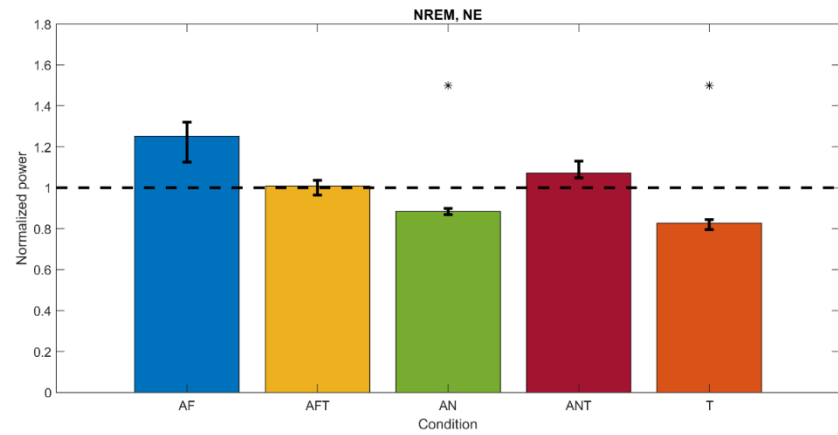


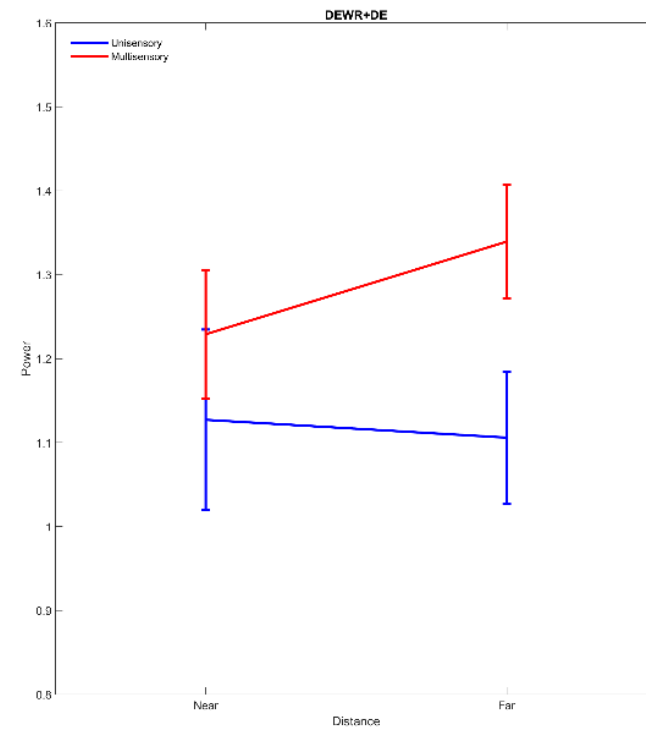
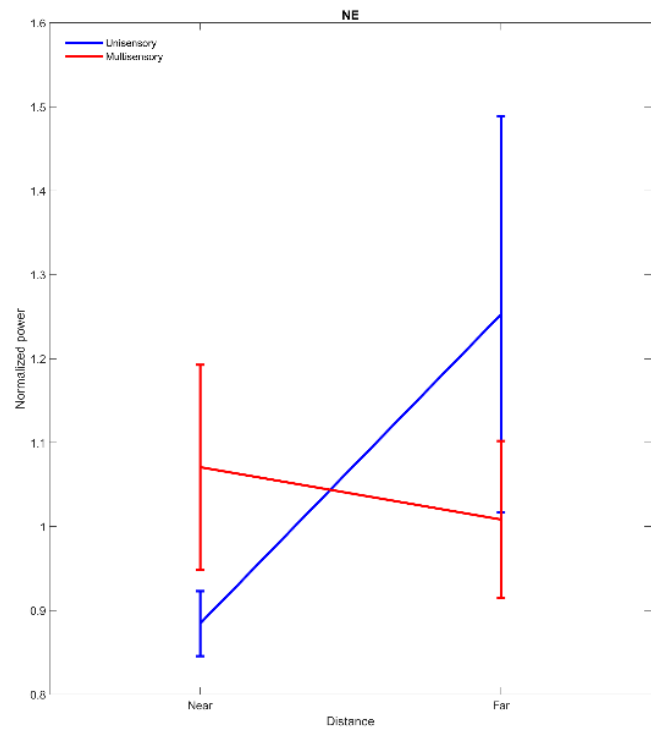
K. Diserens





