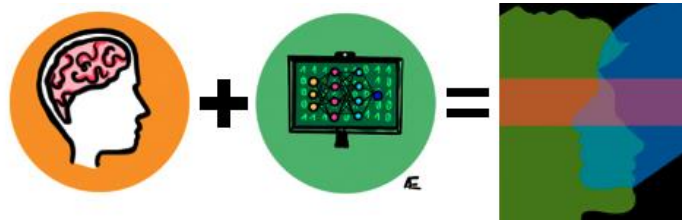


# Brain-Computer Interfaces for Human Cognitive Augmentation



Davide Valeriani, PhD  
Sr Machine Learning Scientist – Neurale Inc.

UW Neural Engineering Seminar – 21 May 2021

# Agenda

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- **Part 1:** Past and current research
- **Part 2:** Working at Neurable
- Q&A and open discussion

# What is human augmentation?

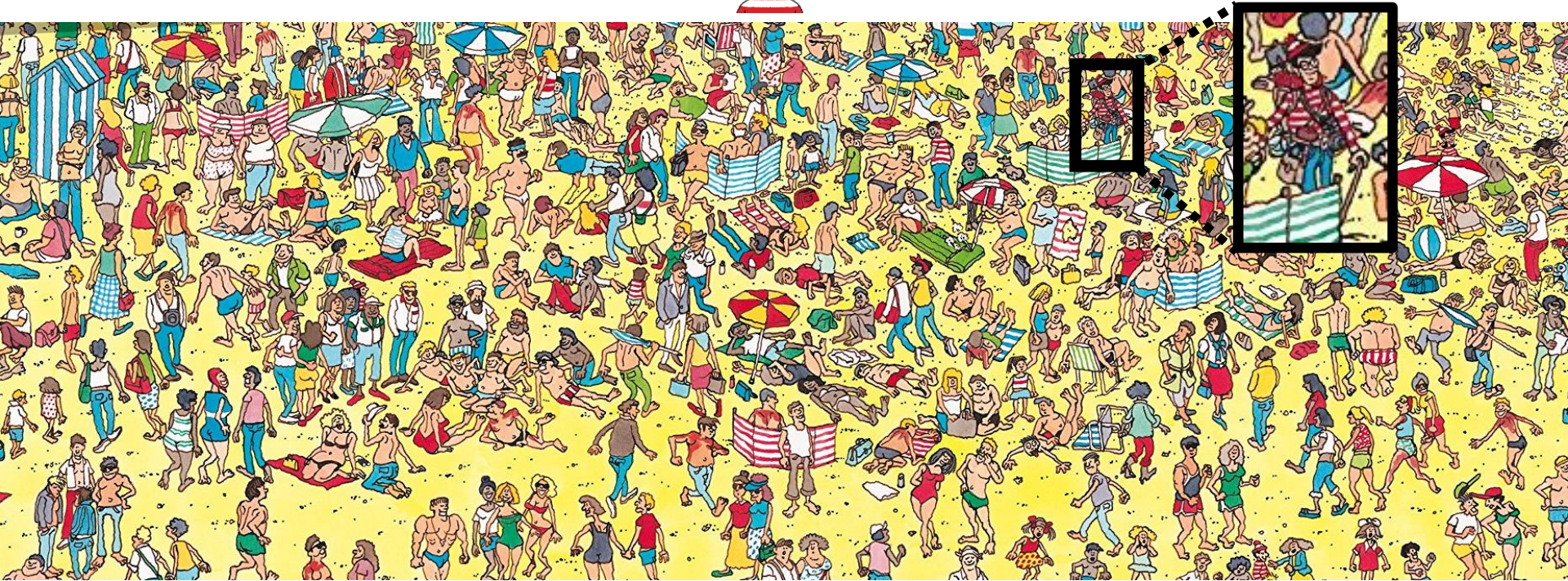
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# Decision-making could be difficult

Where is Waldo (or Wally)?



# Critical decision-making

- **High uncertainty scenarios**
  - Military: is this suspect a threat?
  - Medical: does the patient have this disorder? Would this treatment work?
  - Finance: is this stock's price going to increase?
- **Errors have serious negative consequences**
  - Loss of lives / money





# Strategies to minimize errors

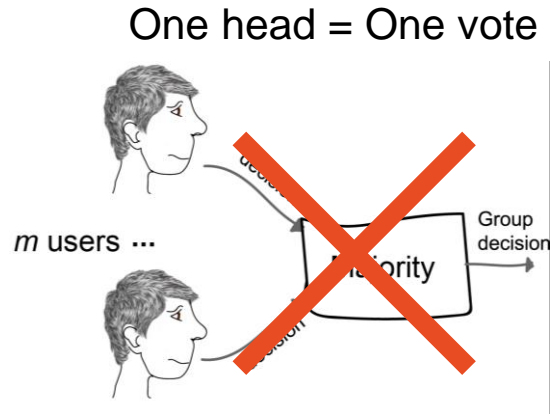
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- Make decisions in **groups** (wisdom of crowds), as they are often more accurate than individuals
  - Panels, committees, boards, etc.
- Use **artificial intelligence** (AI) to replace or complement human judgments

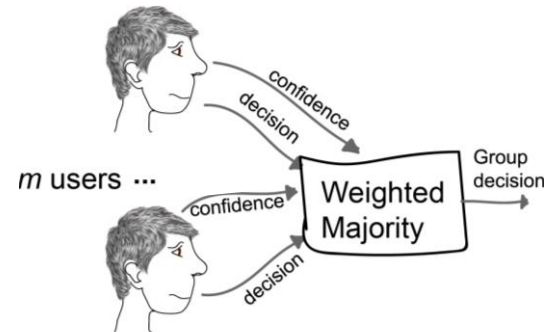


# Enabling optimal group decision-making

- How do groups integrate multiple opinions?
  - **Standard majority** (democracy)
  - **Weighted majority** (expertise-based, confidence-based, ...)



## Confidence-based integration



# How to estimate confidence?

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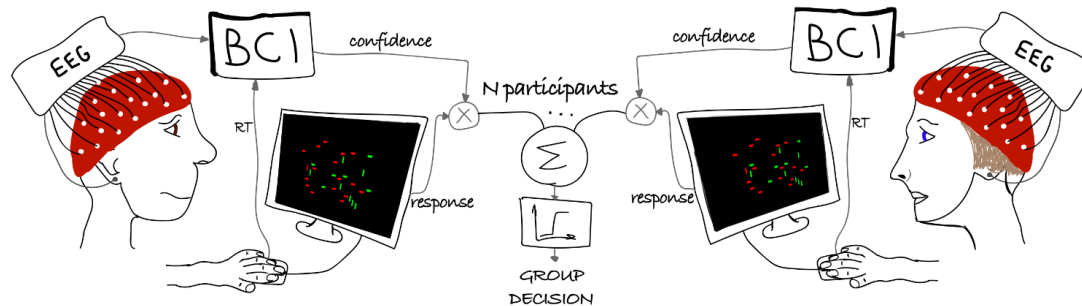
- We could **ask people** to report their confidence
- Ideally, we want confidence to **correlate with accuracy**  
    → The more confident you are, the more likely you are to be correct
- People often are **over/under confident**  
    → This is one of the causes why groups could fail

