EMBODIMENT in VIRTUAL REALITY

A platform for manifold studies: from human perception to telepresence and rehabilitation

FCT eNTERFACE'13

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Universitat de Barcelona

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eventLAB Neuroscience & Technology

THE EVENT LAB

Experimental Virtual Environments for Neuroscience and Technology

eventLAB
Neuroscience
& Technology

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- 10 PhD students

- 7 technical staff
- 2 administrators
- short term visitors

OUTLINE

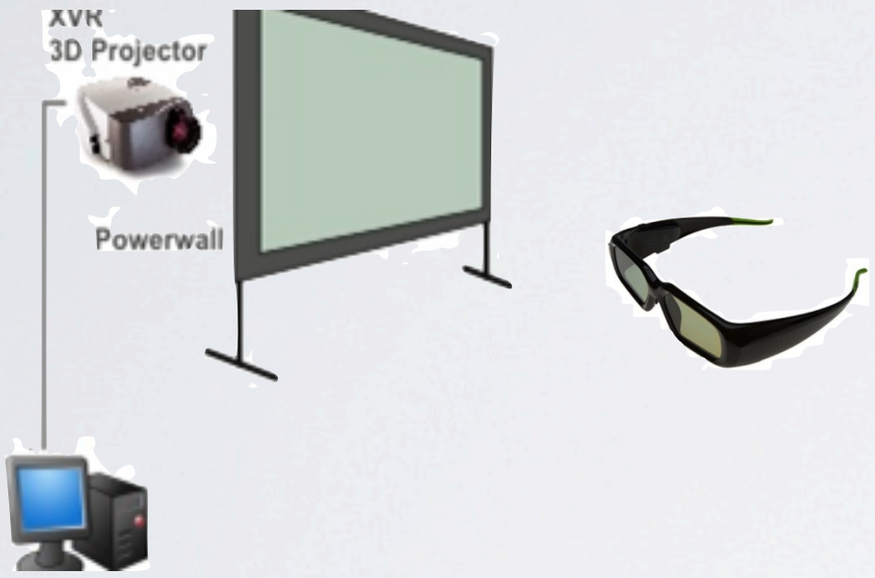
- **Devices for Virtual Embodiment**
- **Multisensory Basis of Own Body Perception**
- **Body illusions**
- **Body ownership in VR: from perception to behavior**
- **Being a Robot**
- **VR for Telepresence: The BEAMING technology**

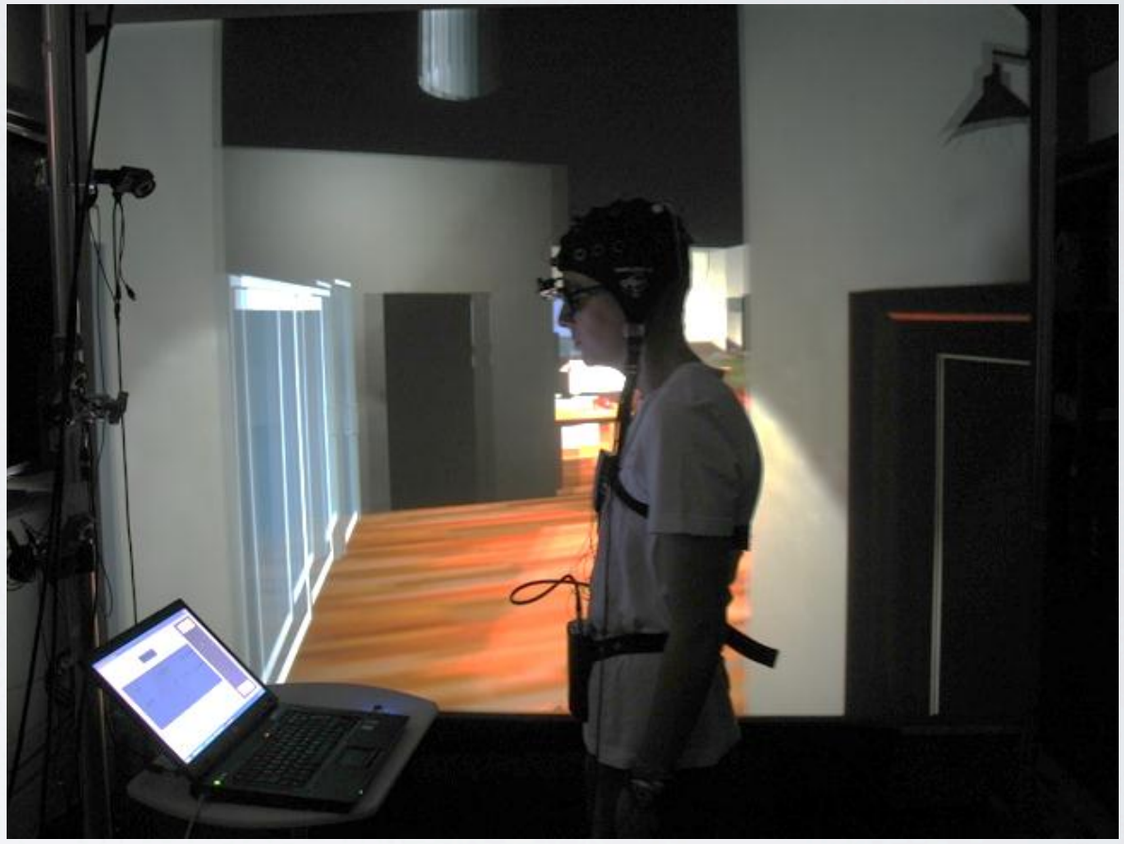
DEVICES FOR VIRTUAL EMBODIMENT

- Immersive Visual Displays
- Tracking Systems
- Haptic Devices
- Physiological Devices

VISUAL DISPLAYS

The Power Wall

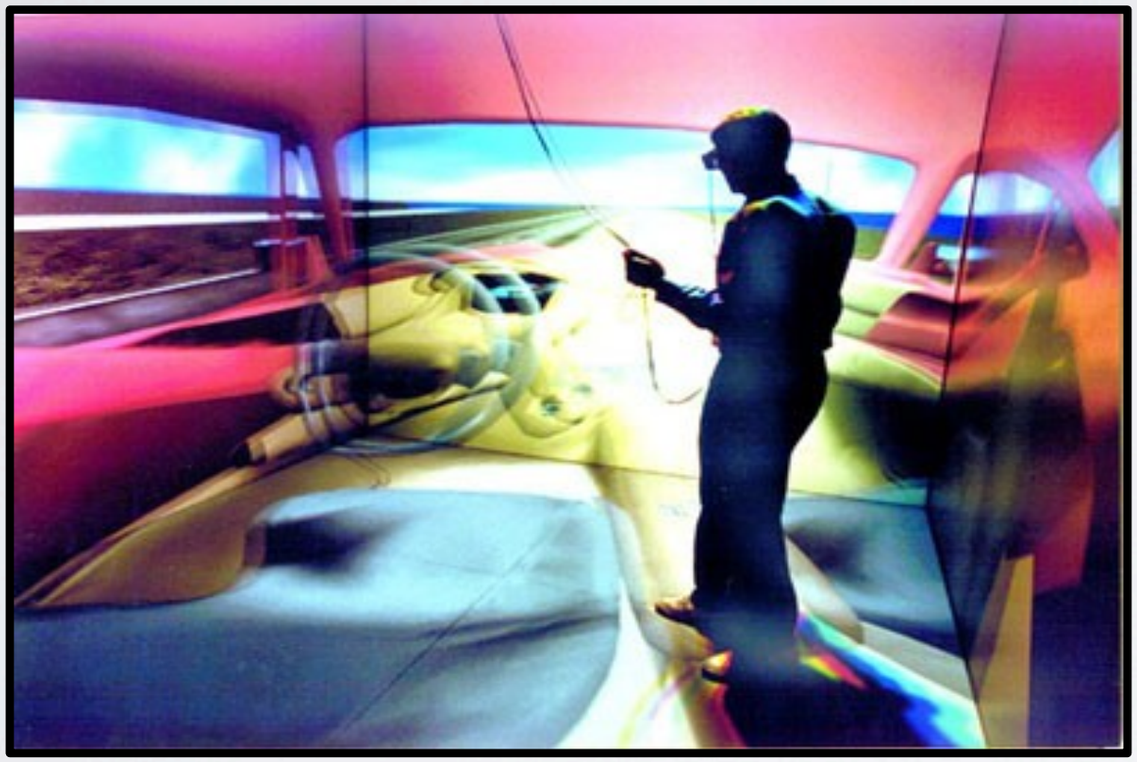


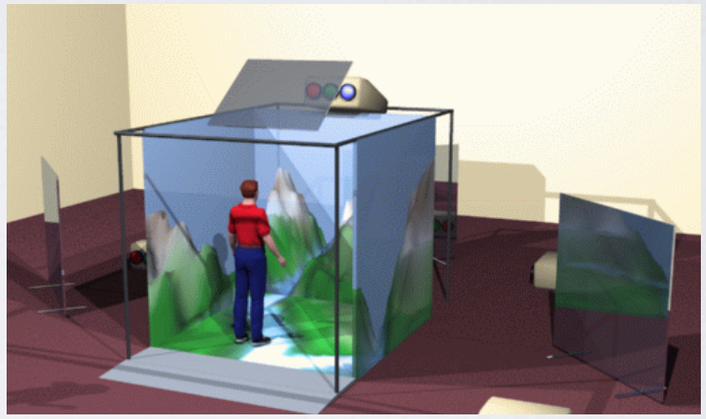


- 2 x 1.8 m^2 screen
- 1 3D Projector
- Stereo Glasses (synchronized)
- Head tracking

