Boulic - Virtual Reality
May 12th 2025

Embodied Virtual Reality; Limits and applications

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Laboratory of Cognitive Neuroscience
Center for Neuroprosthetics
Brain & Mind Institute
EPFL

We can only experience the world from the perspective of our body

Virtual Reality Embodiment allows experiencing the world from the perspective of another body

Embodiment

- **Avatar**
  - Self-representation of a participant
  - ≠ virtual human / 3D character / NPC

- A concomitant factor to Presence

  The perceiving of one's world entails the co-perceiving of where one is in the world

  Gibson, 1979.

J. Lanier dataglove (1987)

Sense of Embodiment

- Definition *

The ensemble of sensations that arise in conjunction with being inside, having, and controlling a body.

- Sense of self-location
- Sense of agency
- Sense of body ownership

Kilteni, K., Groten, R. and Slater, M. (2012) 'The Sense of Embodiment in Virtual Reality', *Presence* 21(4), 373–387.

* quite widely accepted in the VR community

Body ownership illusion

- The **“illusion that the virtual body is their own —even though they know for sure that it is not.”**

- Embodiment involves:
  - 1PP view of the body
  - Visuomotor or visuotactile synchrony

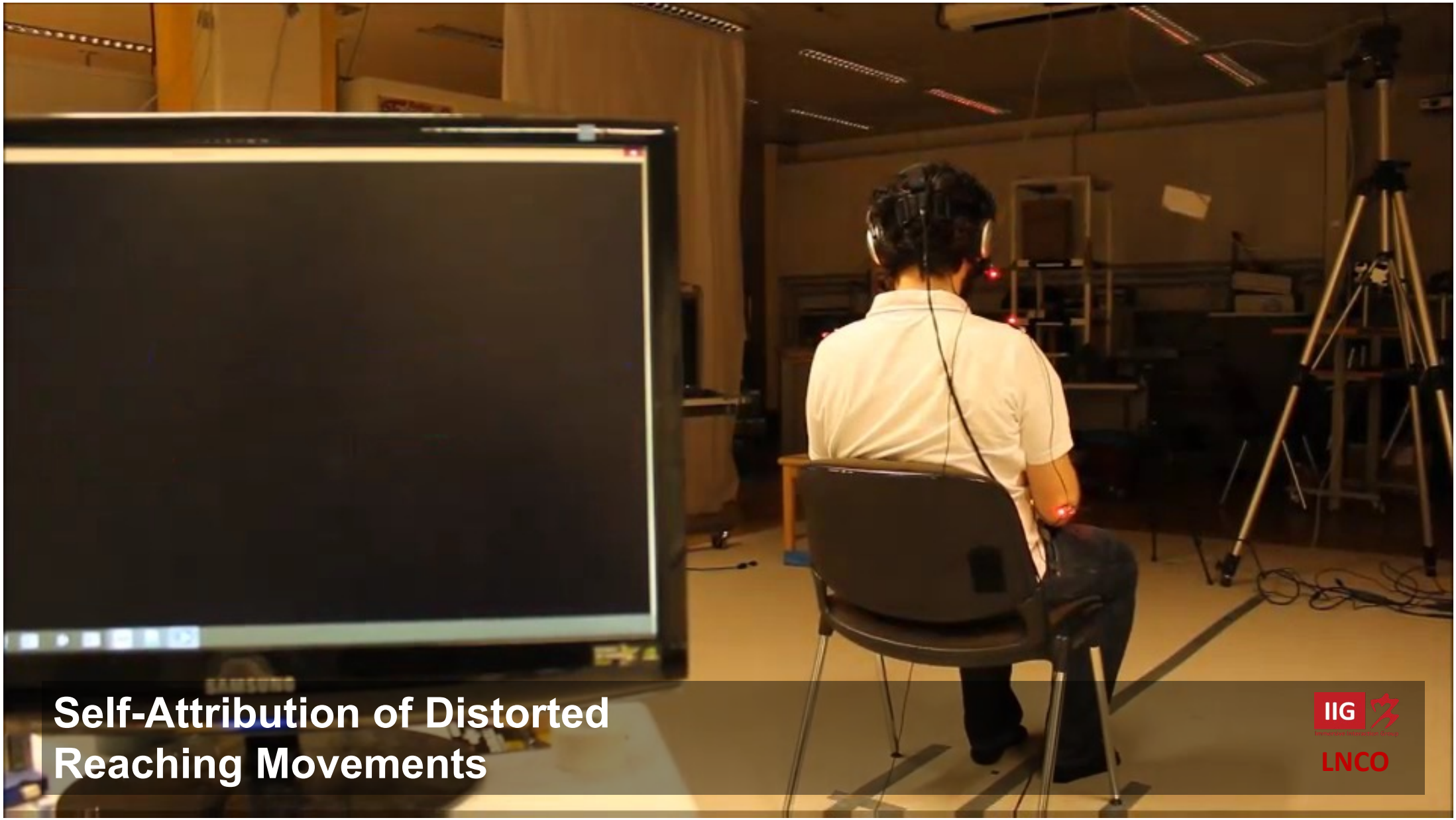
What are the conditions and limits of VRE?

Research work by Ronan Boulic (Immersive Interaction Group, EPFL) and Bruno Herbelin (LNCO, EPFL)

IIG Immersive Interaction Group

BLANKE LAB

CHAIR IN COGNITIVE NEUROPROSTHETICS



Self-Attribution of Distorted Reaching Movements

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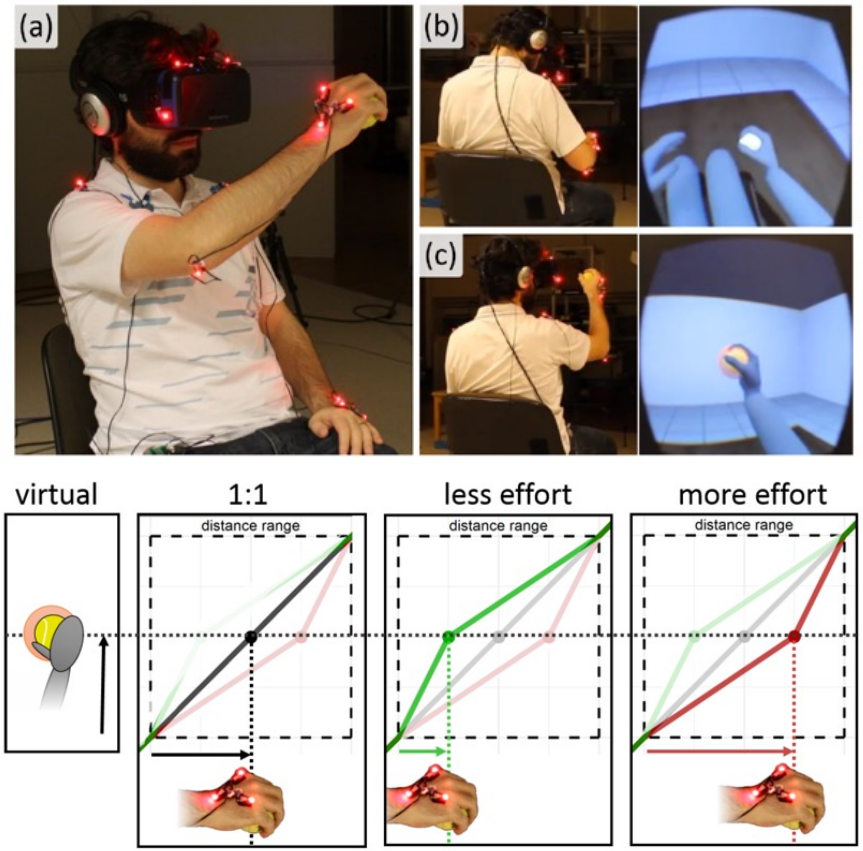
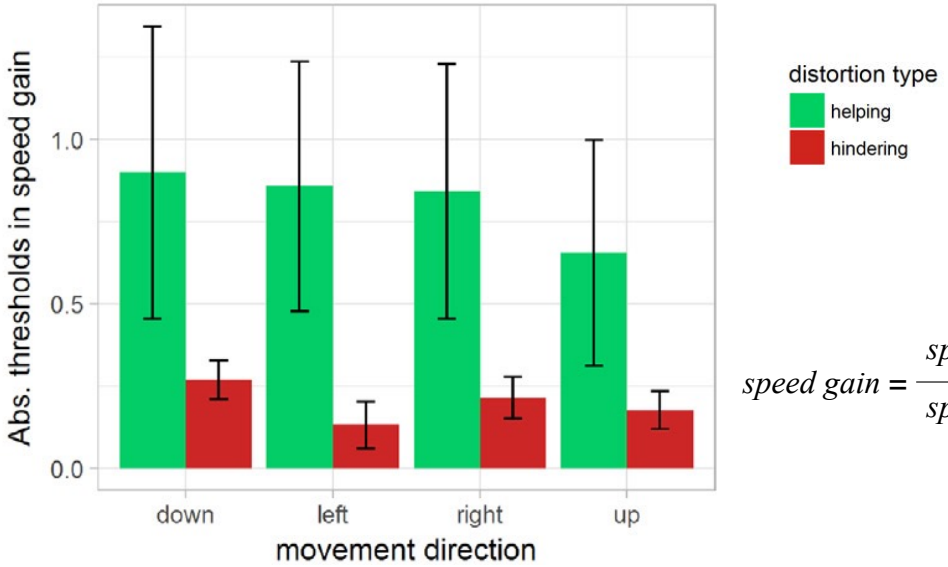
Self-Attribution of Distorted Reaching Movements

Galvan-Debarda et al. 2018 – Computer & Graphics 76(142-52)