# No consciousness simply = no response?





# PPS index formula

---

$$\text{PPS index} = (\text{ANT-AN-T}) - (\text{AFT-AF-T})$$



Multisensory index  
near

Multisensory index far

# PPS index formula

---

$$\text{PPS index} = (\text{ANT-AN-T}) - (\text{AFT-AF-T}) = \text{ANT-AN-AFT+AF-T+T}$$

Multisensory index  
near

Multisensory index far

# PPS index formula

---

$$\text{PPS index} = (\text{ANT-AN-T}) - (\text{AFT-AF-T}) = \text{ANT-AN-AFT+AF-T+T}$$

Multisensory index  
near

Multisensory index far

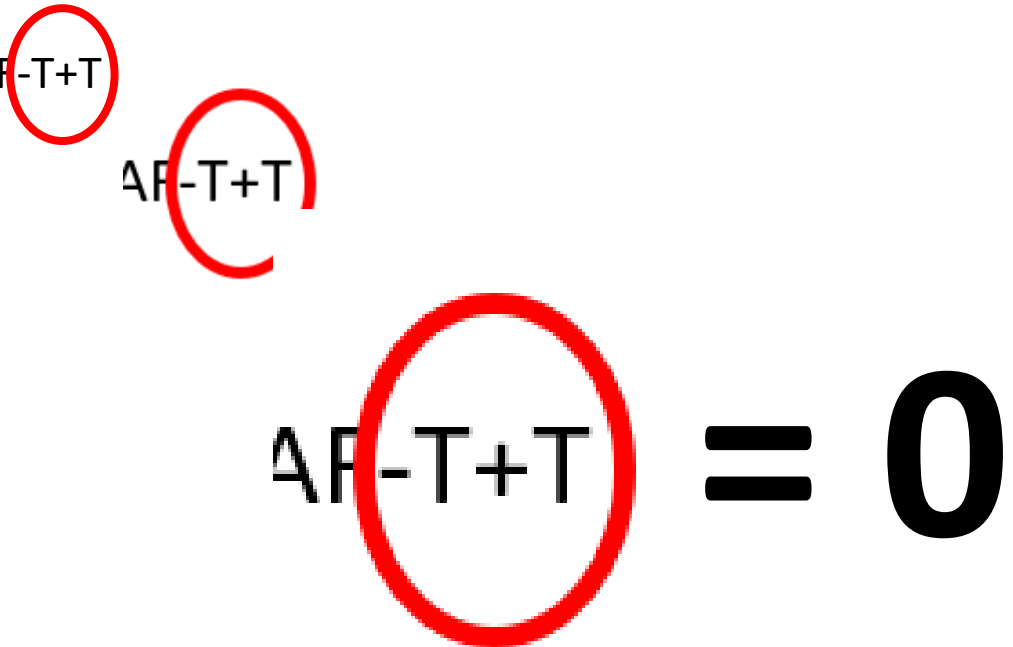
# PPS index formula

---

$$\text{PPS index} = (\text{ANT} - \text{AN} - \text{T}) - (\text{AFT} - \text{AF} - \text{T}) = \text{ANT} - \text{AN} - \text{AFT} + \text{AF} - \text{T} + \text{T}$$

Multisensory index near      Multisensory index far

$\text{AF} - \text{T} + \text{T} = 0$



# PPS index formula

---

$$\text{PPS index} = (\text{ANT-AN-T}) - (\text{AFT-AF-T}) = \text{ANT-AN-AFT+AF-T+T}$$

Multisensory index  
near

Multisensory index far

AF-T+T

$$\text{AF-T+T} = 0$$