**Can we use machine learning to decode objective confidence from neural recordings?**

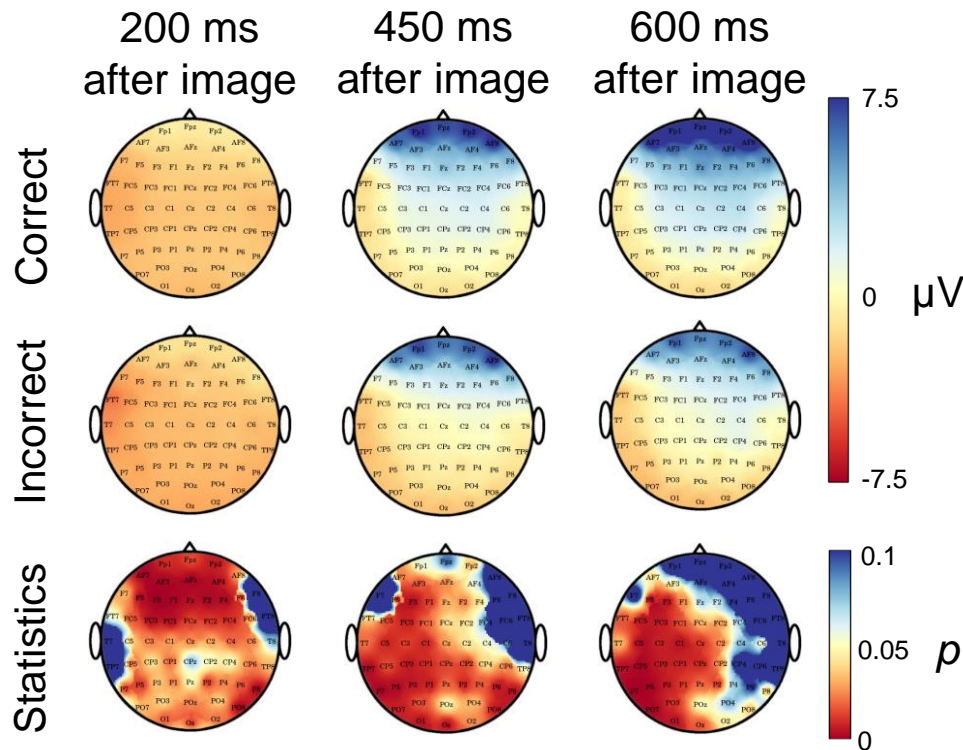
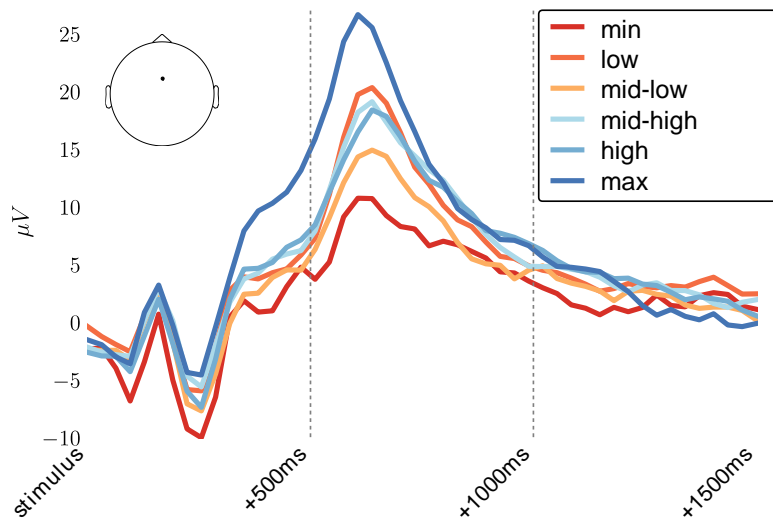
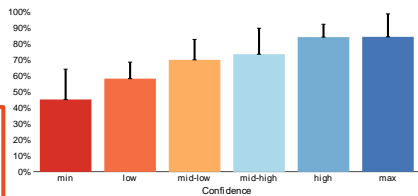
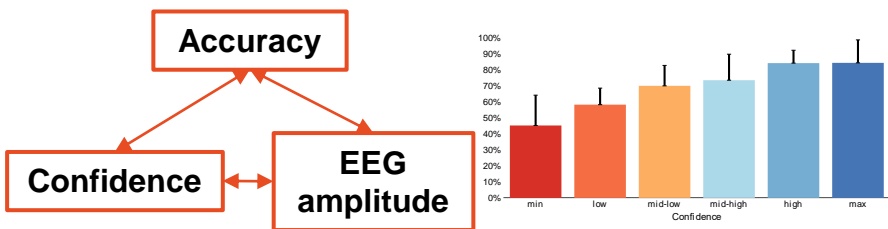


# Collaborative Brain-Computer Interfaces

- Combine EEG and machine learning to estimate the decision confidence of each group member
  - ↳ how likely the decision is to be correct
- Use these confidence estimates to **weigh individual decisions** and obtain group decisions

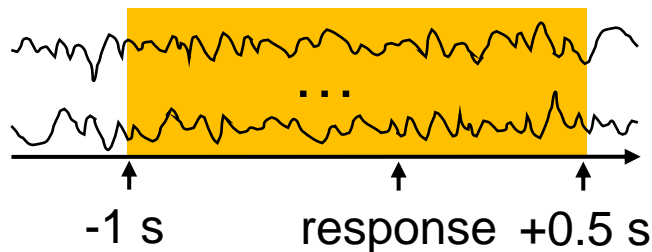
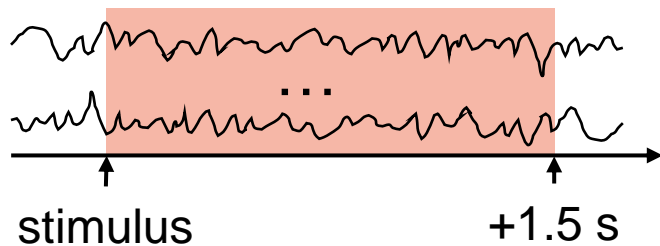


# Neural correlates of decision confidence



# Decoding decision confidence

- Stimulus-locked and Response-locked epochs



- Classifier trained to predict the **correctness** of the decision

- Label = +1 for *incorrect* responses
- Label = -1 for *correct* responses



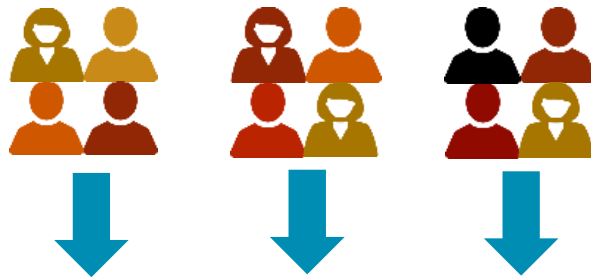
# Simulate groups

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Individuals perform  
the **same experiment**

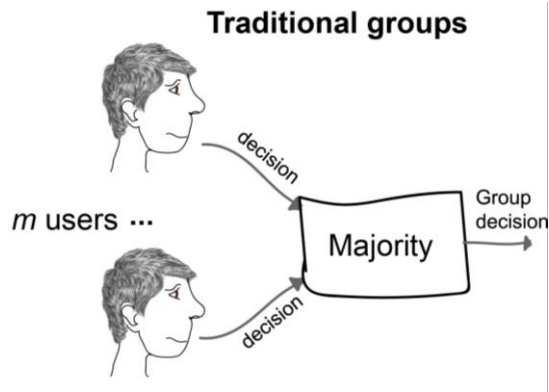


Individual data combined  
offline in **all possible  
groups** of a given size  $m$

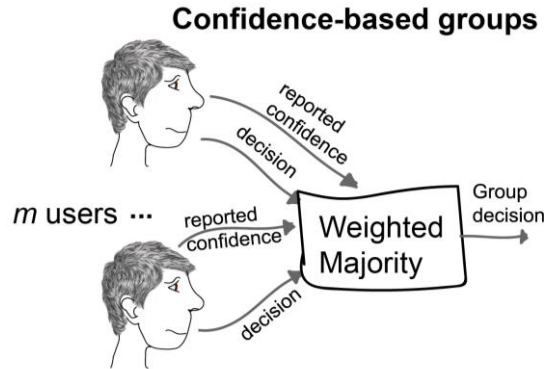


Average performance of  
 $m$ -sized groups

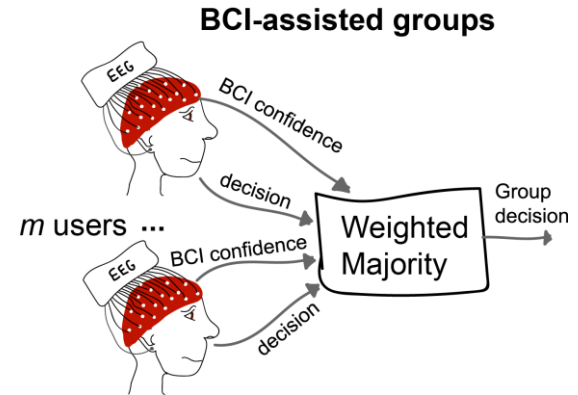
# Making group decisions



One head = One vote



Confidence reported  
by the participants



Confidence decoded  
from the EEG



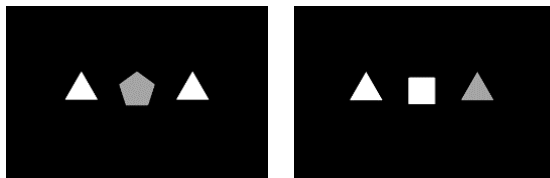
# Framework tested with various tasks

## Speech perception



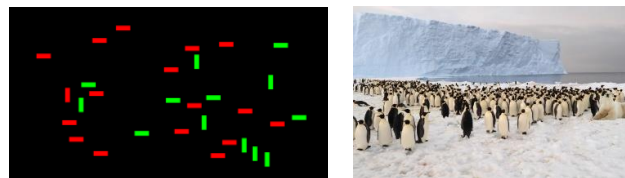
Valeriani et al., *IEEE EMBC'16* (2016)