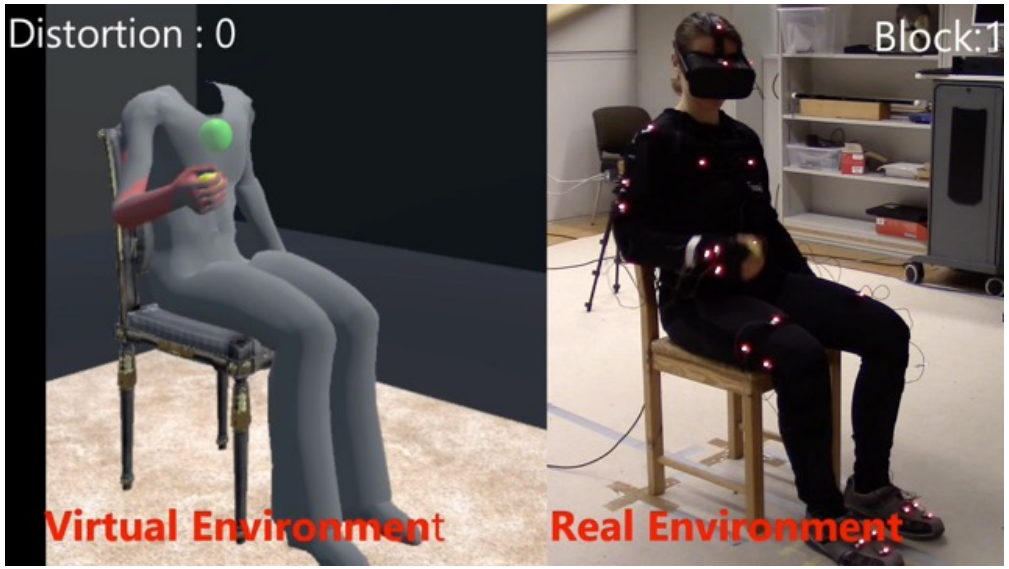


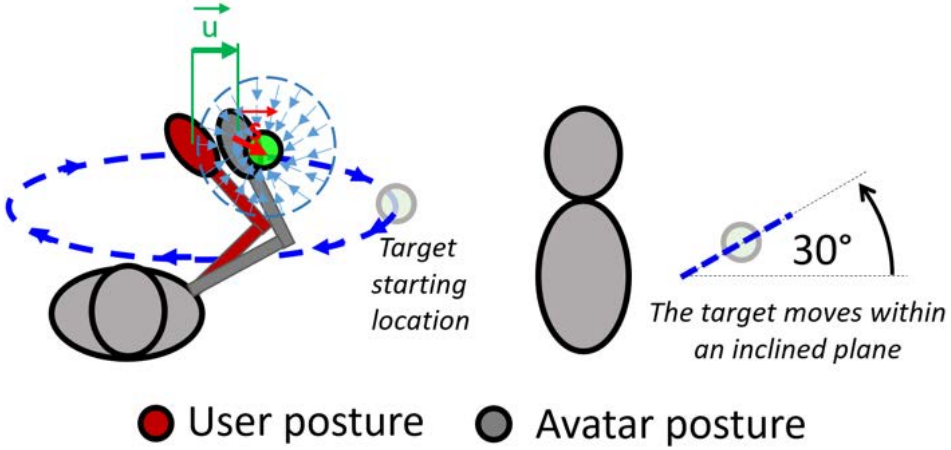
$$speed\ gain = \frac{speed_V}{speed_P} - 1$$

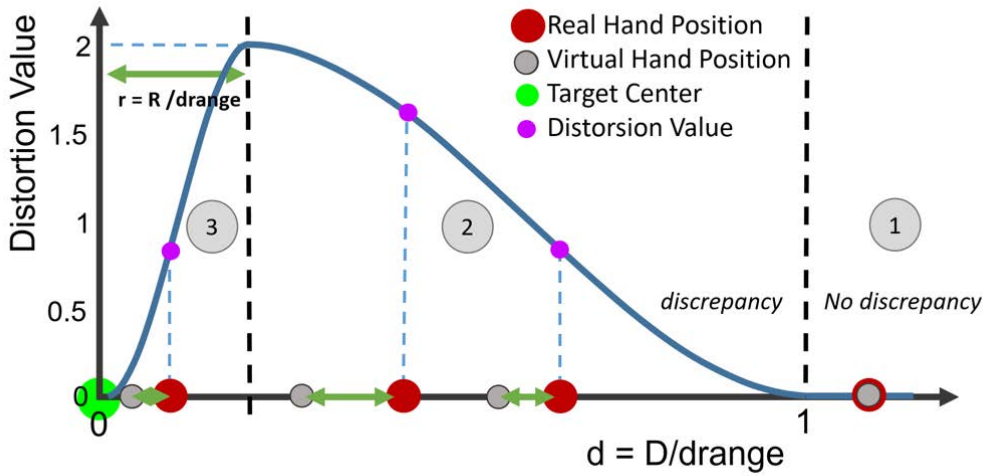
Helping reaching movement is good and not easily detected
Hindering movement is critical

Reconciling Being in-Control vs Being Helped

Porssut et al. – Accepted IEEEVR 2019

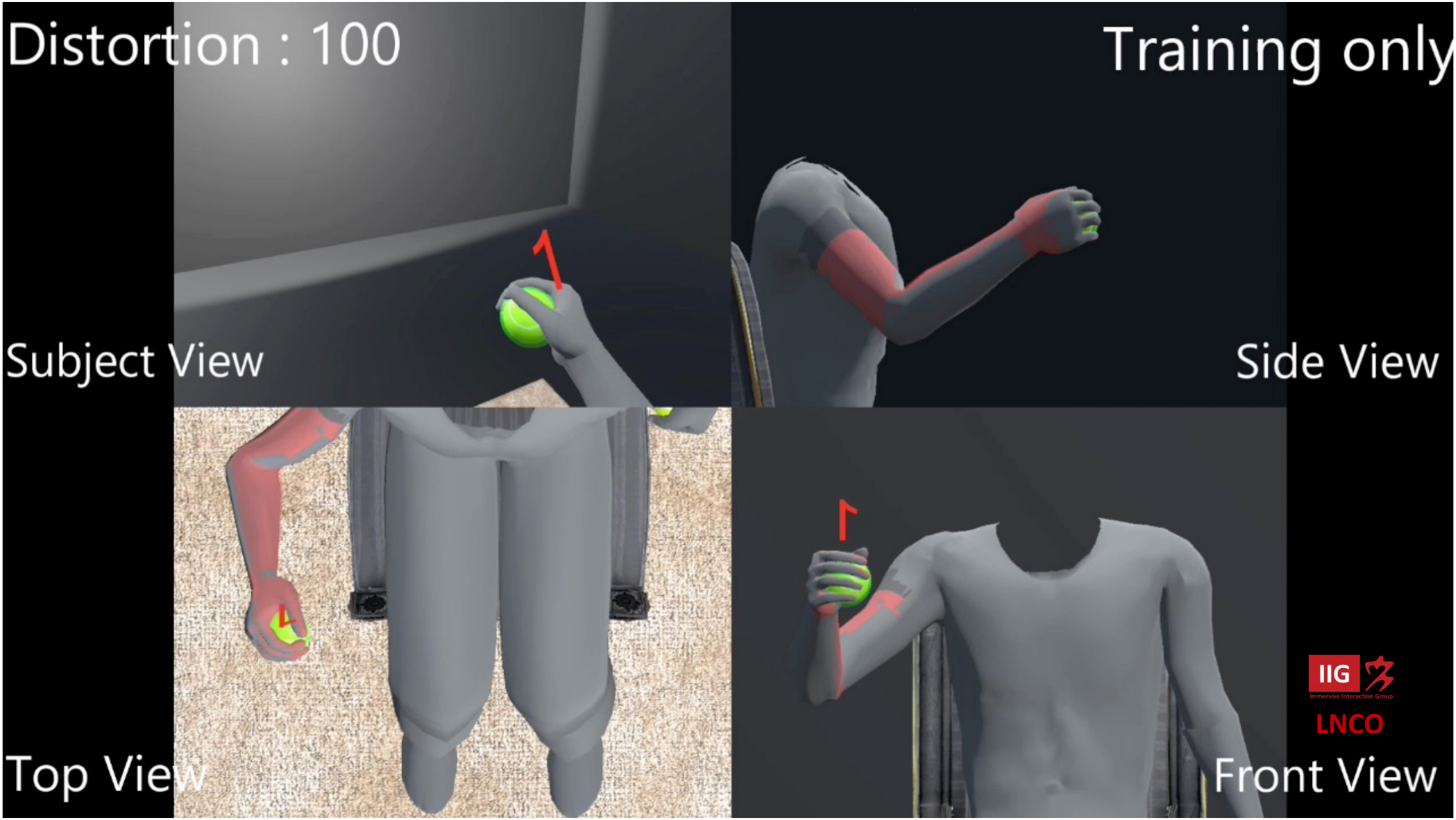






BLOC 1 - Self-attribution Threshold

BLOC 2 – Progressive Distortion


Distortion : 100
Training only
Subject View
Side View
Top View
Front View
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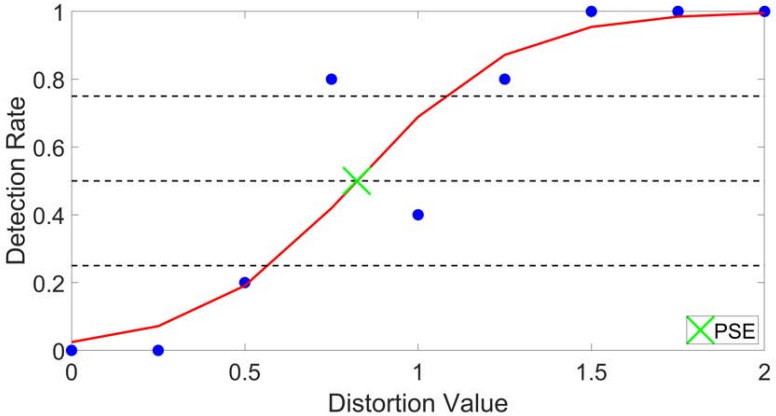
Reconciling Being in-Control vs Being Helped

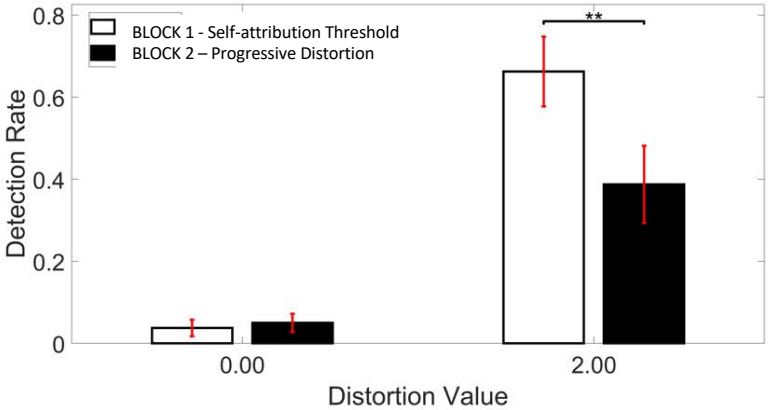
Results (N=24)