VISUAL DISPLAYS

The CAVE





- 4 Screens
- 4 3D Projectors (with calibrated mirrors)
- Stereo Glasses (synchronized)
- Head Tracking

VISUAL DISPLAYS

Head Mounted Displays (HMD)

nVision SX111 by NVIS

- FoV: 120°h x 64°v
- 1. 3 Kg
- Res: 1280 x 1024

Oculus Rift

- FoV: 90°h x 110°d
- 380 Kg
- Res: 640 x 800

TRACKING SYSTEMS

Intersense

Inertial Technology:

6 DoF Gyroscopes, Accelerometer

Head Tracker

Object Tracker

Hand Tracker

TRACKING SYSTEMS

Kinect

Optical Technology

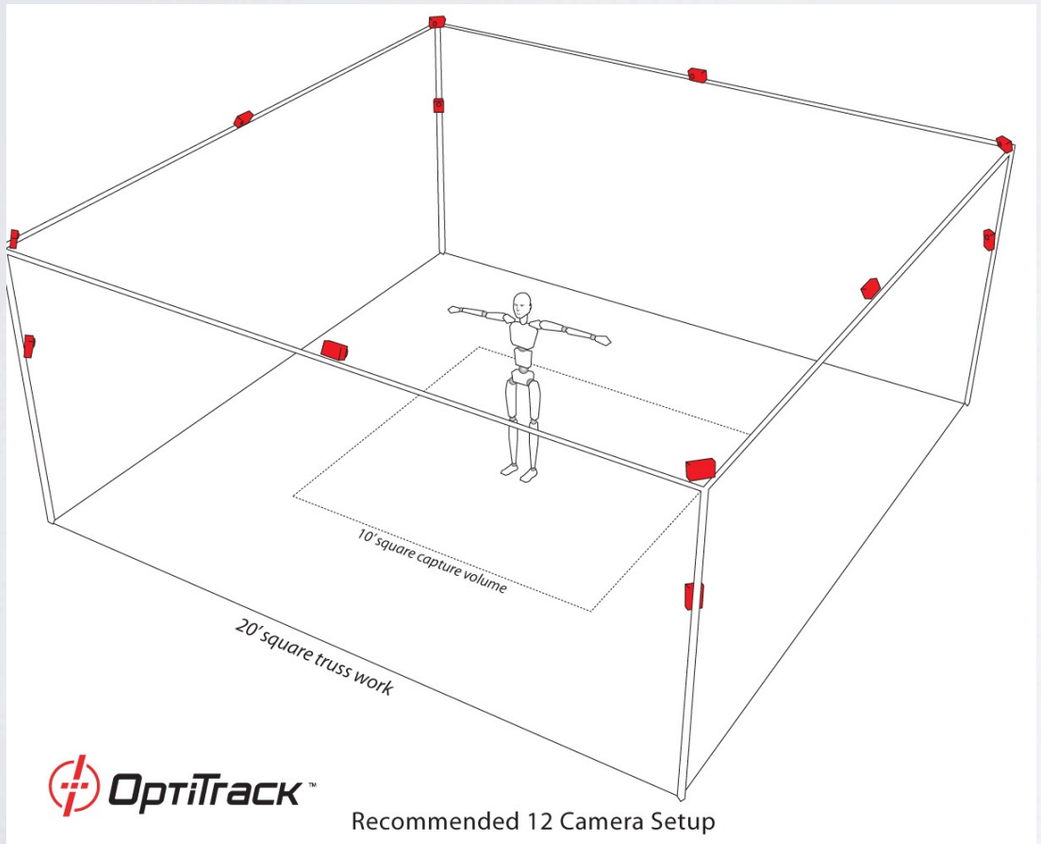
- Body Tacking
- Facial Tracking

TRACKING SYSTEMS

OptiTrack

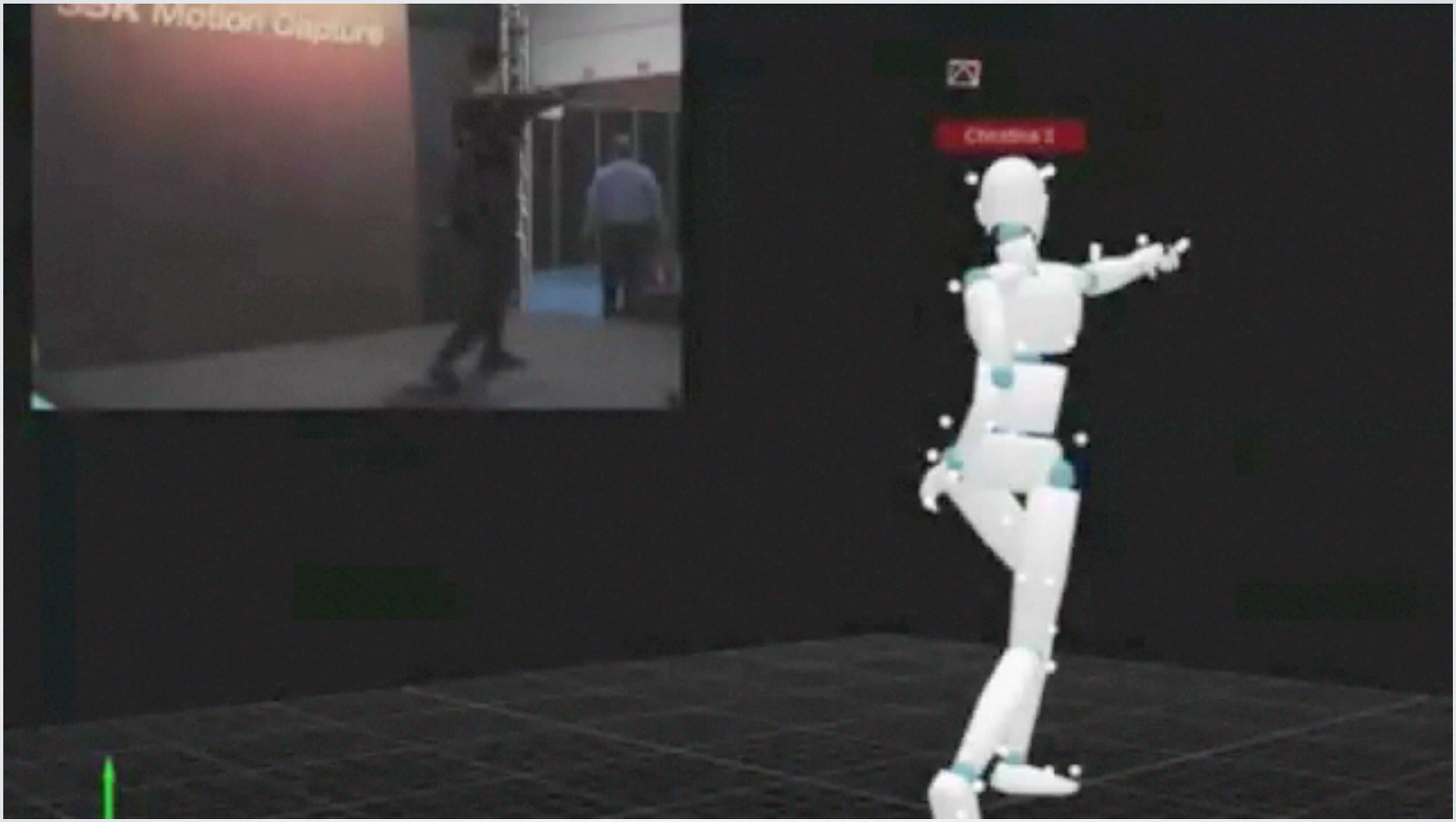
Optical Technology

- 12 Infrared Cameras
- Triangulation of the position
- Reflector Markes



- Body Tacking
- Facial Tracking

TRACKING SYSTEMS



TRACKING SYSTEMS

Xsense

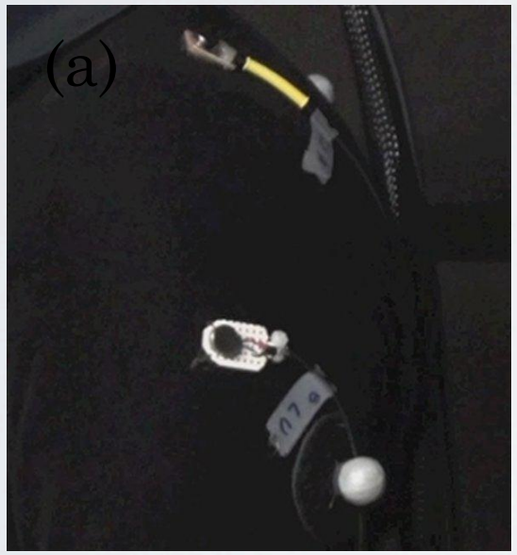
Inertial Technology

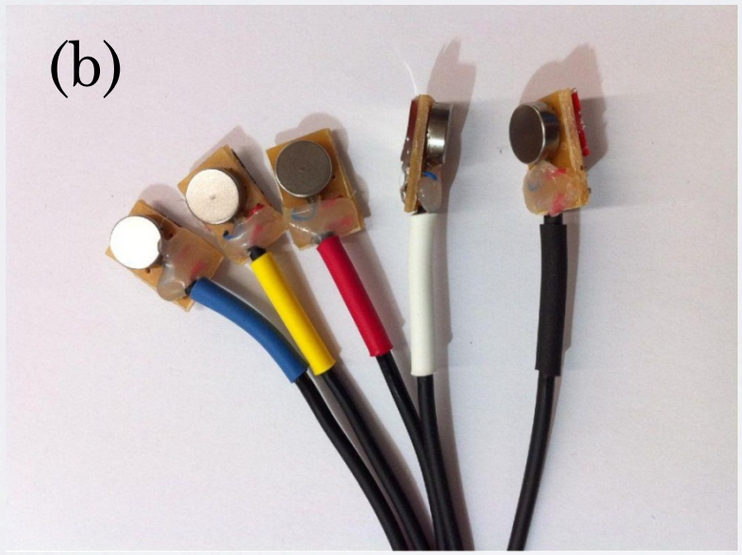
- 6 DoF Accelerometers
- NO cameras
- Indoor/Outdoor