## Visual matching



Poli et al., *PLoS ONE* (2014)

## Visual search



Valeriani et al., *IEEE NER'15* (2015)  
Valeriani et al., *IEEE Trans Bio Eng* (2016)  
Valeriani et al., *Scientific Reports* (2017)

## Video feeds



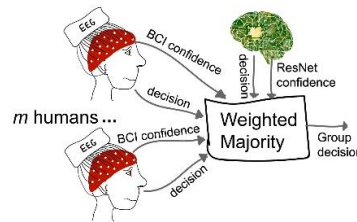
Valeriani et al., *BCI Meeting* (2018)

## Pandemic scenario



Valeriani et al., *BCI Meeting* (2021)

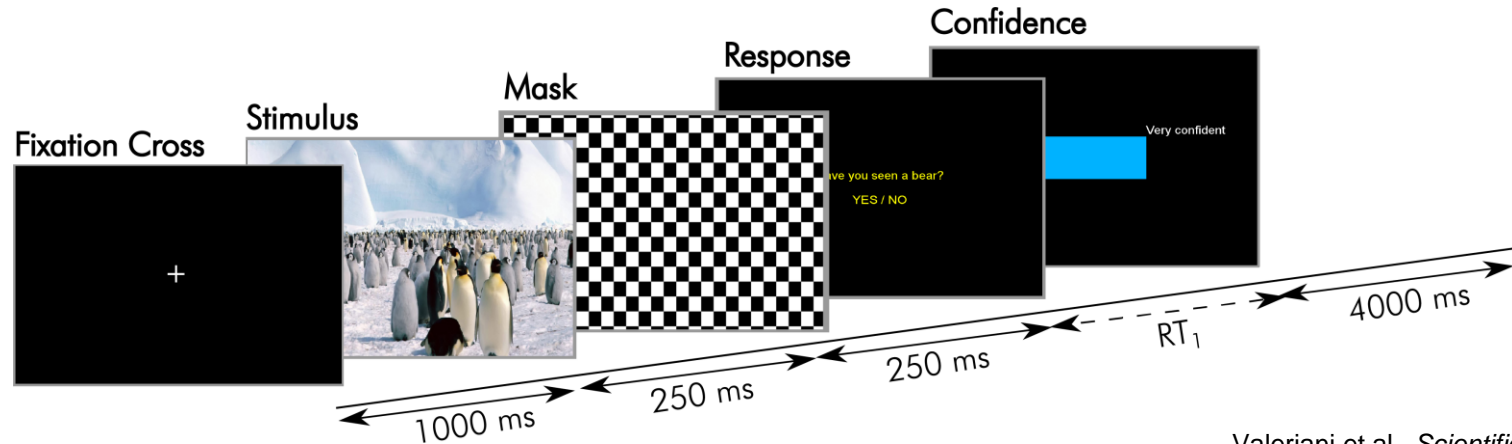
## Face recognition w/wo AI



Valeriani et al., *IEEE NER'17* (2017)  
Valeriani and Poli, *PLoS ONE* (2019)

# Realistic visual search

- Arctic environment full of penguins
- Decide whether the picture contains a **polar bear**
- After each decision, participants report confidence 0-10



# Try it

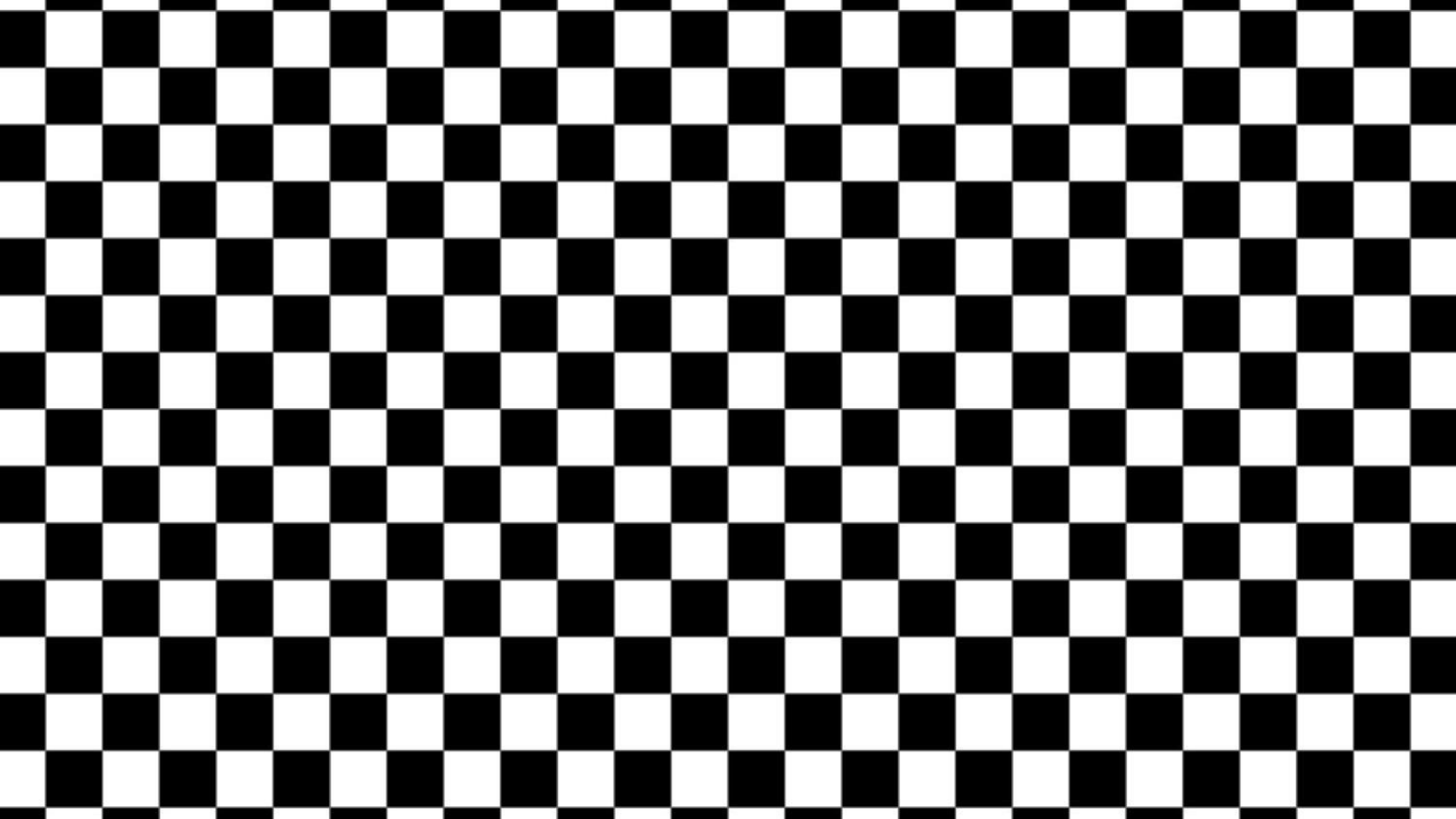
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Get ready