DETECTION RATE

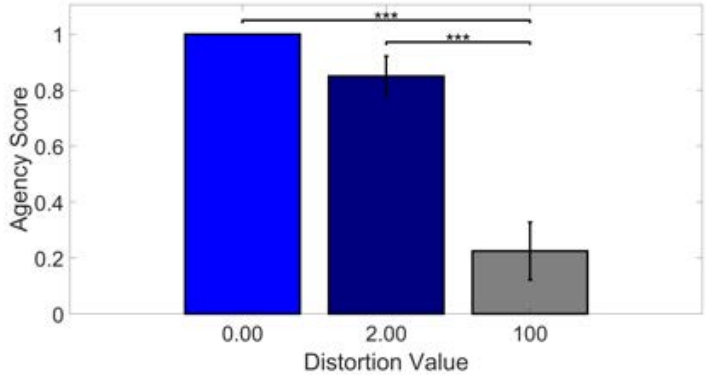
Example Subject

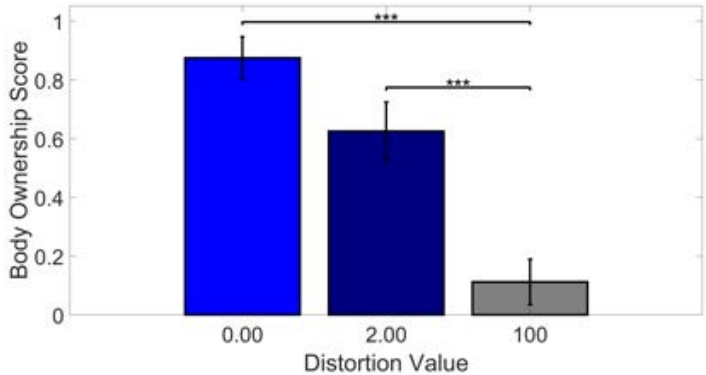


Group



AGENCY AND OWNERSHIP





Self-Contact Visuo-tactile Congruency is stronger than Agency

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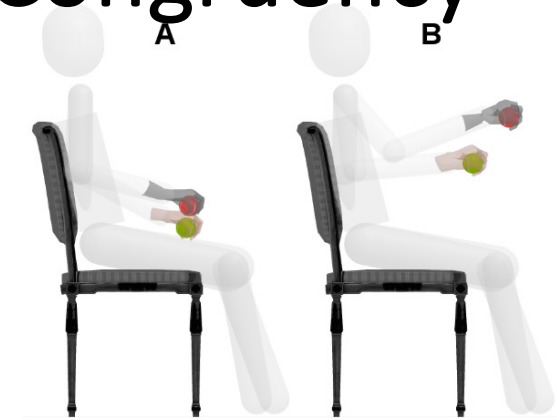
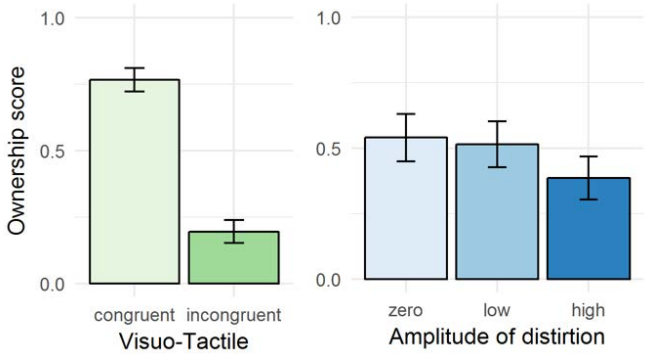
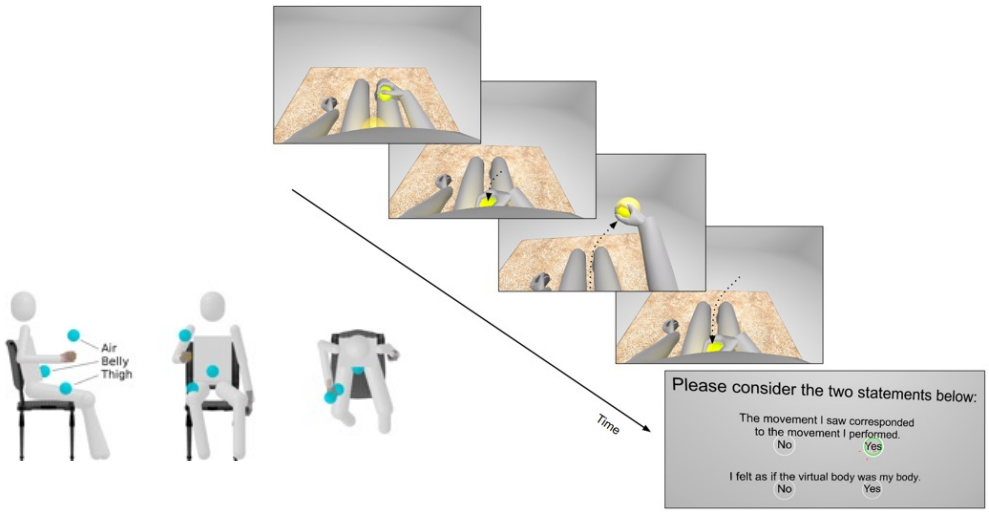
Self-Contact Visuotactile Congruency

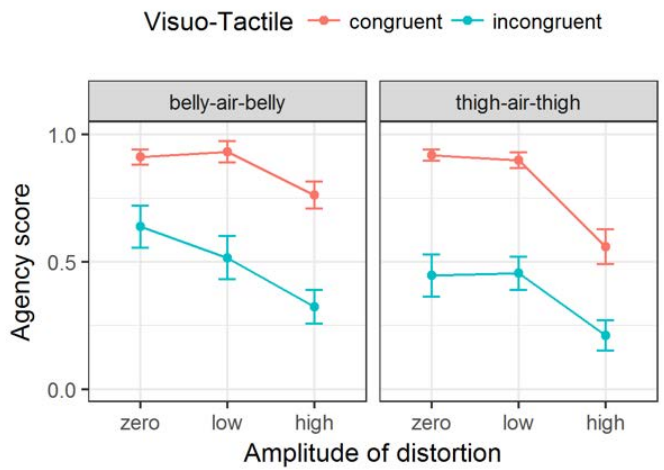
Bovet et al. – IEEEVR 2018



Self-Touch is critical,
And more important than agency



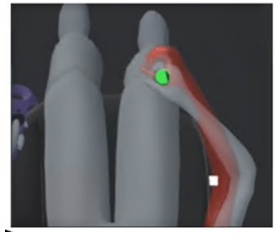




Hitting articular limits

An internal haptic feedback can break embodiment

Flexed

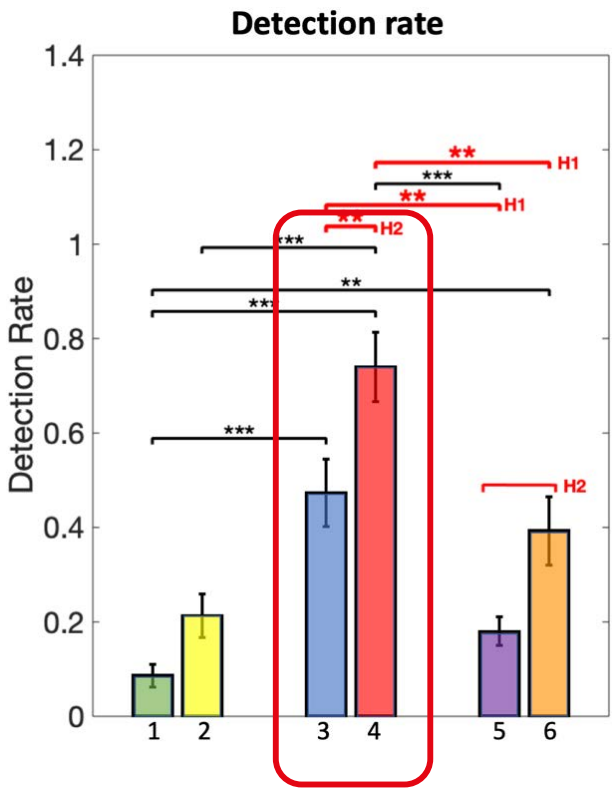


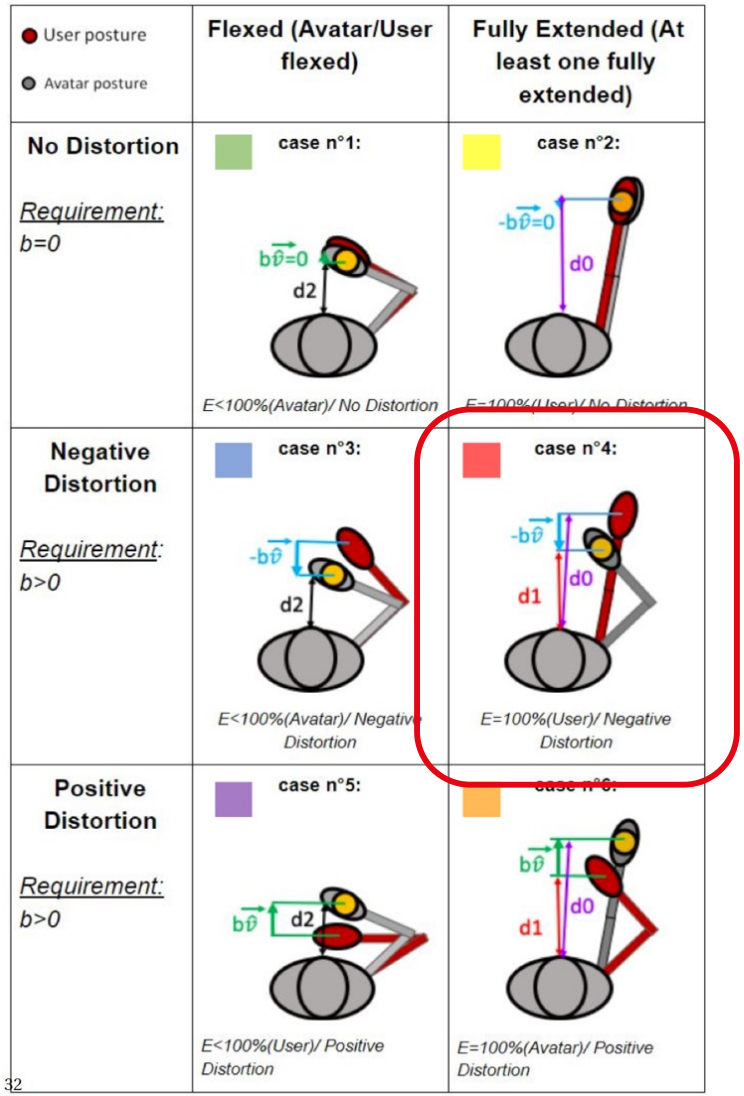
Fully Extended

Avatar
User

Porssut et al.
PLOS ONE 2020

Miscalibration or distortion: hitting full arm extension is detected with 80% acuracy.