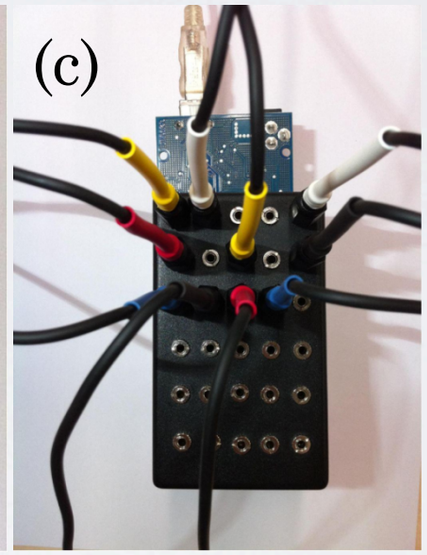
TRACKING SYSTEMS

HAPTIC DEVICES

Vibrators controlled
via Arduino boards







(a) Vibrator on the suit. (b) Vibrators. (c) Arduino board.

HAPTIC DEVICES

Haptic Gloves

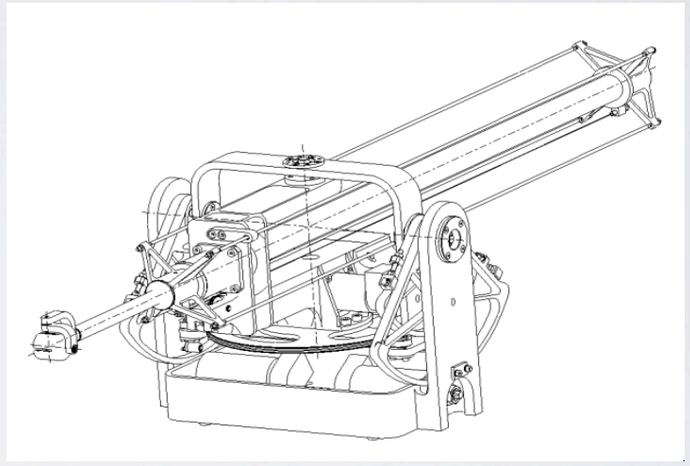
to track hand movements

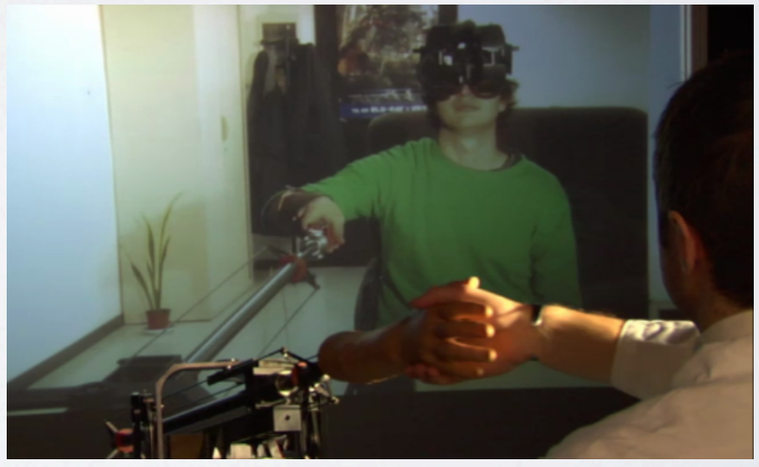
to exert force feedback to the hand
and simulate interaction with
objects in the virtual scene

HAPTIC DEVICES

Force Feedback Devices

Phantom





HAPTIC DEVICES

Manual control of
"registered" tracked objects

PHYSIO DEVICES

Monitoring participants' response to VT
Controlling avatars' behaviuor

- Temperature
- GSR - Galvanic Skin Response
- HR - Heart Rate
- EMG - Electromyogram
- EEG - Electroencephalogram

EMBODIMENT IN VR

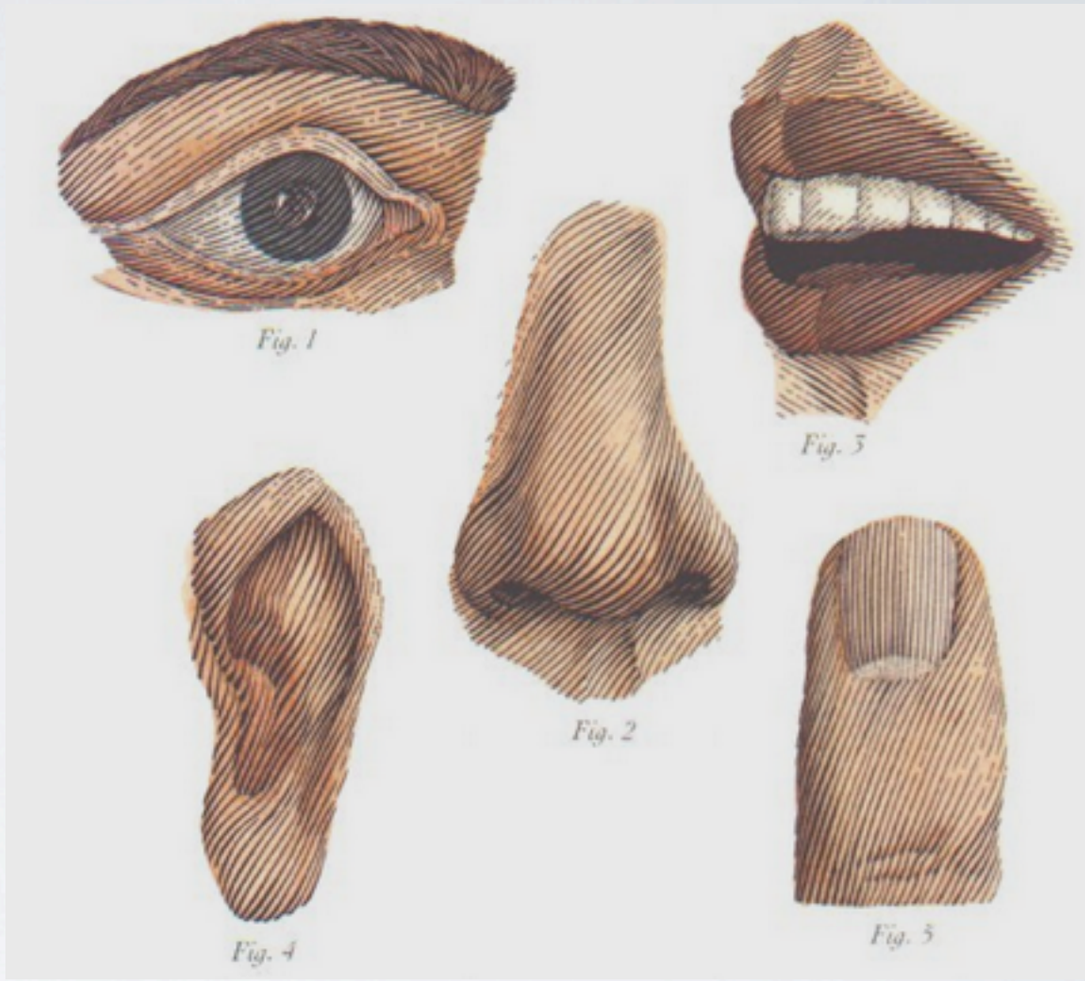
An Example

OWNERSHIP ILLUSIONS
as
EMERGING PERCEPTS

- Multisensory Dimension of Body Perception (an overview)
- Body illusions (some examples)
- Ownership Illusions in VR (some examples)

SENSORY CHANNELS FOR BODY PERCEPTION

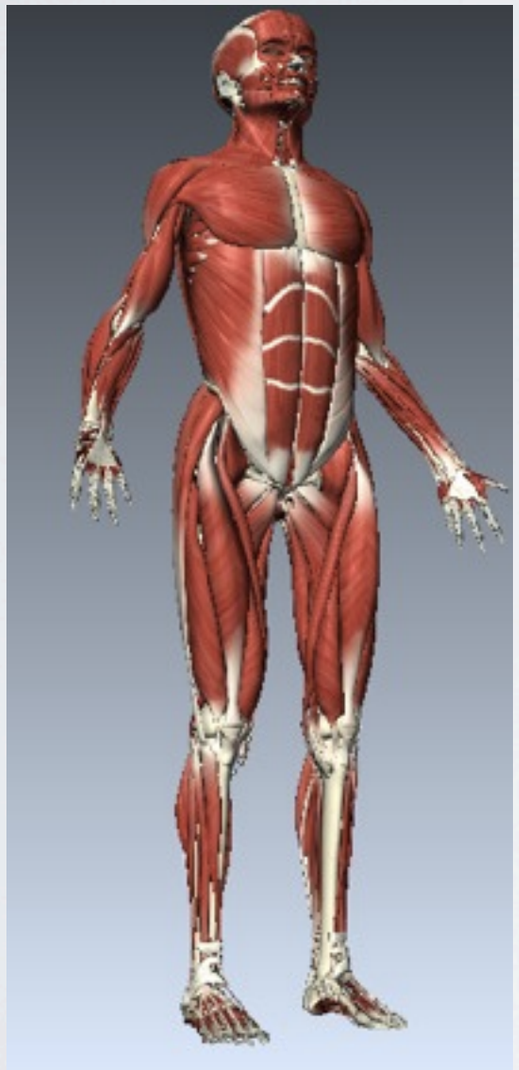
- Vision
- Hearing
- Smell
- Taste
- Somatosensory system
  - Touch
  - Thermoception
  - Nociception
  - Proprioception
  - Interoception