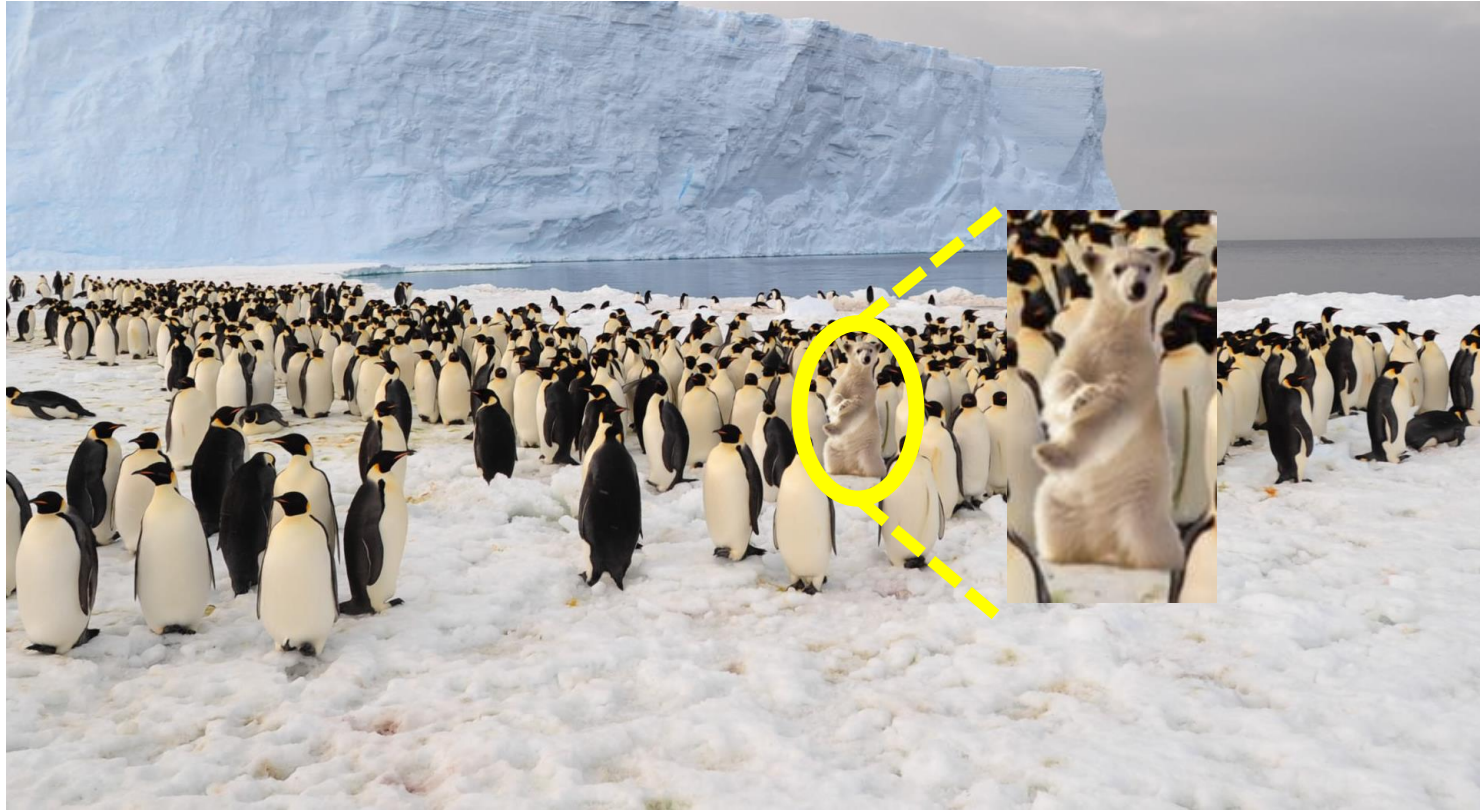




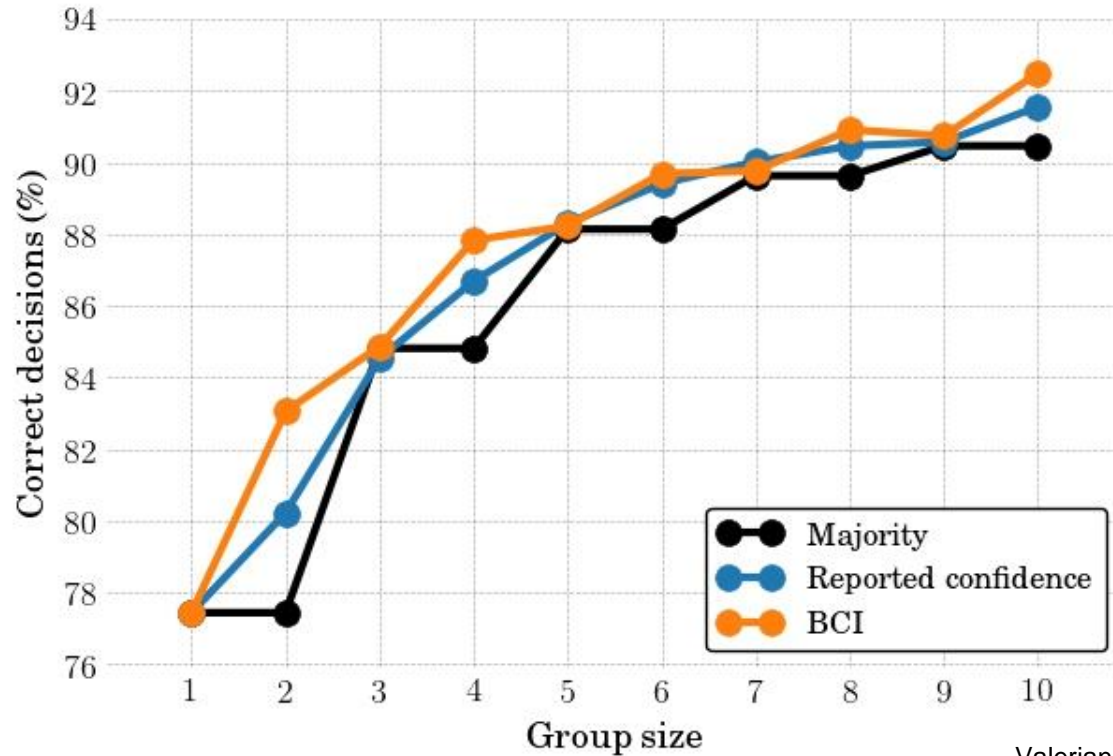




# Have you seen a polar bear?



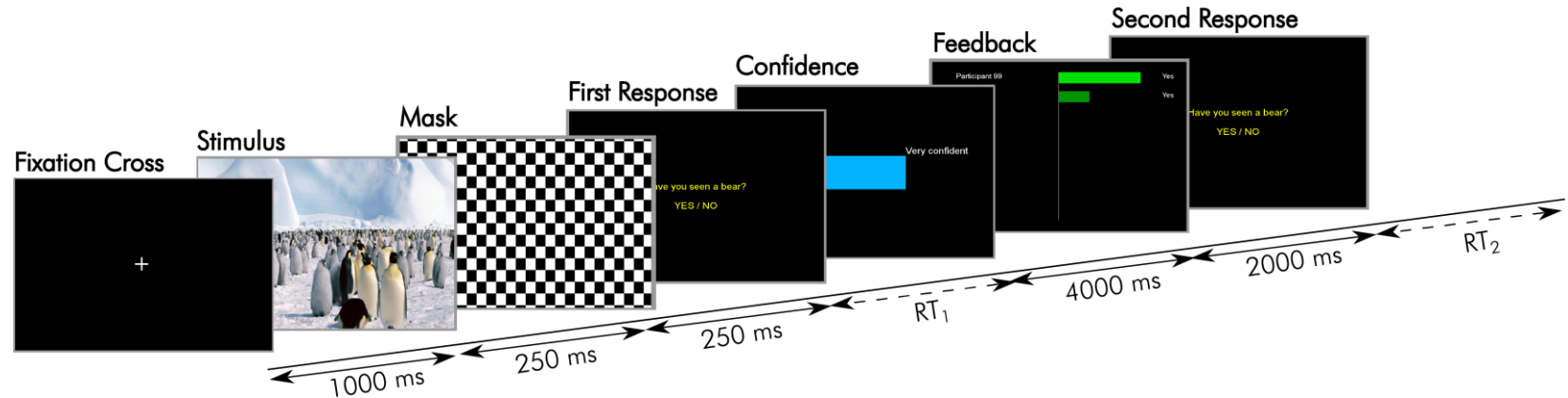
# Group performance



Valeriani et al., *Scientific Reports* (2017)