Break in embodiment in immersive VR

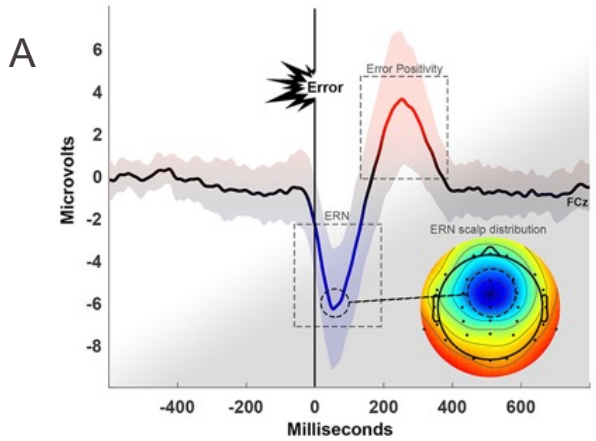
- Immersion, Presence and Body ownership illusion
  - Avatar 3D body
  - Mixed reality
- Sense of Embodiment* (SoE)
  - Body ownership
  - Agency
  - Self-location
- Break in embodiment (BiE)
  - Interruption of at least one component causing a disruption of the SoE

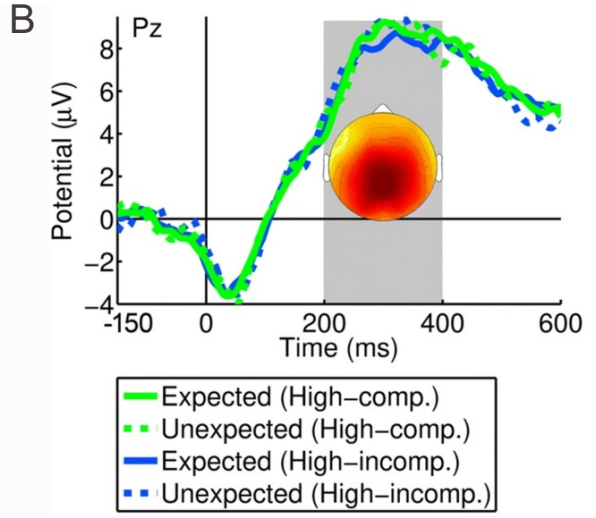
* K. Kilteni, R. Groten, and M. Slater (2012) “TheSense of Embodiment in Virtual Reality,”Presence: Teleoperators and Virtual Environments,vol. 21, pp. 373–387.

EEG Signature of Error detection

- Error-related Potentials (ErrPs)
  - Event-related potential in the EEG resulting from detection of an ”error”
  - Sequential negative and positive deflections in the central area of the brain (fig A)
    - Error-Related Negativity (ERN)
    - Error Positivity (Pe)

- Accumulation of error (fig B)
  - ERN and Pe are influenced by changes in a preceding (prime) task
  - Pe amplitude modulated by expectation

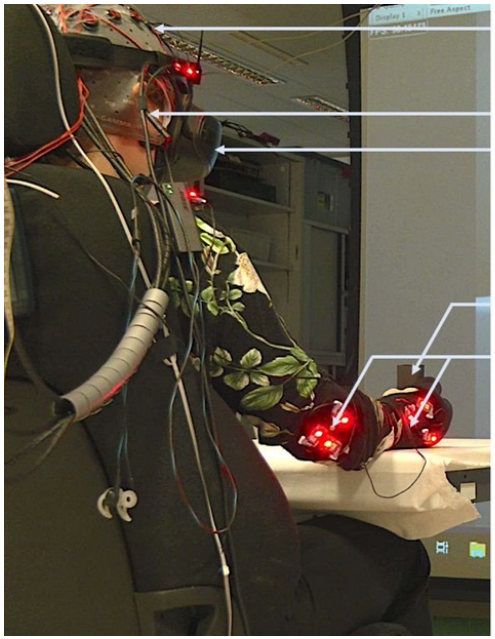


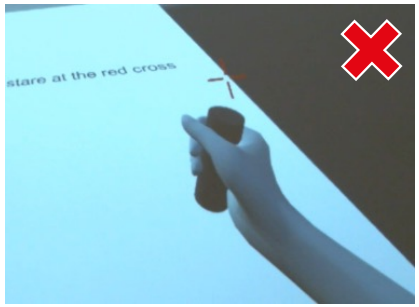


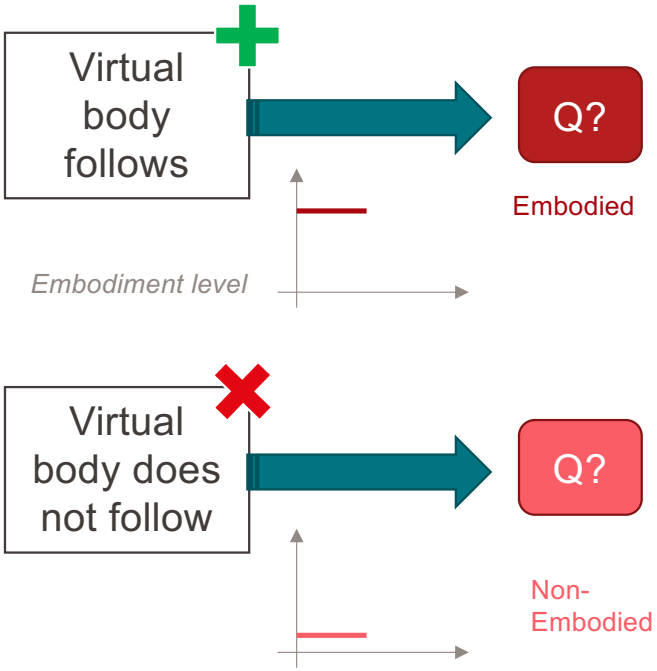
[A] Overbye K, Bøen R, Huster R and Tamnes C (2020) Learning From Mistakes: How Does the Brain Handle Errors?. Front. Young Minds. 8:80. doi: 10.3389/frym.2020.00080

[B] R.Steinhauser, R.Wirth, W.Kunde, M.Janczyk, and M.Steinhauser (2018), Common mechanisms in error monitoring and action effect monitoring. Cognitive, Affective and Behavioral Neuroscience, vol. 18, pp.1159–1171.

Experimental paradigm; induce body ownership illusion







Experimental paradigm

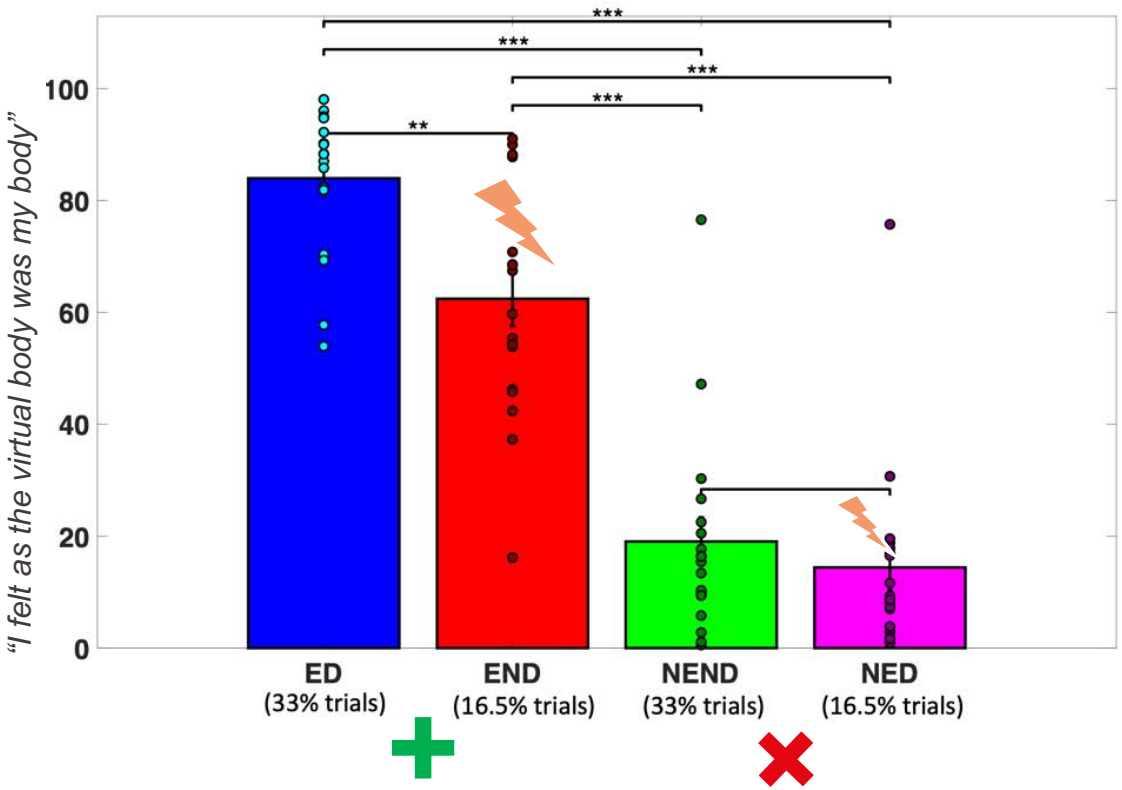
Error-related Potentials Modulated by
a Break in Embodiment in Virtual Reality

Thibault Porssut, Fumiaki Iwane, Bruno Herbelin, Ricardo Chavarriaga, José del R.Millán, Ronan Boulic