SENSORY CHANNELS FOR BODY PERCEPTION

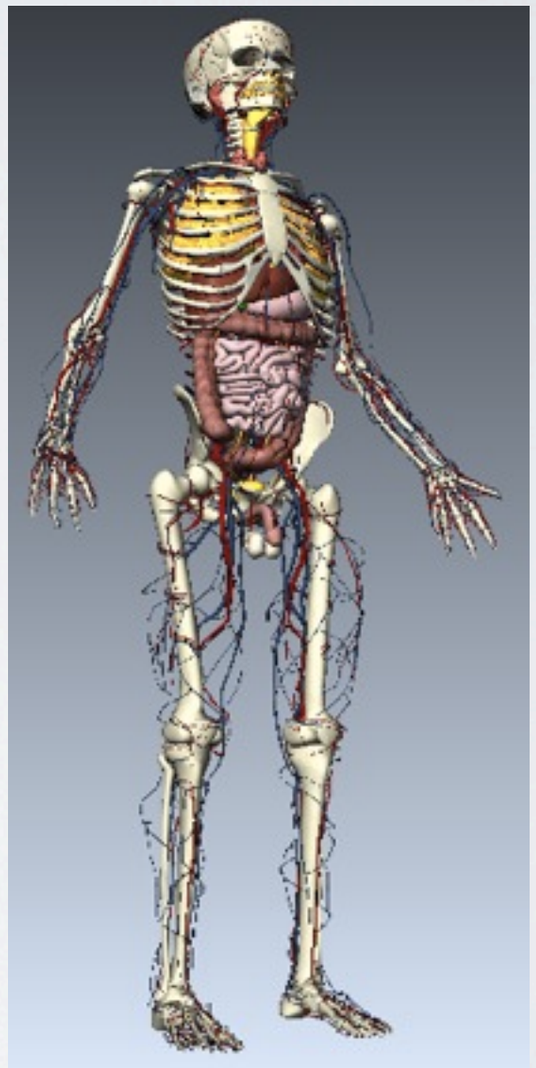
- Proprioception

"position sense"



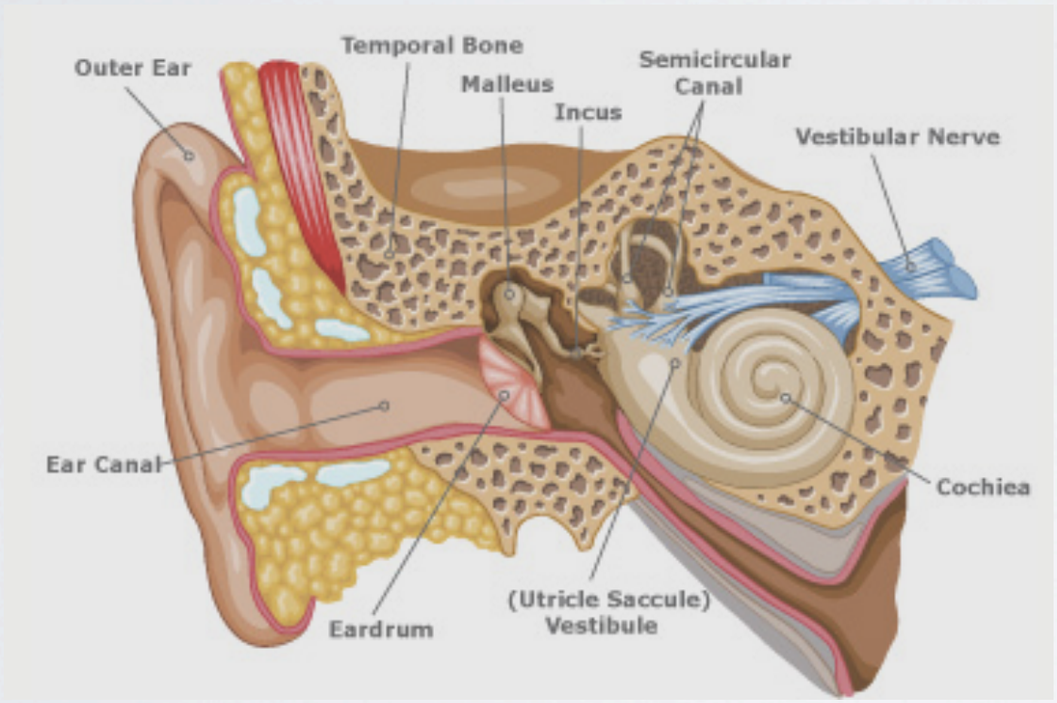
- Interoception

"sense of the physiological state of the body"



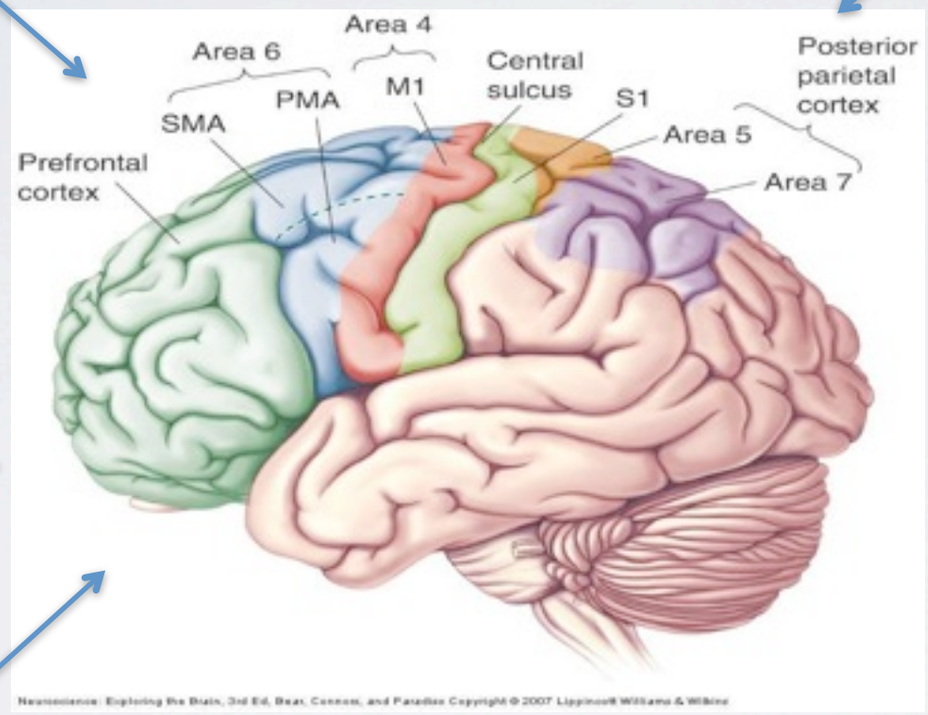
SENSORY CHANNELS FOR BODY PERCEPTION

- Vestibular system



A SINGLE BODY PERCEPT

- Thermoception
- Nociception
- Vision
- Touch
- Hearing
- Smell
- Taste



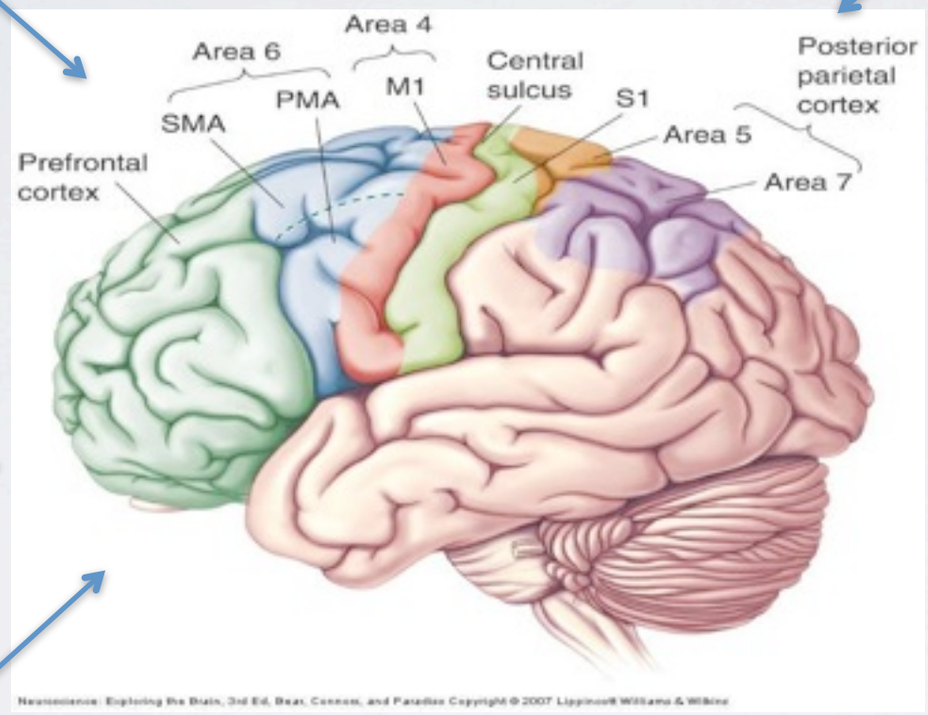
- Vestibular system
- Interocetpion
- Proprioception