# What if pairs communicate?

Collected new data from 16 **paired participants** exchanging information

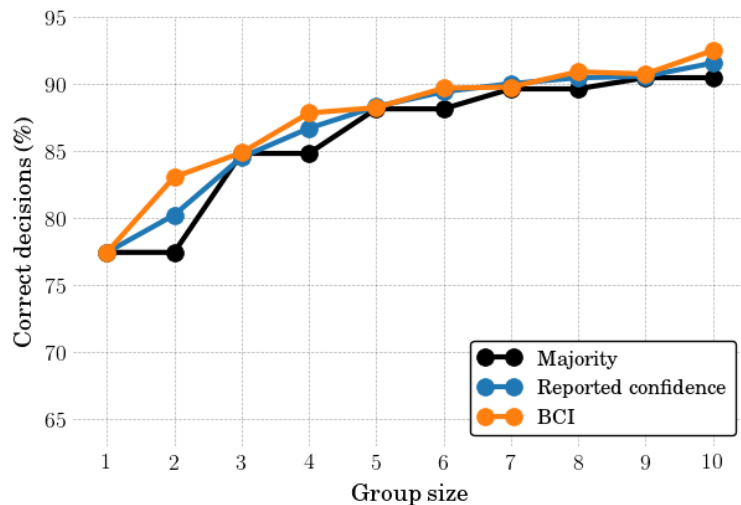




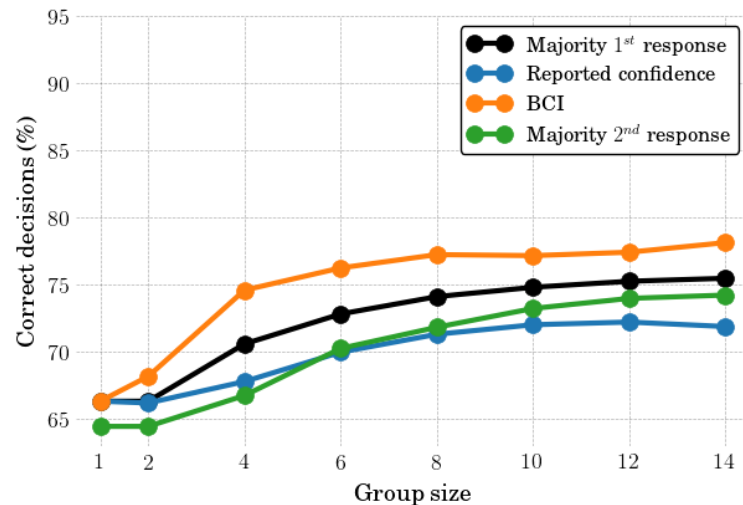
# Do groups benefit from interaction?

**No:** communication damages individual accuracy

## No communication



## With communication

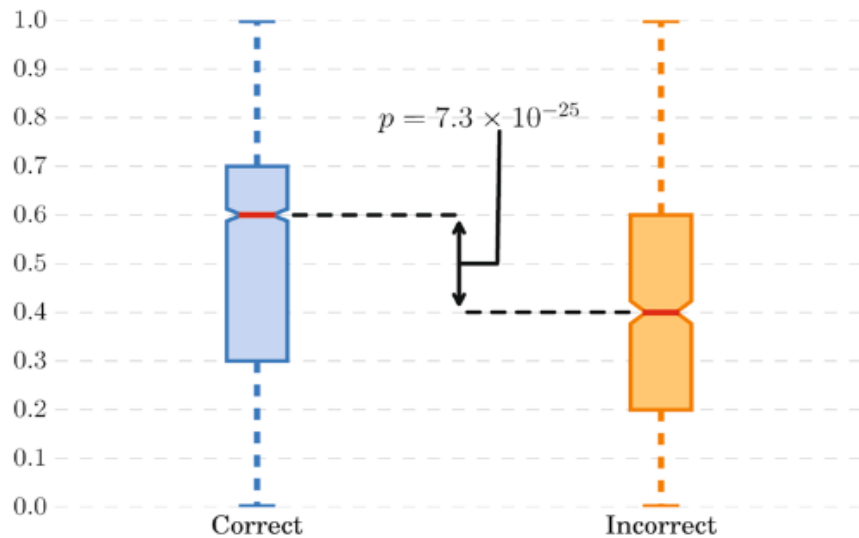


Valeriani et al., *Scientific Reports* (2017)

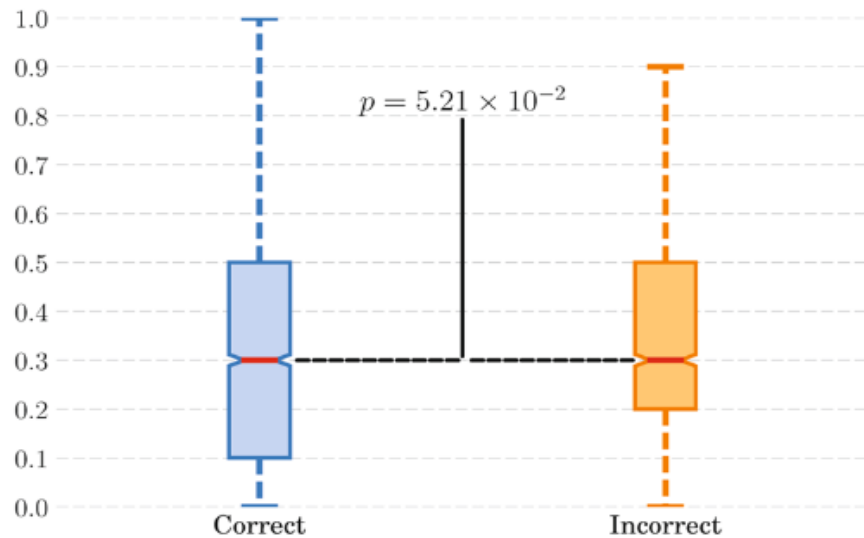
# What about metacognition?

Reported confidence stops predicting objective accuracy

**No communication**



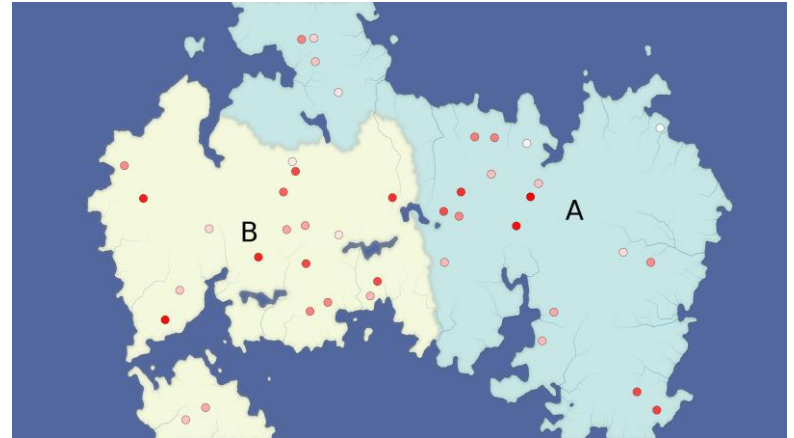
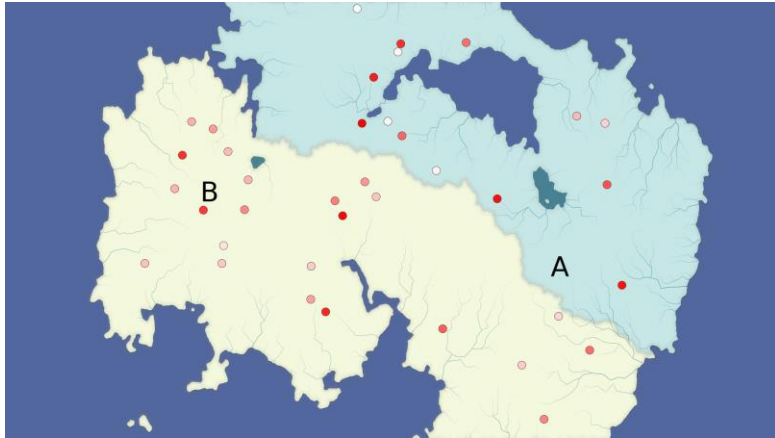
**With communication**



Valeriani et al., *Scientific Reports* (2017)

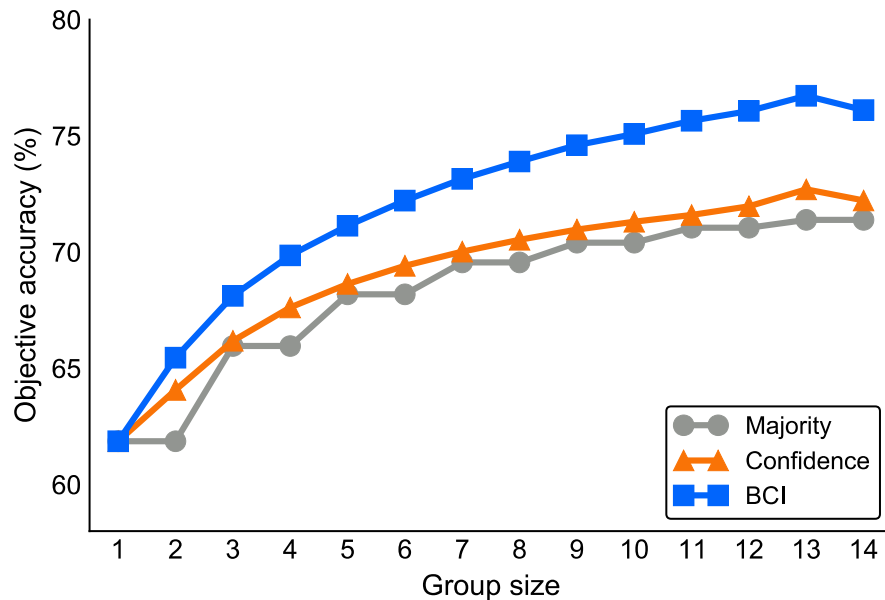
# Realistic decision-making

- Context: **epidemic threat**
- Dots represent cases, color represents severity
- Task: decide which region is more in danger