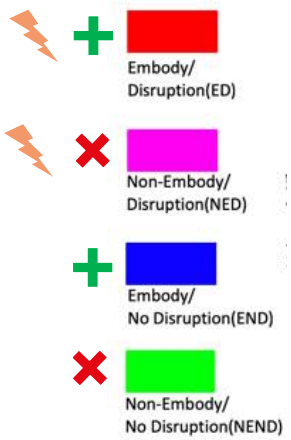
Bruno Herbelin

Results

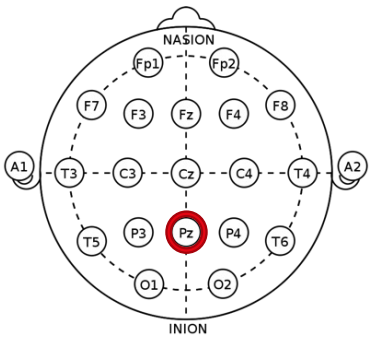
Body ownership question

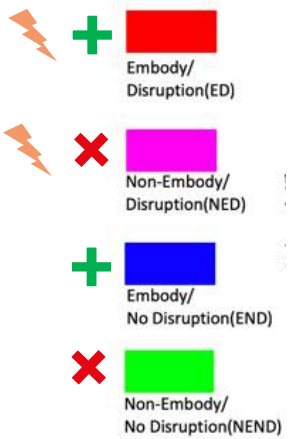


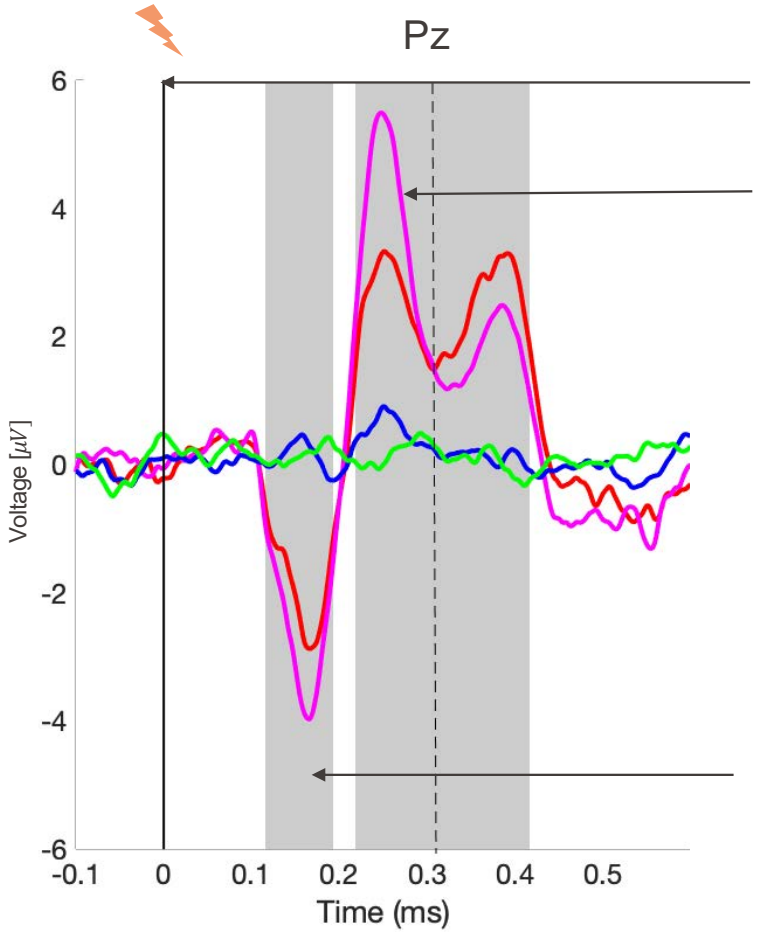
Validates our experimental manipulation: a BiE is introduced by our disruption condition