- Motor control

ONE BODY

A SINGLE BODY PERCEPT

- Thermoception
- Nociception
- Vision
- Touch
- Hearing
- Smell
- Taste



- Vestibular system
- Interocetpion
- Proprioception

- Motor control

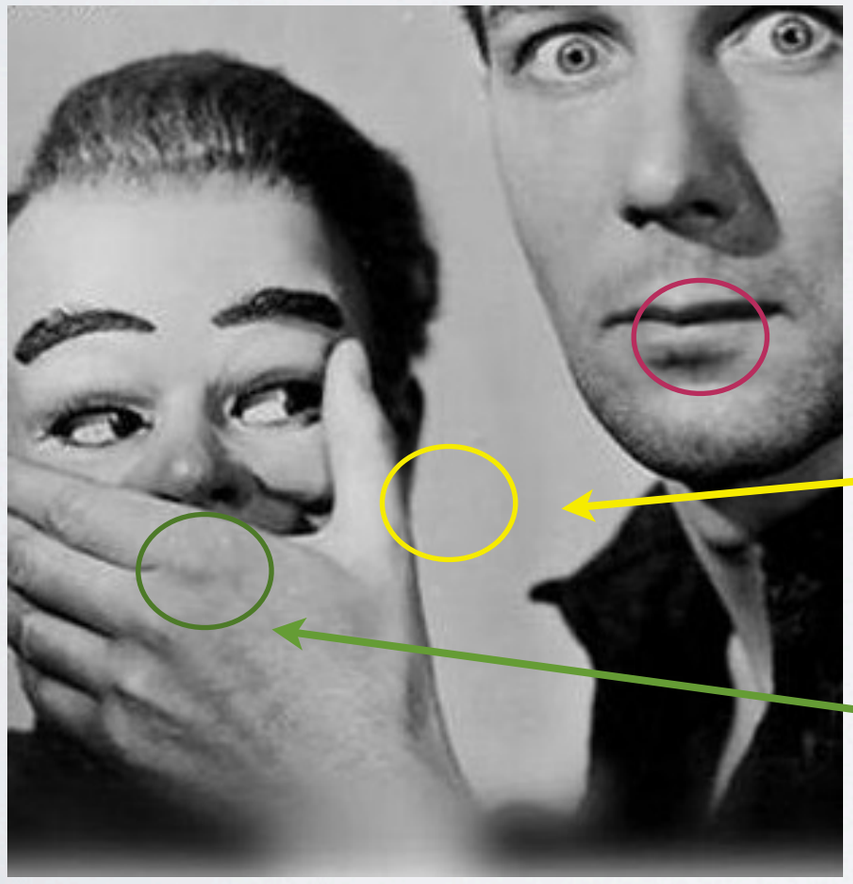
ONE BODY

MULTISENSORY INTEGRATION

MULTISENSORY INTEGRATION

process in which the concurrent information from different sensory modalities is combined, returning a SINGLE percept different form the ones corresponding to the single modalities.

Example: VENTRILOQUIST EFFECT



"Where the voice come from?"

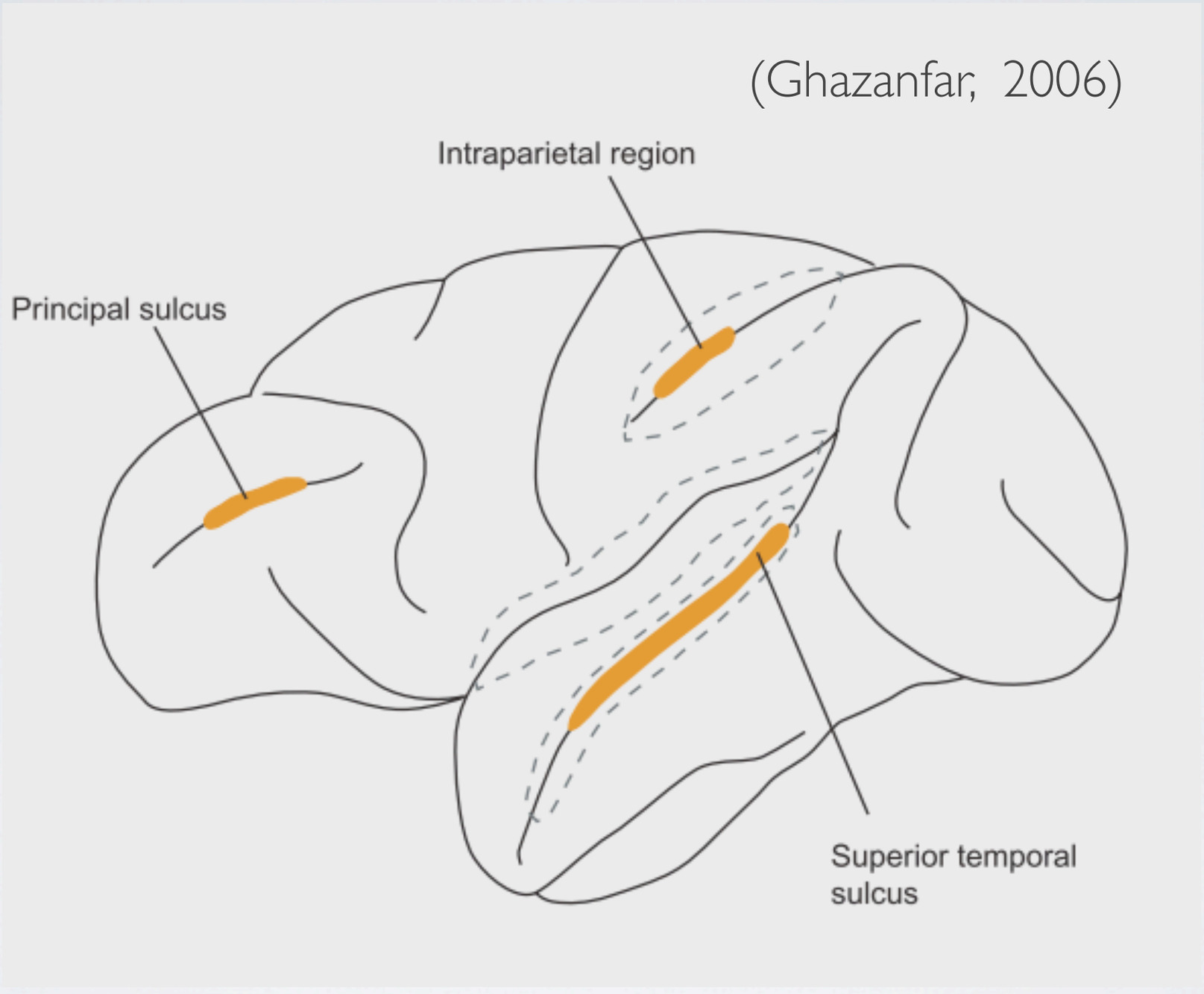
SOUND ONLY

SOUND + VISION

VISION ONLY

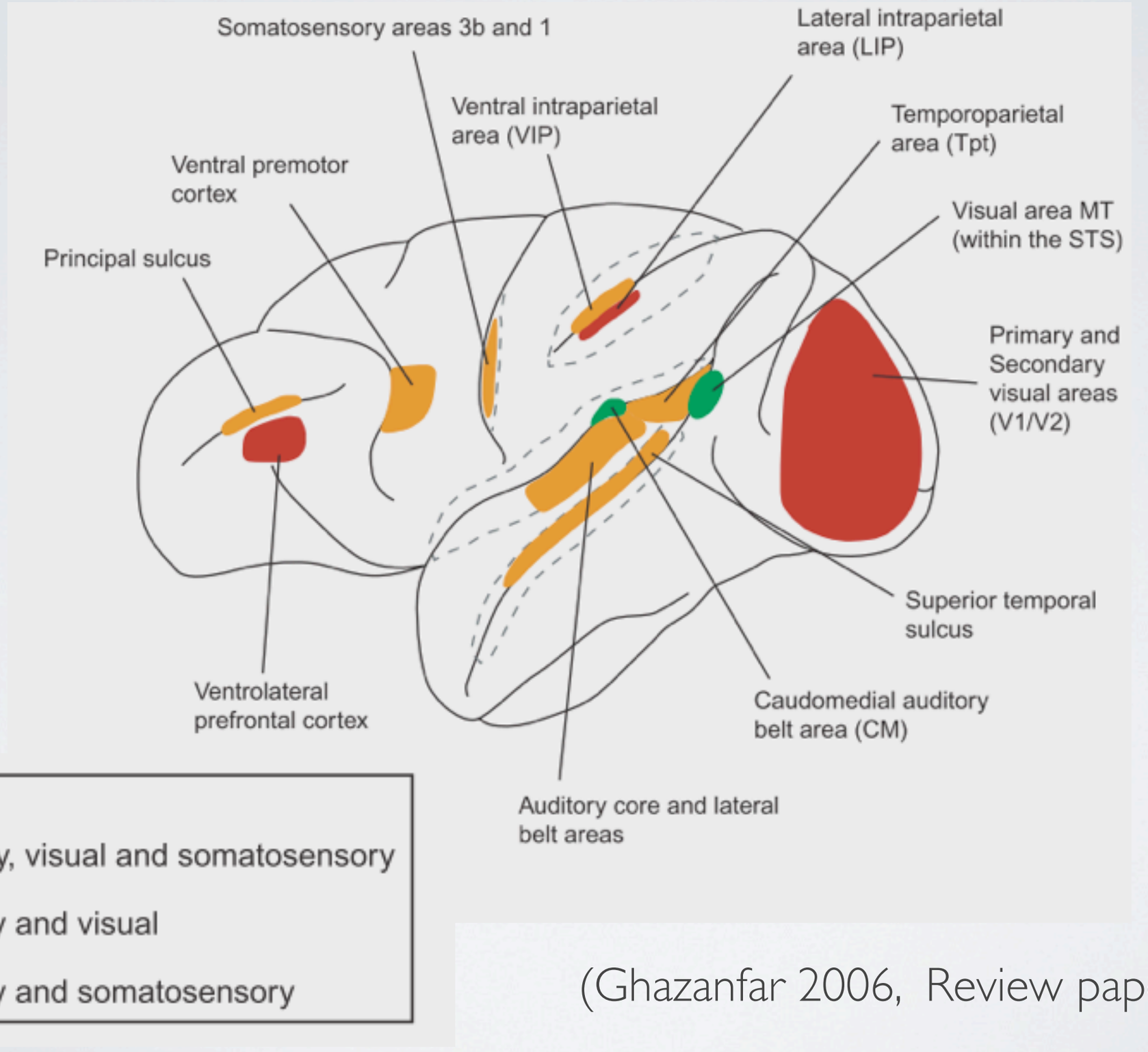
SITES OF MULTISENSORY INTEGRATION

(Ghazanfar, 2006)