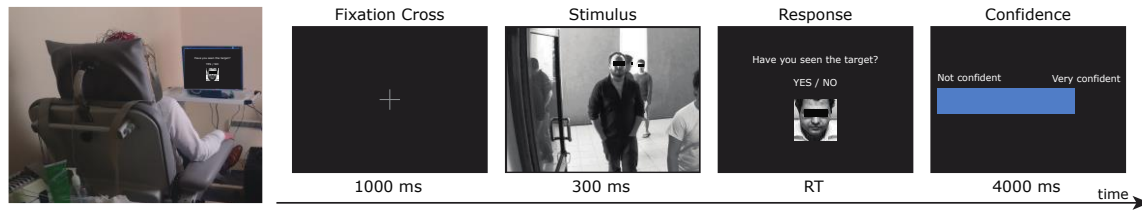
# BCI-assisted groups of humans

BCIs deliver significant improvement in group performance



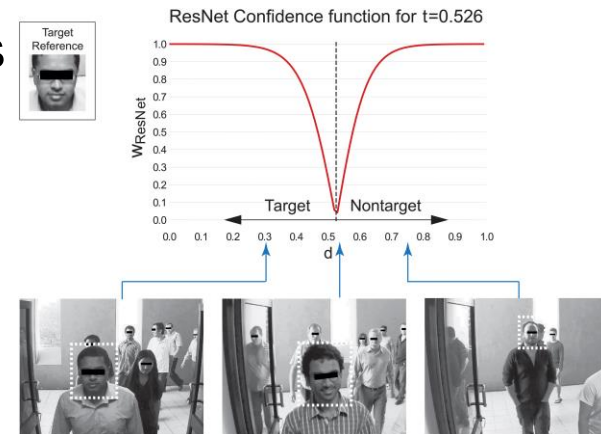
# Enhancing face recognition

## Experimental protocol



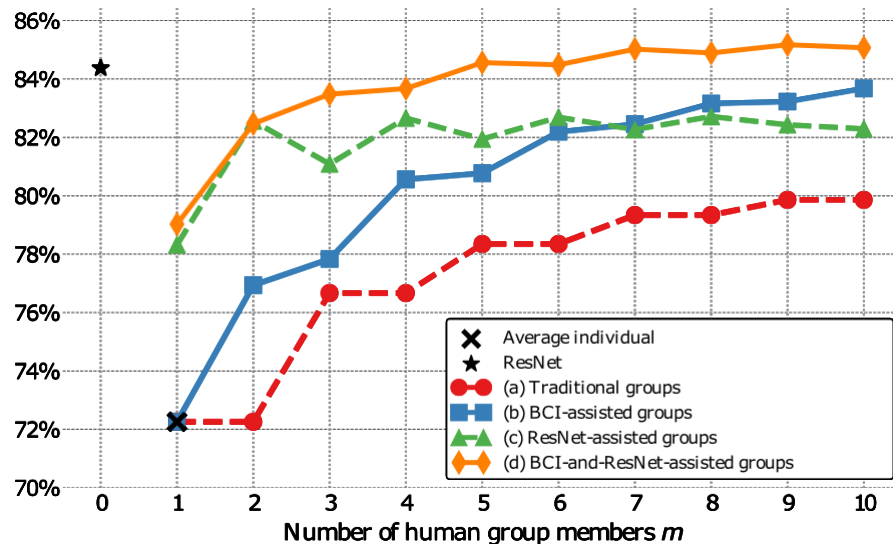
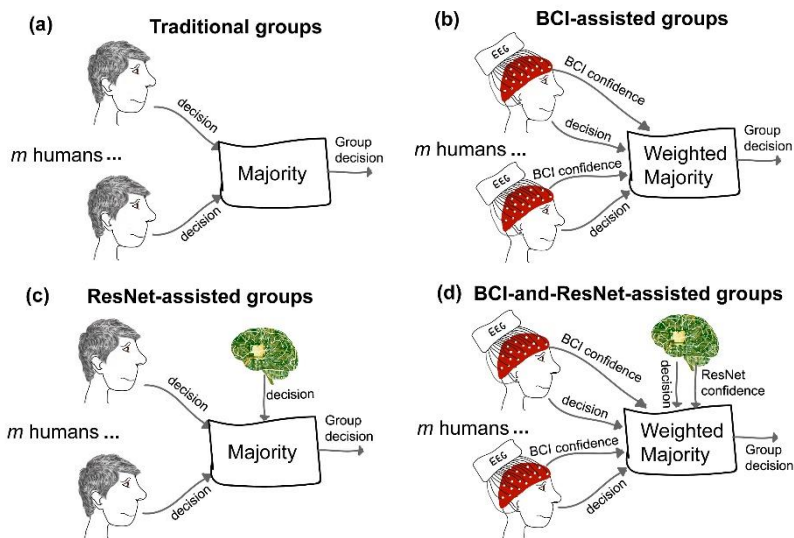
## Deep learning algorithm to perform the same task:

- Residual neural network, 29 convolutional layers
- Pre-trained model on 3 million images of faces
- AI able to estimate its own confidence



# Results

## Different strategies for making group decisions

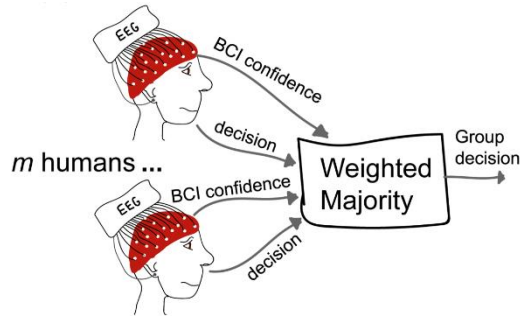




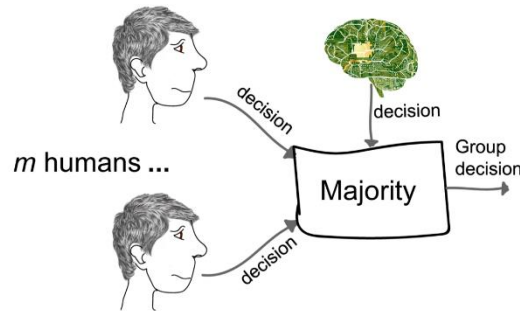
# Towards human-machine teaming

Integrate AI into groups at three different levels

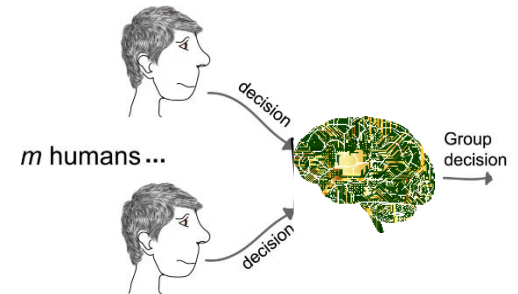
AI as **personal assistant**  
(Brain-Computer Interface)



AI as additional  
**team member**



AI as **group assistant**



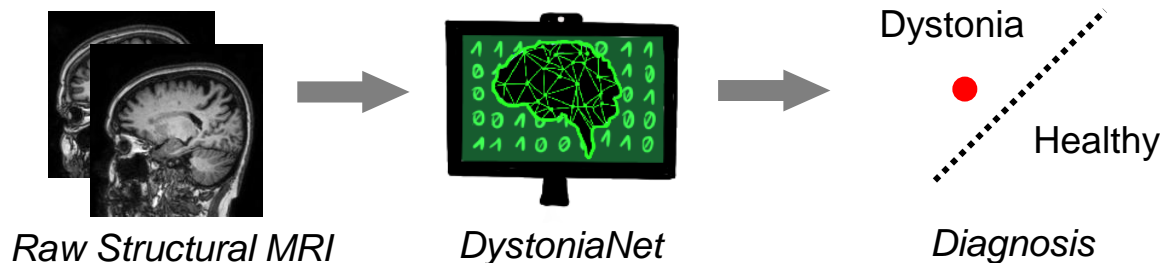
# Diagnosis of dystonia

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- Dystonia is a neurological movement disorder characterized by involuntary muscle contractions, leading to abnormal movements and postures
- Objective biomarkers of dystonia are **non-existent**
  - **Poor agreement** rate between clinicians (Cohen's  $\kappa = 0.05-0.52$ )
  - **Up to 10.1 years** of delay in diagnosis
- Conventional brain MRI is normal
- Neuroimaging studies defined **microstructural abnormalities**