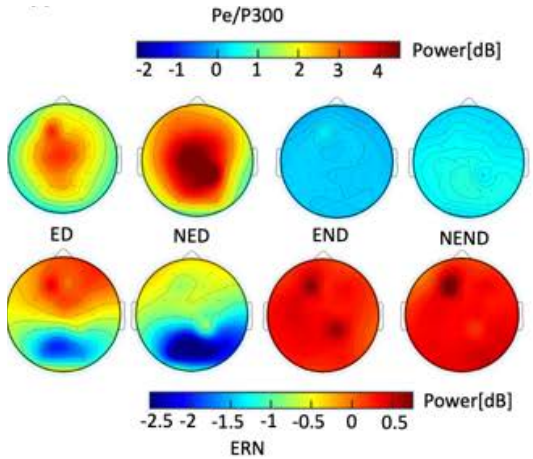


EEG signature of Break in Embodiment



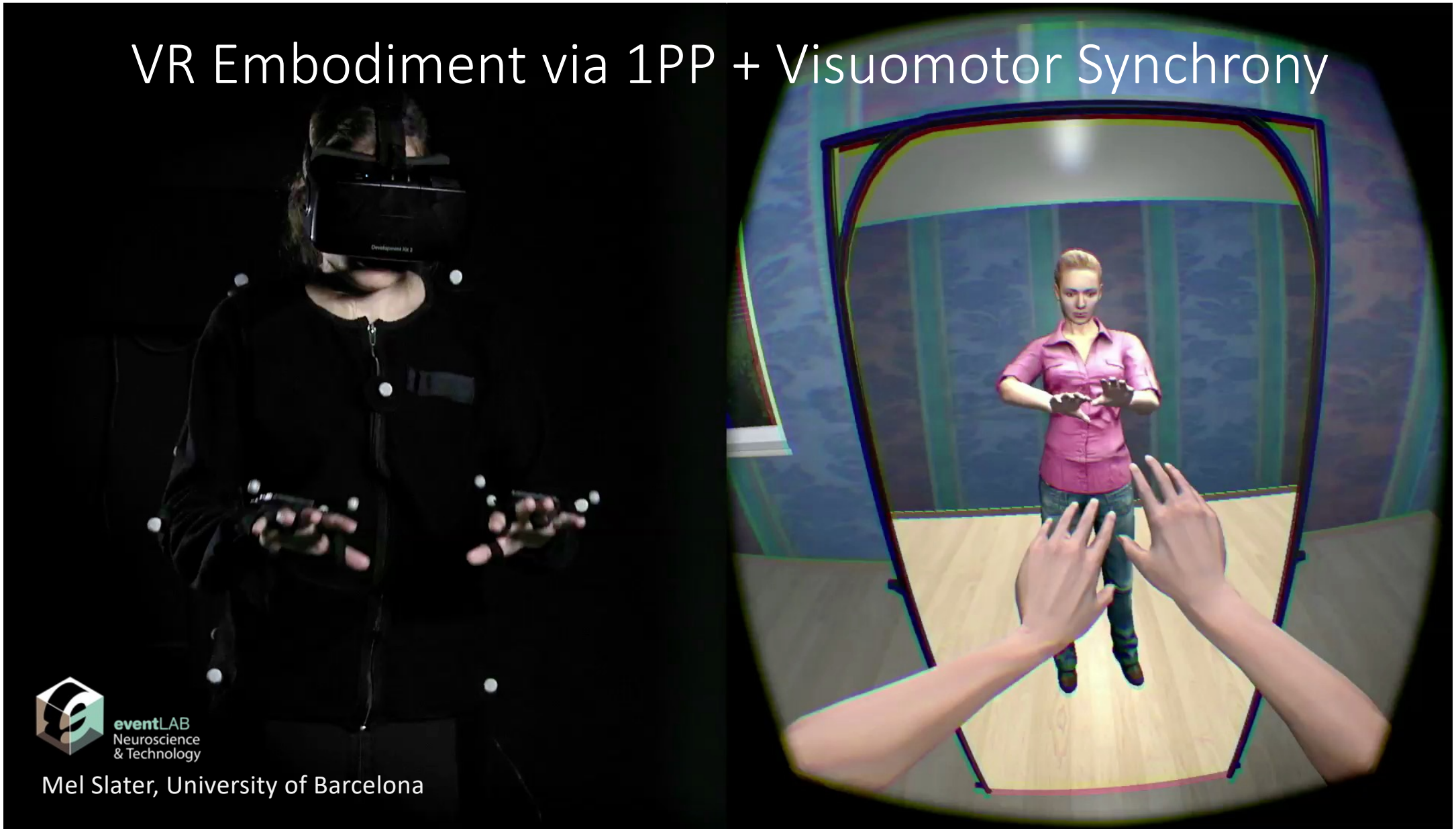




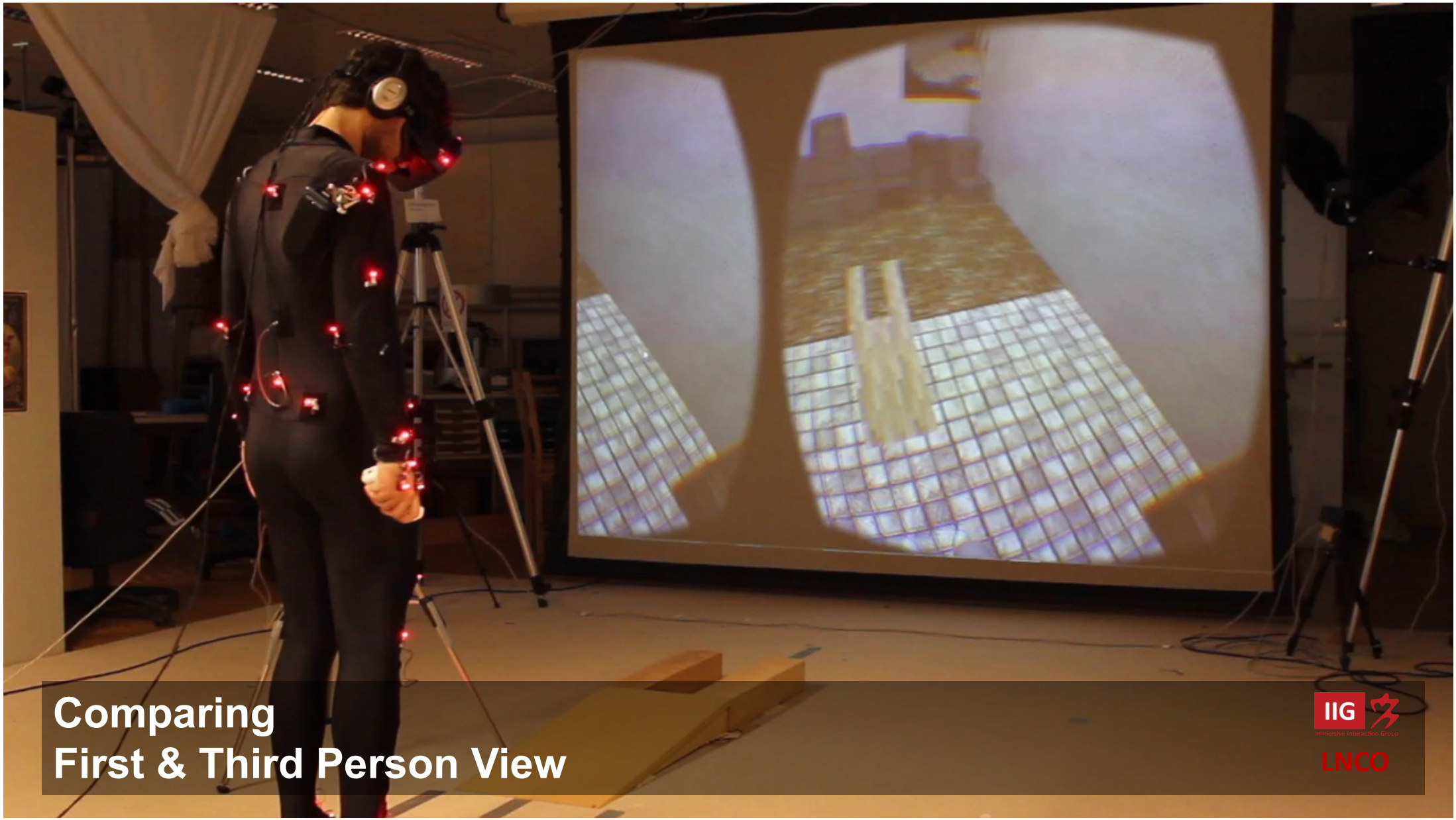


Porssut, T., Iwane, F., Chavarriaga, R., Blanke, O., Millán, J. del R., Boulic, R., & Herbelin, B. (2023). **EEG signature of breaks in embodiment in VR.** PLOS ONE, 18(5), e0282967. https://doi.org/10.1371/journal.pone.0282967

VR Embodiment via 1PP + Visuomotor Synchrony



Mel Slater, University of Barcelona



Comparing First & Third Person View

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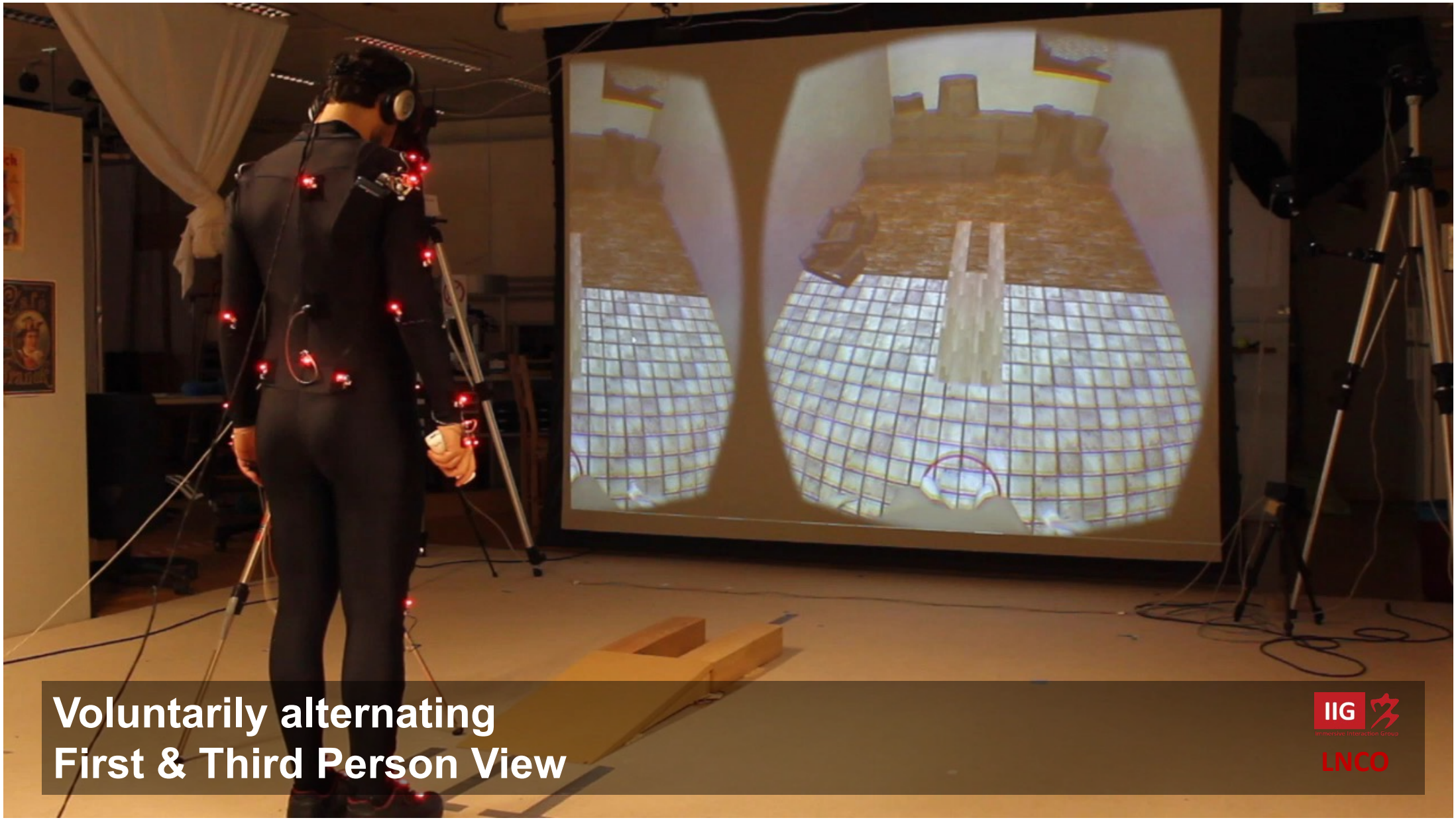
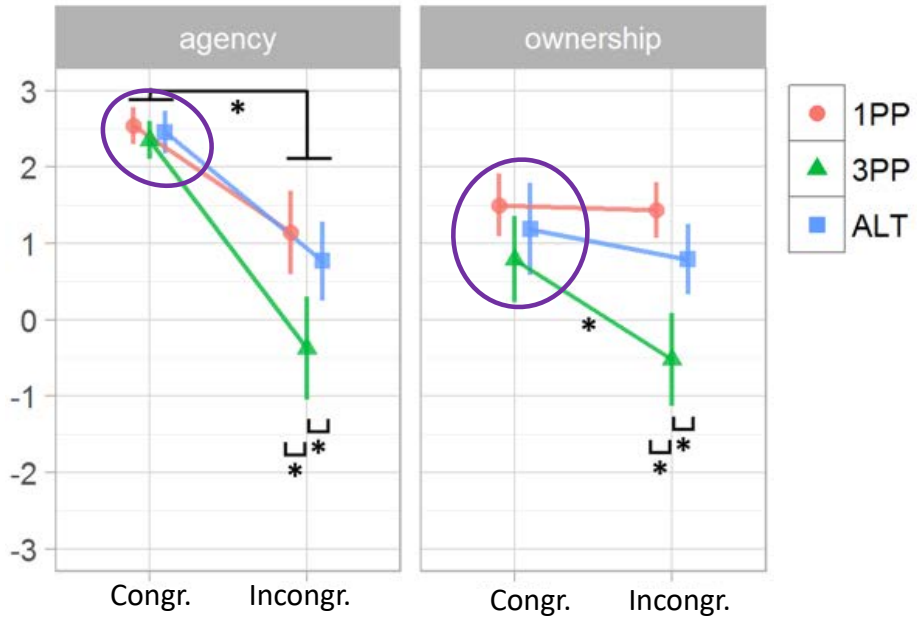

Voluntarily alternating
First & Third Person View
IIG
LNCO

Voluntarily alternating First & Third Person View

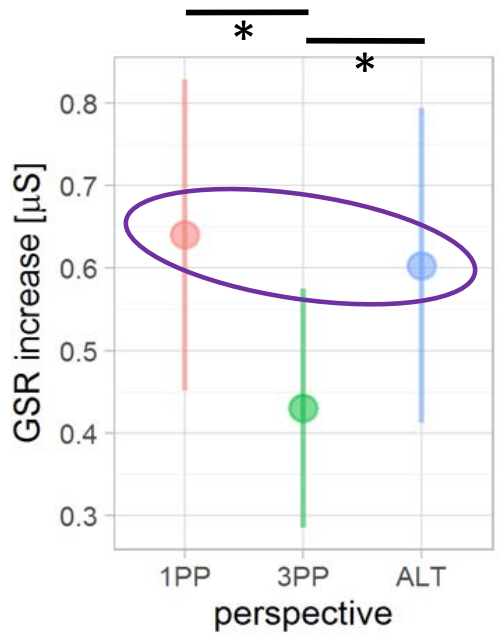
Galvan-Debarda et al. –PLOS ONE 2017

Questionnaire result



Strong embodiment in congruent visuo-motor-tactile condition for both 1st and 3rd P. view

Galvanic skin response to threat



Alternating views can combine the advantages of both

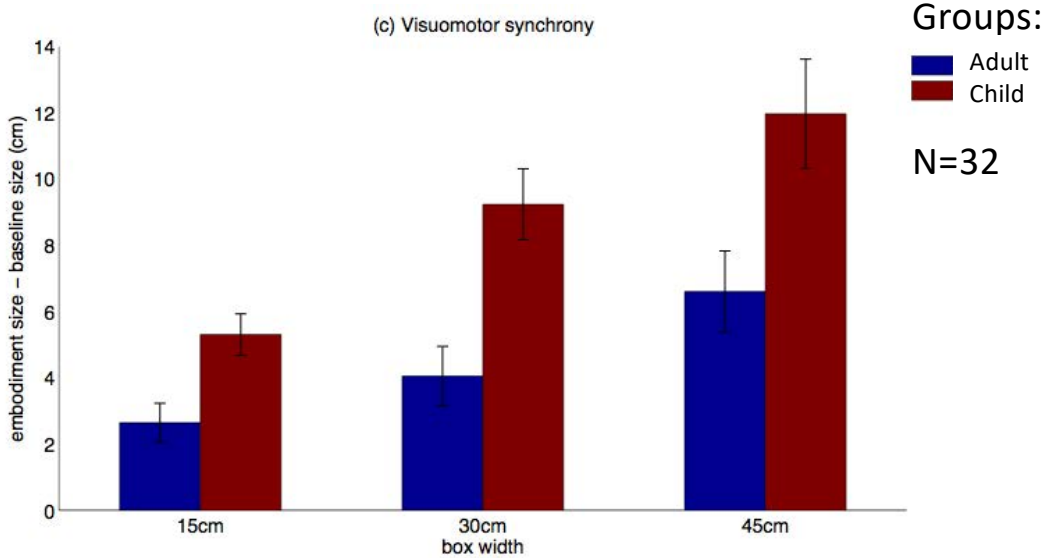
Changes in body representation lead to changes in perception, attitudes and behavior