- Auditory, Visual and Somatosensory

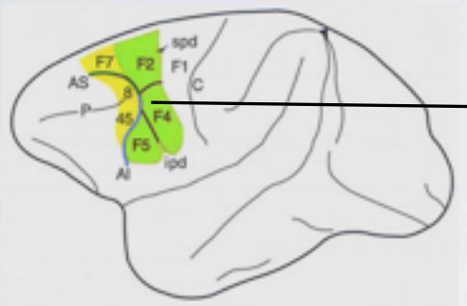
SITES OF MULTISENSORY INTEGRATION



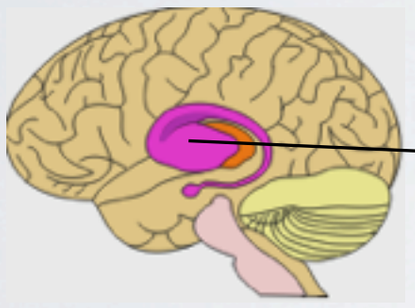
(Ghazanfar 2006, Review paper)

INTEGRATION OF VISION AND TOUCH

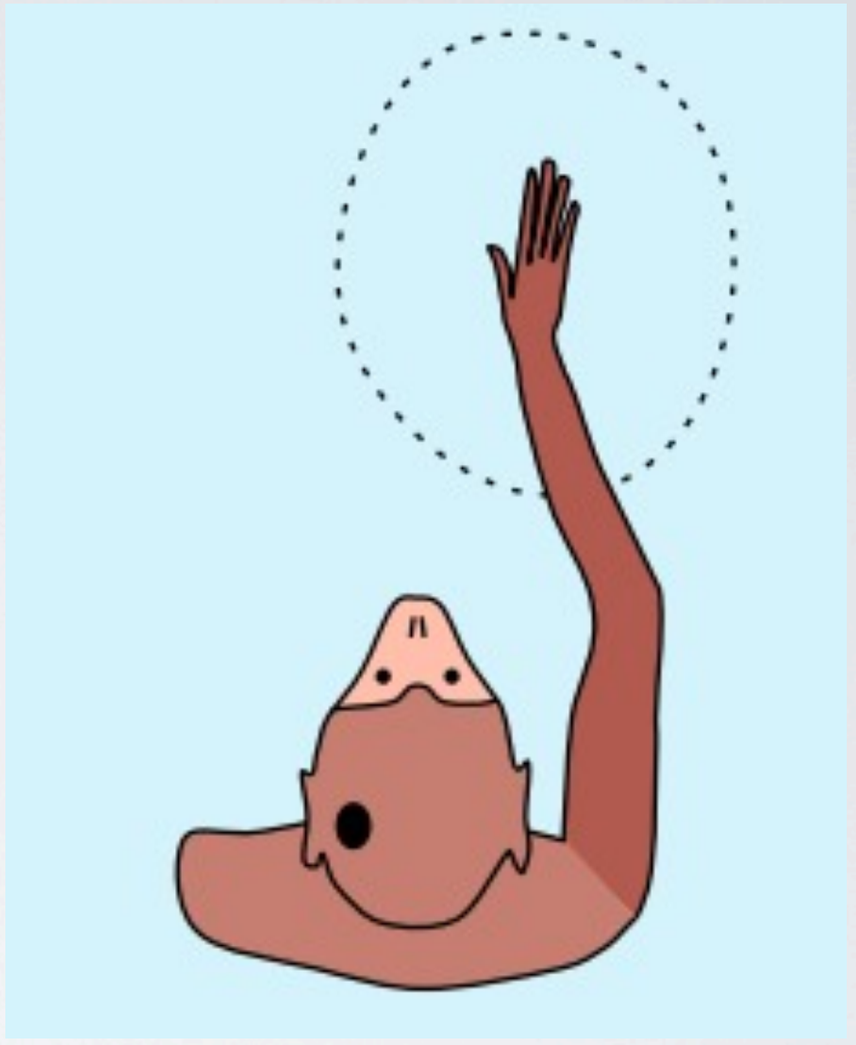
Intraparietal Cortex



Prefrontal Cortex



Putamen



Receptive Fields

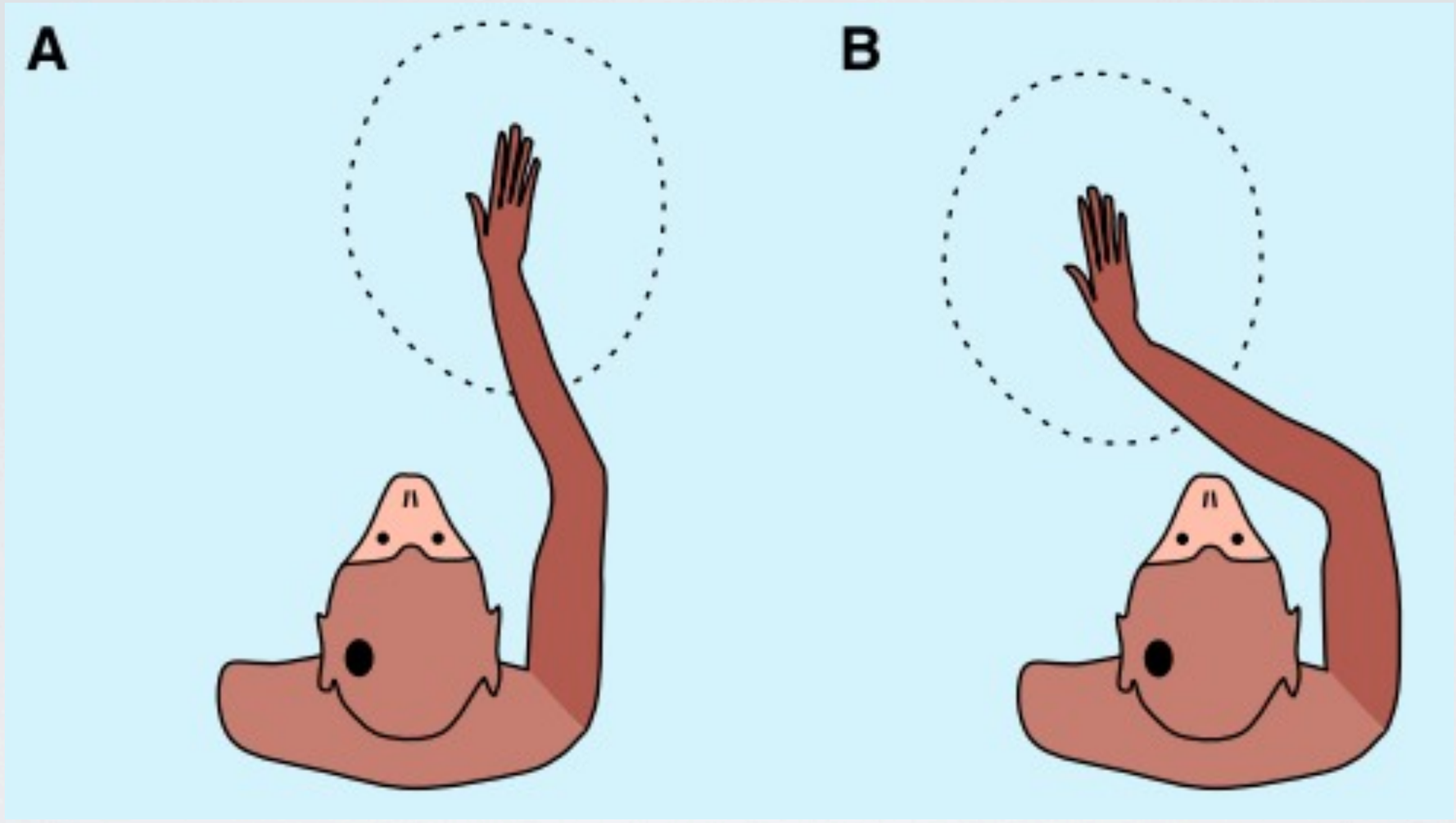
Single neurons respond to both tactile and visual stimuli

Tactile

Visual

INTEGRATION OF VISION AND TOUCH

(Graziano and Gross, 1995; Maravita et al., 2005)