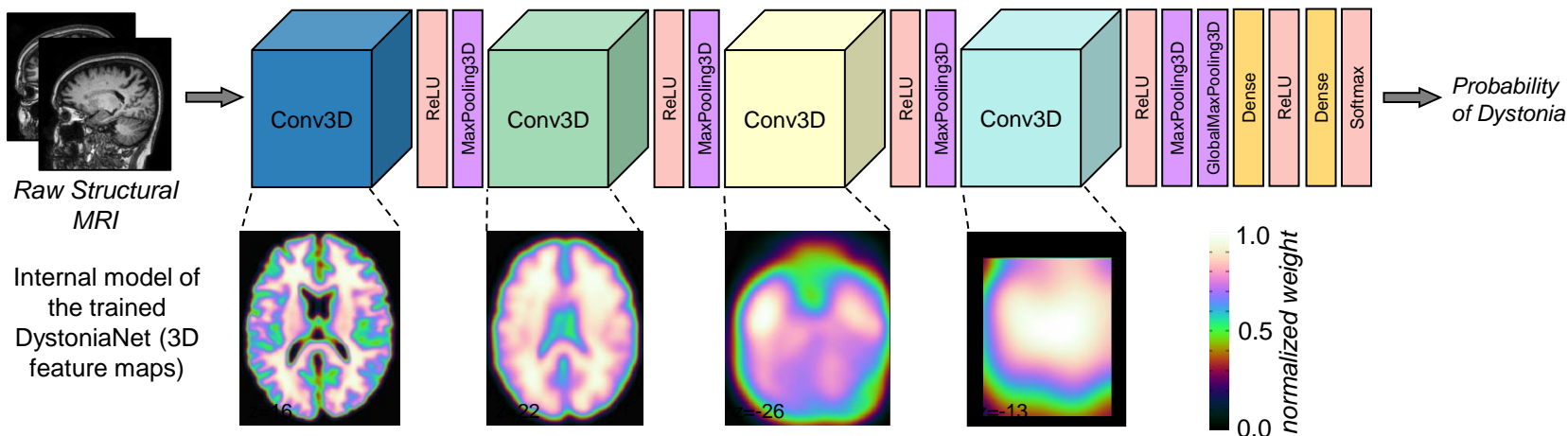
# A novel biomarker of dystonia

- Can brain microstructural changes serve as a diagnostic biomarker of dystonia?
- Developed **DystoniaNet**, a deep learning platform to diagnose dystonia from raw structural MRI data



# DystoniaNet architecture

- Convolutional neural network with a **data-driven** approach to discover a volumetric biomarker from MRI data
- Feature maps make its internal model **interpretable**



# Training and validation of DystoniaNet

- Large dataset of 612 subjects
  - 392 patients with three forms of isolated focal dystonia: laryngeal dystonia (LD), cervical dystonia (CD), blepharospasm (BLS)
  - 220 healthy controls
- DystoniaNet **refers uncertain cases** to further evaluation

## ***Training set***

160 laryngeal  
dystonia patients



160 age/sex-matched  
healthy controls

## ***Validation set***

60 laryngeal  
dystonia patients



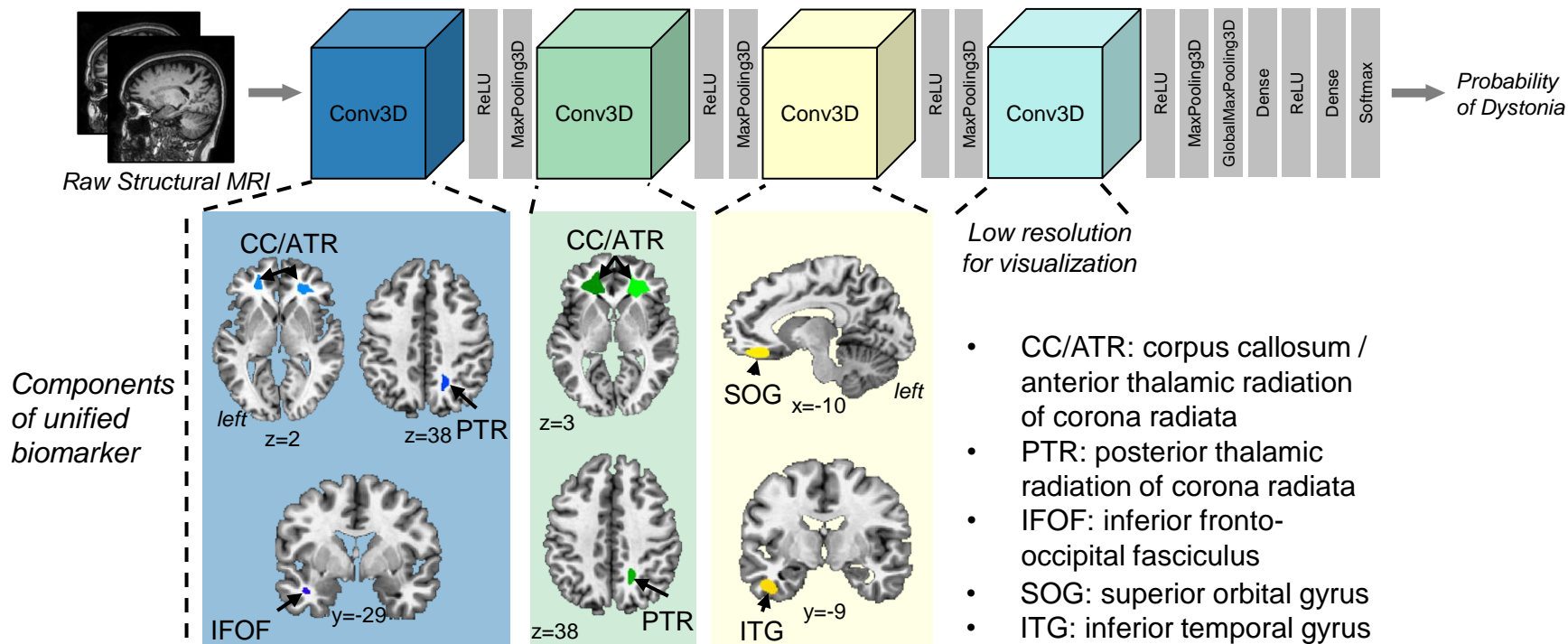
60 healthy controls

## ***Test set***

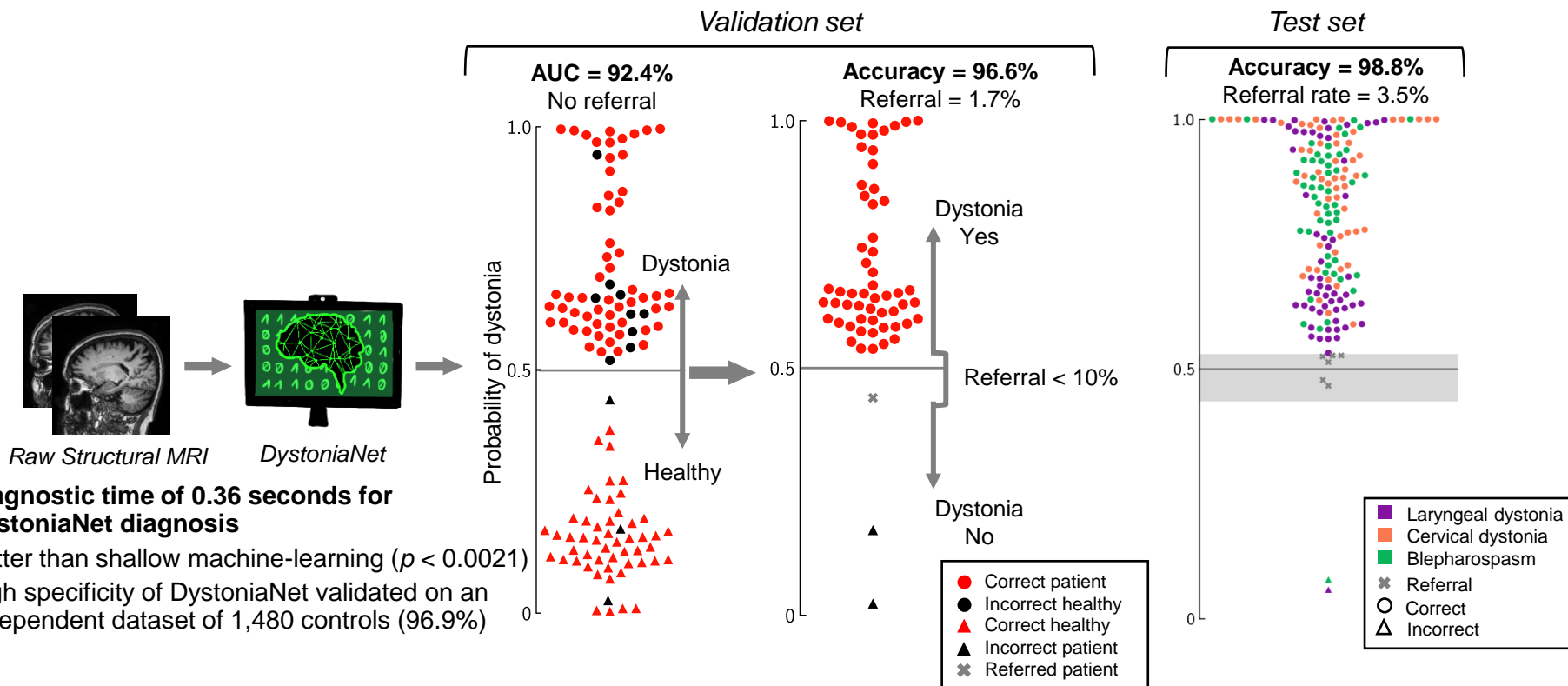
172 dystonia patients:  
59 LD, 59 CD, 54 BLS