Examples from **eventLab**
Prof. Mel Slater
Barcelona University

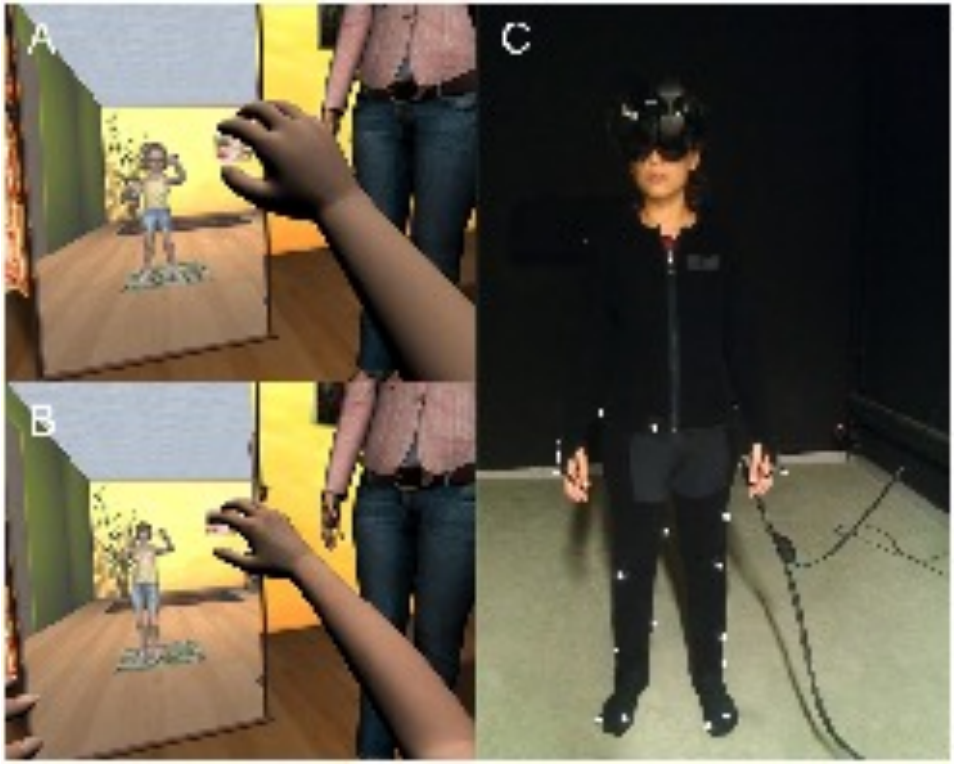
eventLAB
Neuroscience & Technology

Becoming a Child

Just a few moments of multisensory stimulation leads to changes in size perception and self-attributions.



Both groups overestimated the sizes of objects.
Those in the child group double overestimated.



Banakou, Groten, Slater (PNAS, July 2013)

Transforming the Self into a Child

Domna BANAKOU[1], Raphaela GROTEN[1], Mel SLATER[1,2,3]

[1] Facultat de Psicologia , Universitat de Barcelona, Barcelona, Spain
[2] Institucio Catalana Recerca i Estudis Avançats (ICREA), Universitat de Barcelona, Barcelona, Spain
[3] Department of Computer Science, University College London, London, United Kingdom

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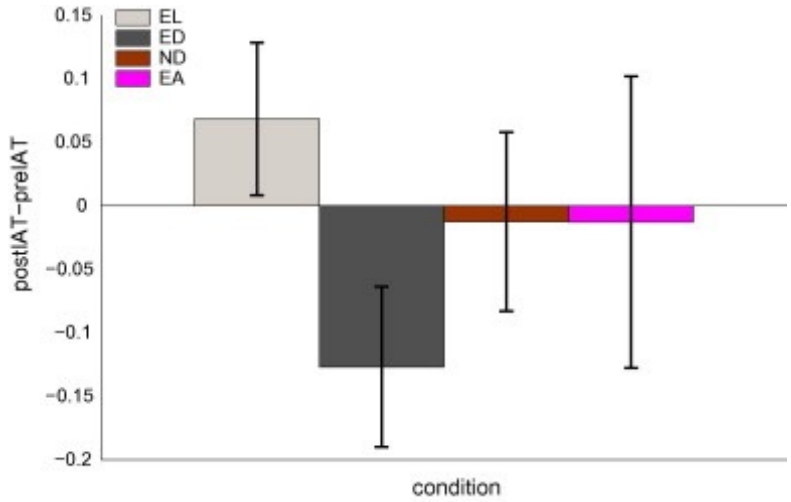
Reducing Implicit Racial Bias

Putting yourself in the skin of a black avatar reduces implicit racial bias

increased bias



decreased bias

Experimental conditions:
Embodied-Light-Skinned (EL)
Embodied-Dark-Skinned (ED)
Non-Embodied Dark-Skinned (ND)
Embodied-Alien-Skinned (EA)

Banakou, Groten, Slater (2013) PNAS
Peck, Seinfeld, Aglioti, Slater (2013) Consc. & Cogn

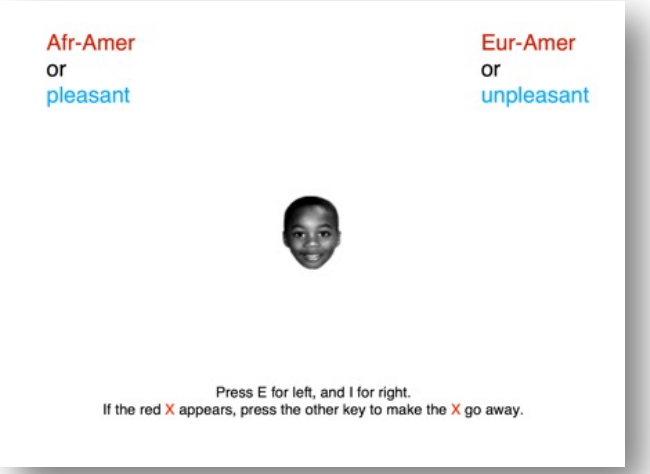
Note

Implicit Association Test (IAT)

If ‘Black’ are faces paired with negative words and ‘White’ faces with positive words faster than the other way around, this shows an ***implicit*** bias.

Note this does not mean that the person is prejudiced but reflects ***implicit*** bias (which may be socially determined)

[See https://implicit.harvard.edu/implicit/demo/](https://implicit.harvard.edu/implicit/demo/)



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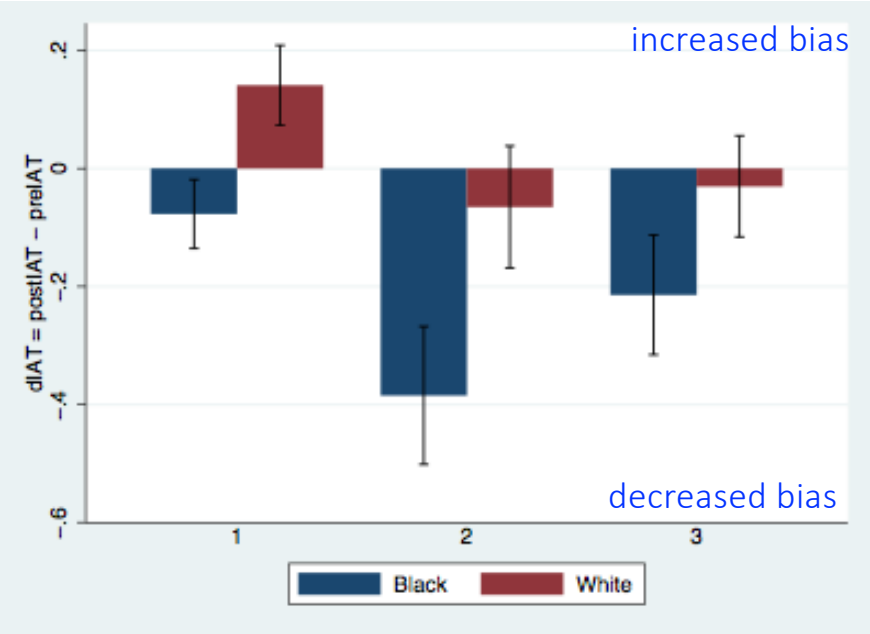
Repetition study - embodiment of White people in Black body reduces implicit bias?