Receptive Fields

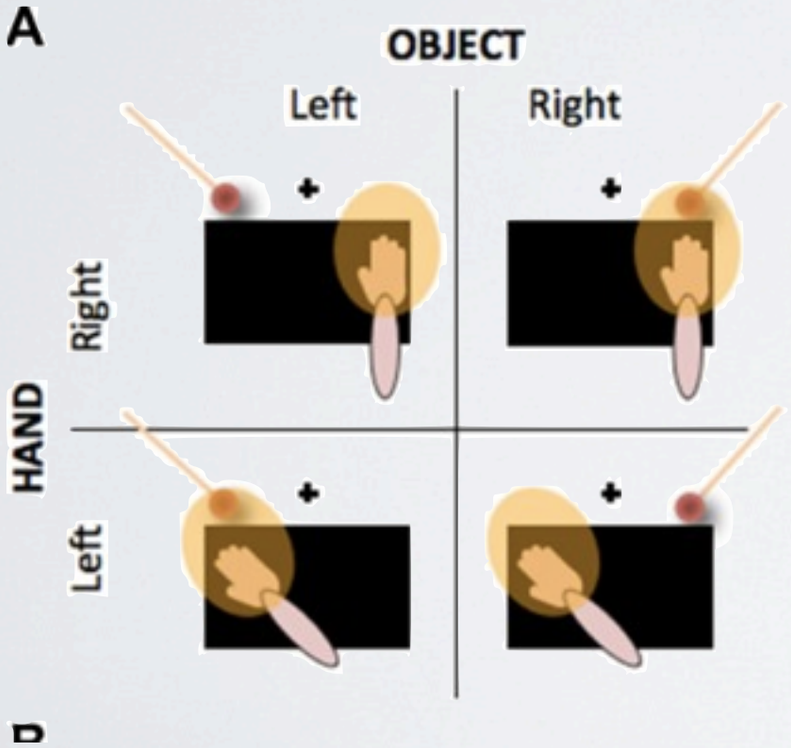
Tactile

Visual

The visual RF is anchored to the hand and moves with it.

INTEGRATION OF VISION AND TOUCH

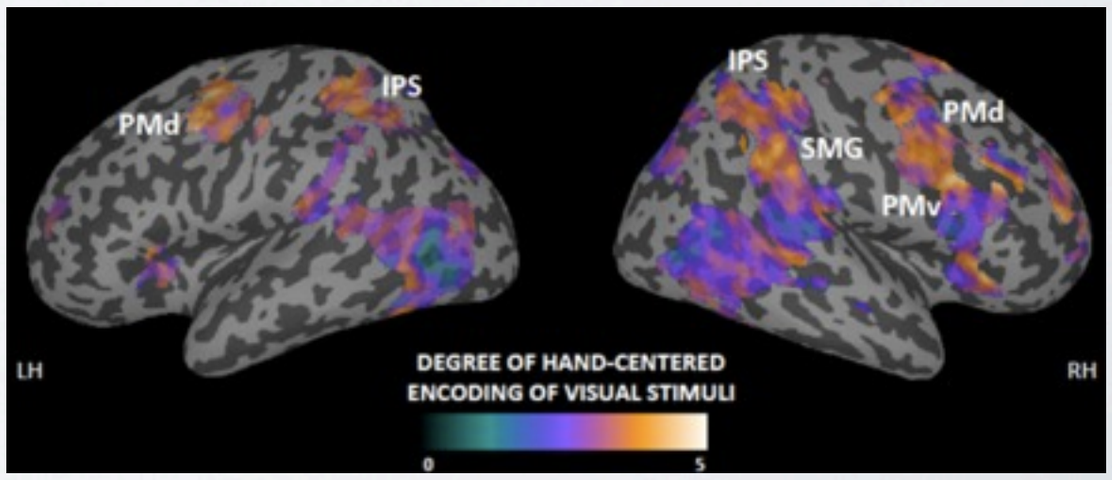
fMRI Study in Humans



(Brozzoli, Gentile and Ehrsson, 2012)

Neurons with hand-centered visual receptive fields have been found in:

- Premotor Cortex
- Parietal Cortex (IPS)
- Putamen

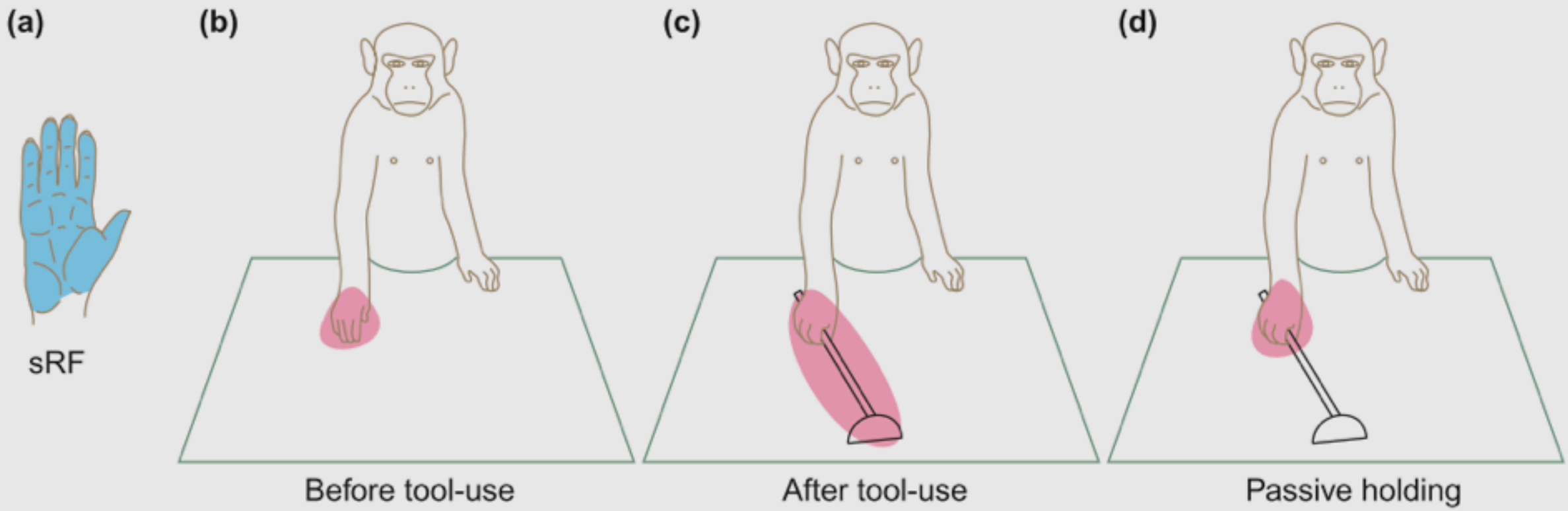


INTEGRATION OF VISION AND TOUCH

Tactile RF

Visual RF

Distal-type neurons



The visual receptive field of bimodal VT neurons extend in space after active tool-use.

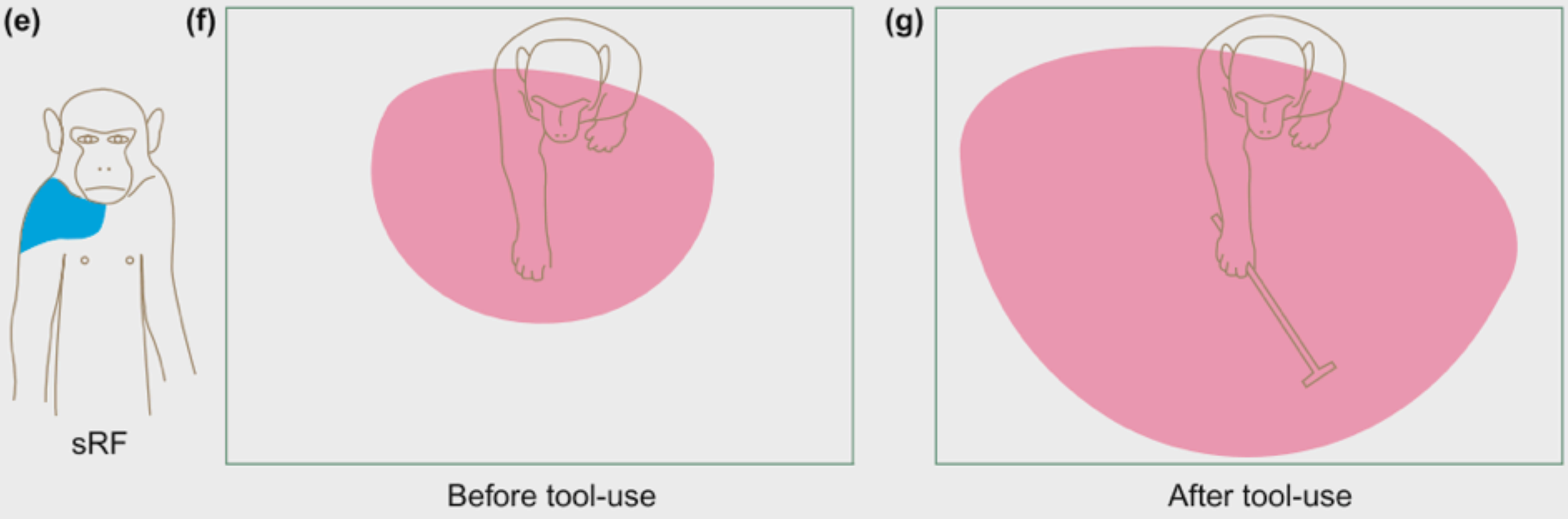
(Iriki et al., 1994)