# DystoniaNet-identified biomarker



# Diagnostic performance

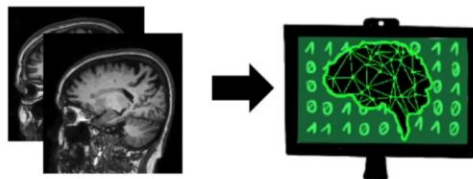




# Demo of DystoniaNet

## DystoniaNet

This application allows you to diagnose dystonia from a raw structural MR image.



### Step 1. Upload a structural MRI

This could be a zip file containing DICOM (.dcm) files, or a single file in NIFTI format (.nii).

Choose File no file selected

### Step 2. Make diagnosis

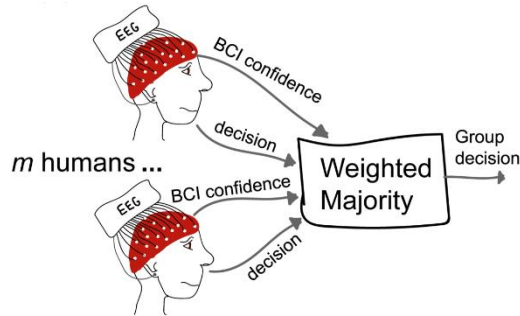
Click the button on the right to make the diagnosis.

Diagnose

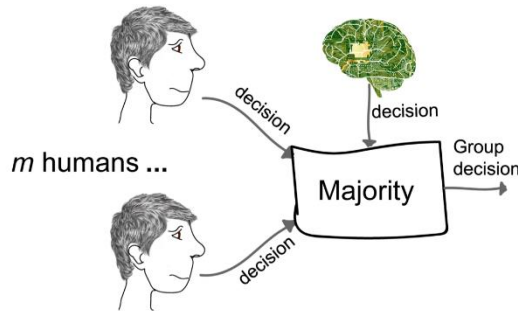
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Integrate AI into groups at three different levels

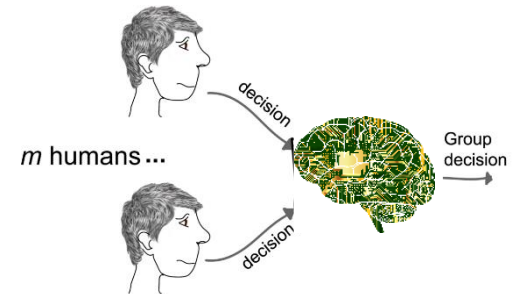
AI as **personal assistant**  
(Brain-Computer Interface)



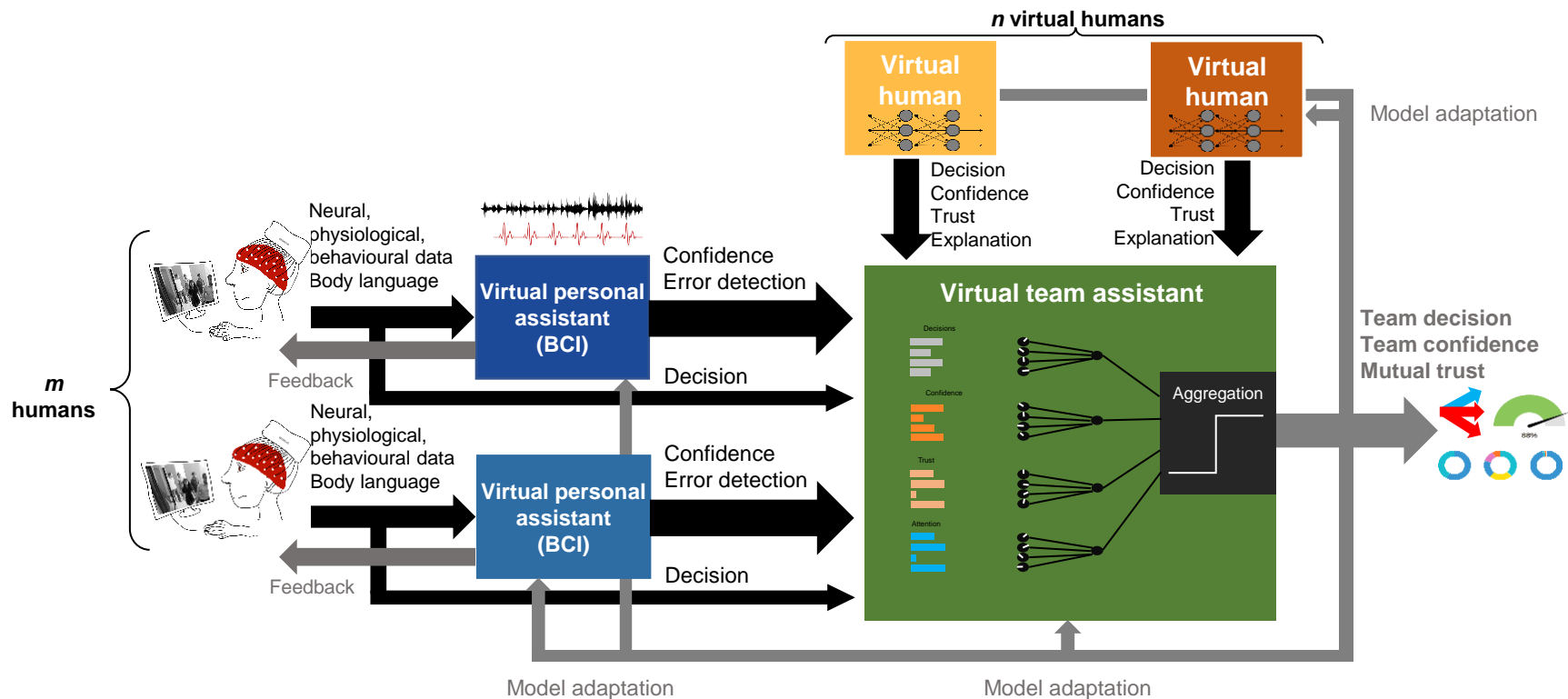
AI as additional  
**team member**



AI as **group assistant**



# Developing a new framework



# What's next?

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- How can we make these BCIs available to everyone?
- In Feb 2021, I joined **Neurable** to bring BCIs out of the labs
- We develop BCI headphones for everyday use (Enten)
- Preorder campaign at ***[igg.me/at/neurable](https://igg.me/at/neurable)***



# Thank you!

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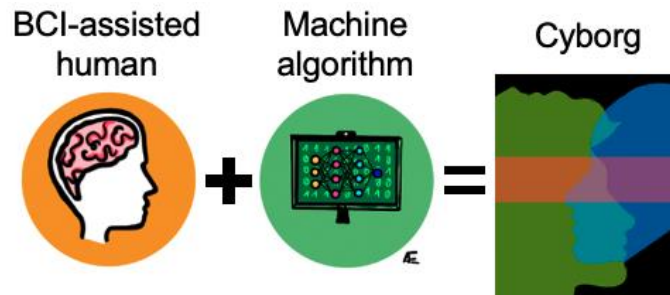
## Questions?

Contact info:

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Graphics by Eleonora Adami, PhD