Change in IAT (N = 89)

- Between Groups Design: 3 groups
  - 1, 2, or 3 exposures, each separated by 3 days
- IAT measured 1 week before 1st exposure
- IAT measured 1 week after last exposure



- Diminution lasts at least 1 week after the end of the exposure
- One exposure is sufficient to observe this effect

Banakou, Parasuram D, Slater (2016) Front. Human Neuroscience

Copresence

- The **“illusion of being there with the others, or virtual togetherness”**

- A corollary of the 3 illusions
  - PI : illusion to be in the same space as the others
  - Psi : take the interaction events as really occurring
  - Embodiment: avatar is needed for representing people in the scene

Slater, Banakou, Beacco, Gallego, Macia-Varela, Olivia (2022), A Separate Reality: An Update on Place Illusion and Plausibility in Virtual Reality, Front. Virtual Real, Volume 3 - 2022 | https://doi.org/10.3389/frvir.2022.914392

Copresence Questionnaires

- Tromp et al. (1998), Steed et al. (1999), Slater et al., (2000)

  There was a sense of being with other people rather than just experiencing computer images
  1 – Not at all Very much- 7

- Garau et al. (2001, 2003) – verbal interaction

  I had a real sense of personal contact with my conversation partner.
  I was very aware of my conversation partner

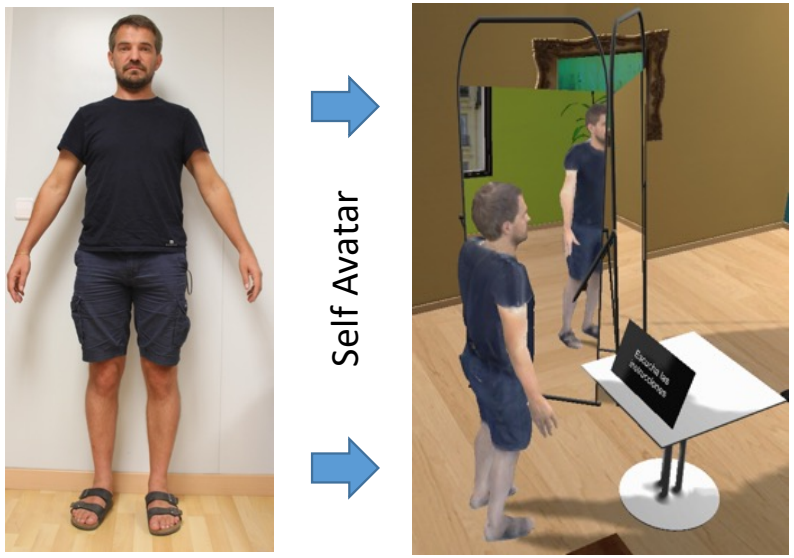
- Poeschl and Doering (2015) – social phobia exposure

  I had the feeling that I perceived other people in the virtual room.
  I felt alone in the virtual environment.

Steed, A., Slater, M., Sadagic, A., Bullock, A., and Tromp, J. (1999). Virtual Real. 1999, 112–115.
Garau, M., Slater, M., Vinayagamoorthy, V., Brogni, A., Steed, A., and Sasse, A. M. (2003). Proceedings of SIGCHI.
Poeschl, S., and Doering, N. (2015). Annu. Rev. Cybertherapy Telemedicine, 58–63

Self Counselling

Basic idea: talking with yourself as if with another person could be helpful for personal problem solving.



Osimo, S. A., Pizarro, R., Spanlang, B., & Slater, M. (2015). Scientific Reports.

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Conversations between Self and Self as Sigmund Freud

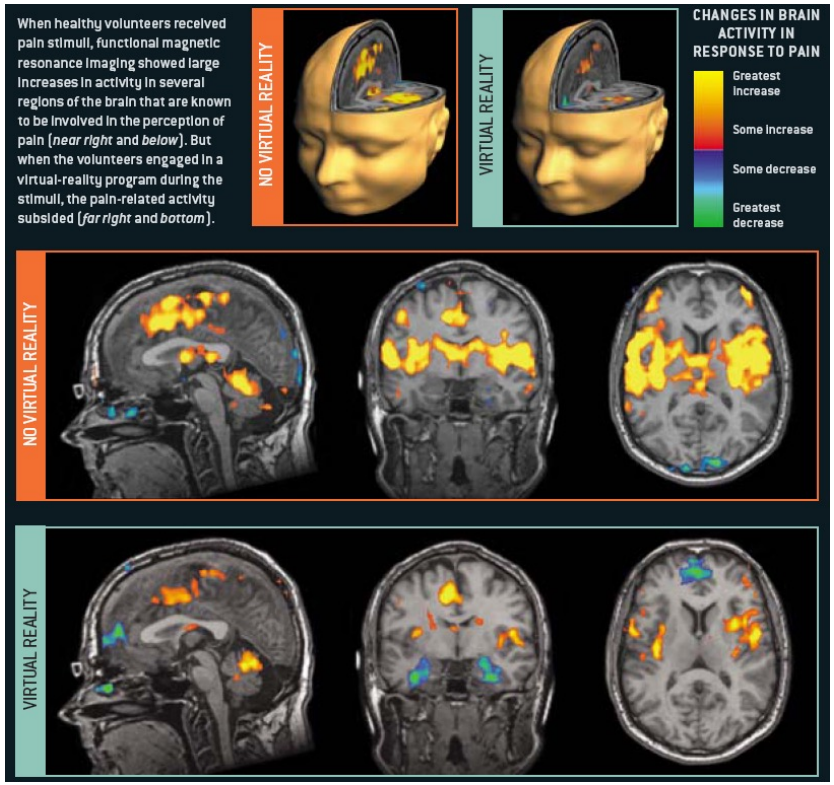
A Virtual Body Ownership Paradigm for Self Counselling

Virtual Reality and Pain

Pain : beyond distraction, disembodiment.

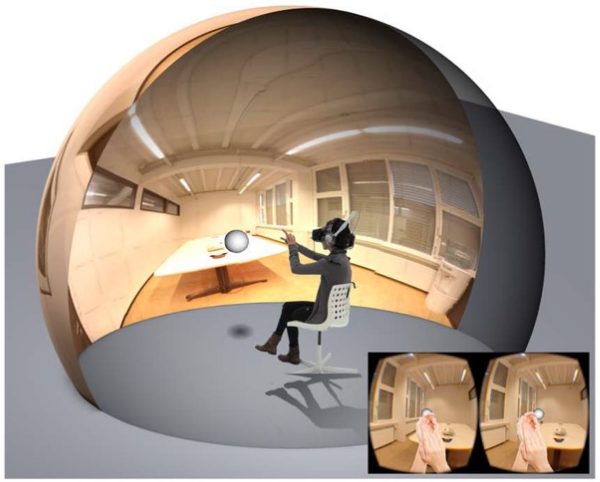
in VR the subject is no more present in her/his body, thus does not experience the pain of the real body

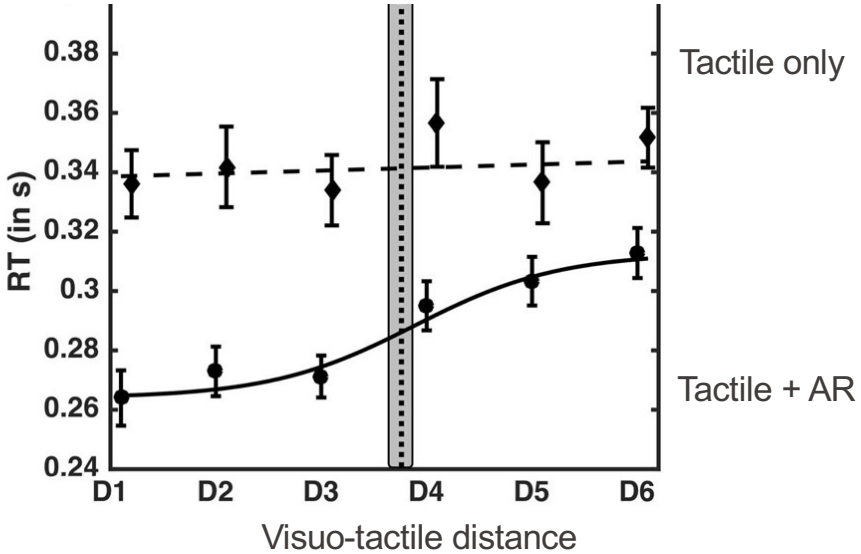
Hoffman et al., 1996, 2000, 2004, 2006



Hoffman, H. Scientific American, April 2004

Recalibration of Peri-Personal Space in augmented reality

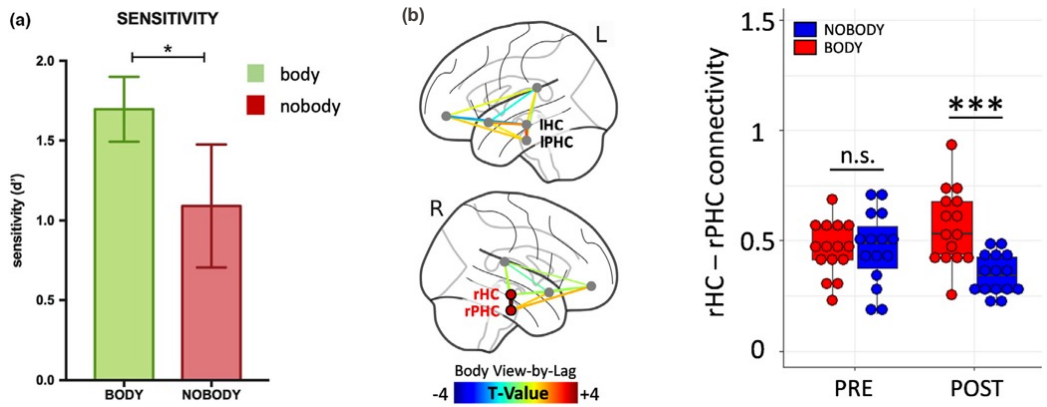




- Link psychophysics with ecological conditions
  - AR vs. Lab conditions
  - EEG
  - Neural Network model

Noel, J.-P., Bertoni, T., Terrebonne, E., Pellencin, E., Herbelin, B., Cascio, C., Blanke, O., Magosso, E., Wallace, M. T., & Serino, A. (2020). Rapid Recalibration of Peri-Personal Space: Psychophysical, Electrophysiological, and Neural Network Modeling Evidence. ***Cerebral Cortex***, *30*(9), 5088–5106. https://doi.org/10.1093/cercor/bhaa103

First-person view in immersive virtual reality modulates episodic memory



VR manipulation during memory encoding: presence or absence of self-body alters retreival performance (a) and shows neural differences pre- vs. post-encoding (b).

Bréchet, L., Hausmann, S. B., Mange, R., Herbelin, B., Blanke, O., & Serino, A. (2020). Subjective feeling of re-experiencing pas events using immersive virtual reality prevents a loss of episodic memory. ***Brain and Behavior***, *10*(6), e01571.

Gauthier, B., Bréchet, L., Lance, F., Mange, R., Herbelin, B., Faivre, N., Bolton, T. A. W., Ville, D. V. D., & Blanke, O. (2020). First-person body view modulates the neural substrates of episodic memory and autonoetic consciousness: A functional connectivity study. ***NeuroImage***, *223*, 117370.

Synthesis

- Technologies for Virtual Reality Embodiment are available and effective
- Embodiment is robust to
  - Change of perspective
  - Movement distortion
  - Various appearance
  - Change of body
- Experiencing being in a different body impacts our perception and judgement of the world

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