INTEGRATION OF VISION AND TOUCH

Tactile RF

Visual RF

Proximal-type neurons



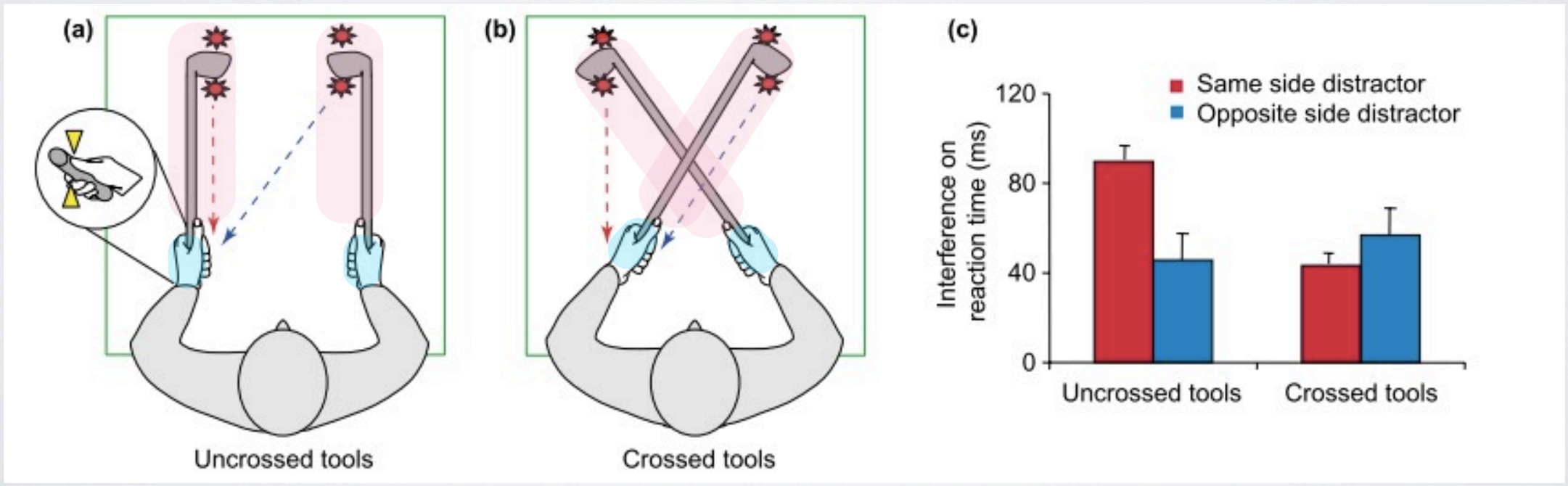
The visual receptive field of bimodal VT neurons extend in space after active tool-use.

INTEGRATION OF VISION AND TOUCH

Tactile RF

Visual RF

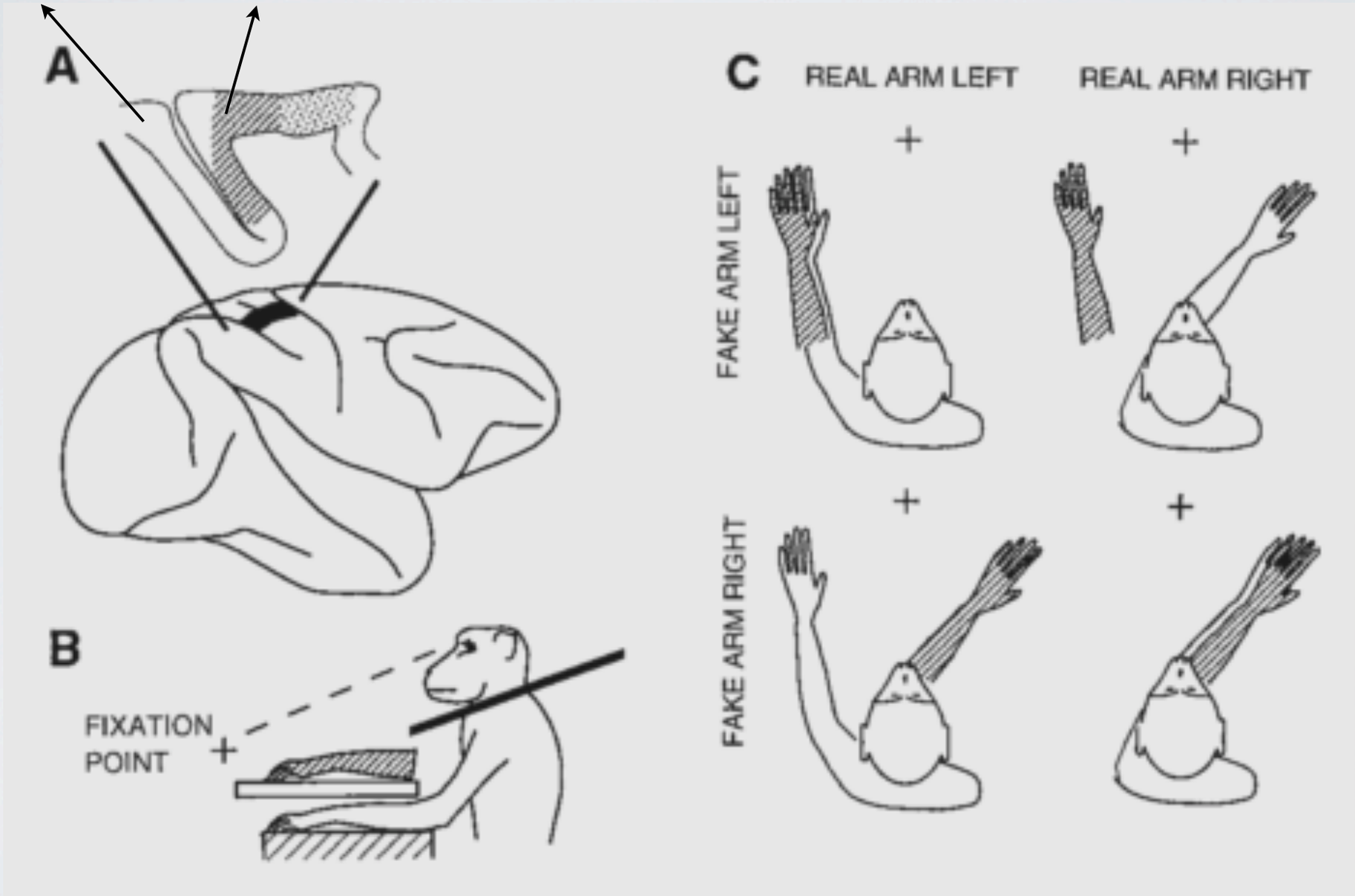
Expansion of the vRF of bimodal VT neurons also found in humans using a psychophysical test (Cross-Congruency-Task)



(Maravita et al., 2002)

INTEGRATION OF VISION AND PROPRIOCEPTION

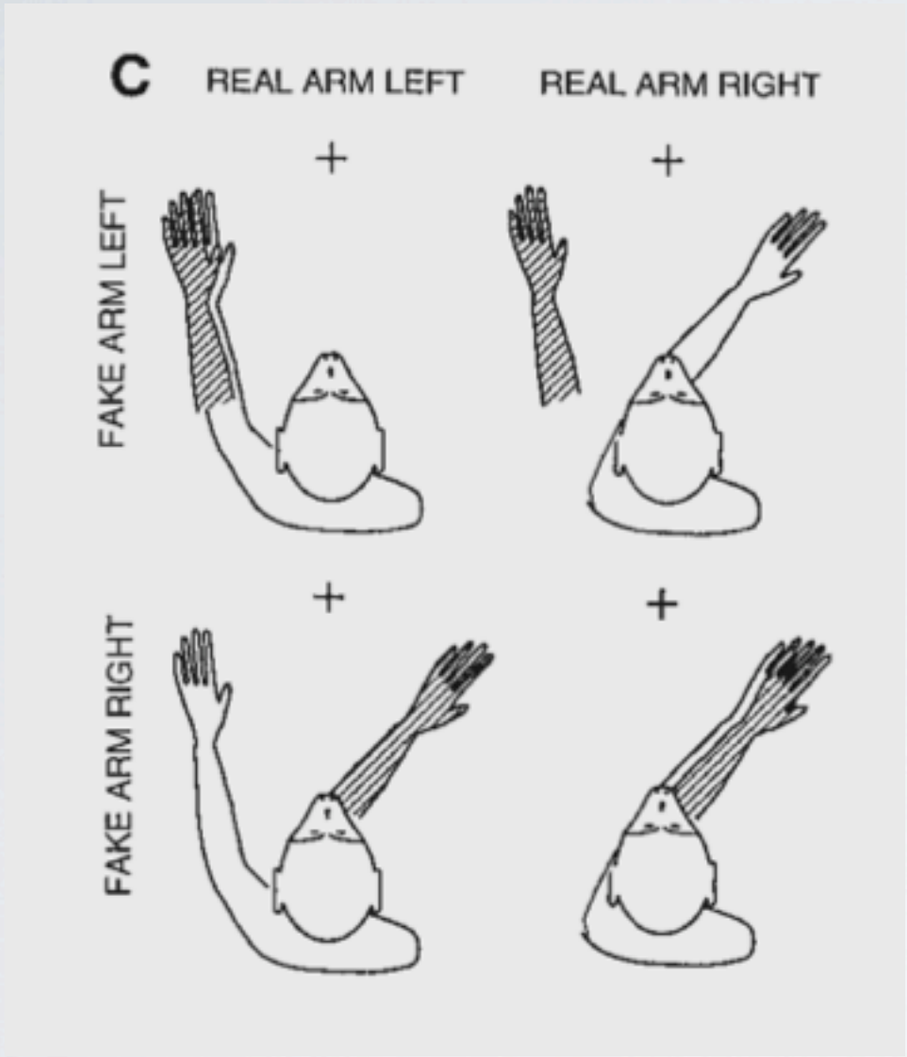
Area 5 Areas 1, 2

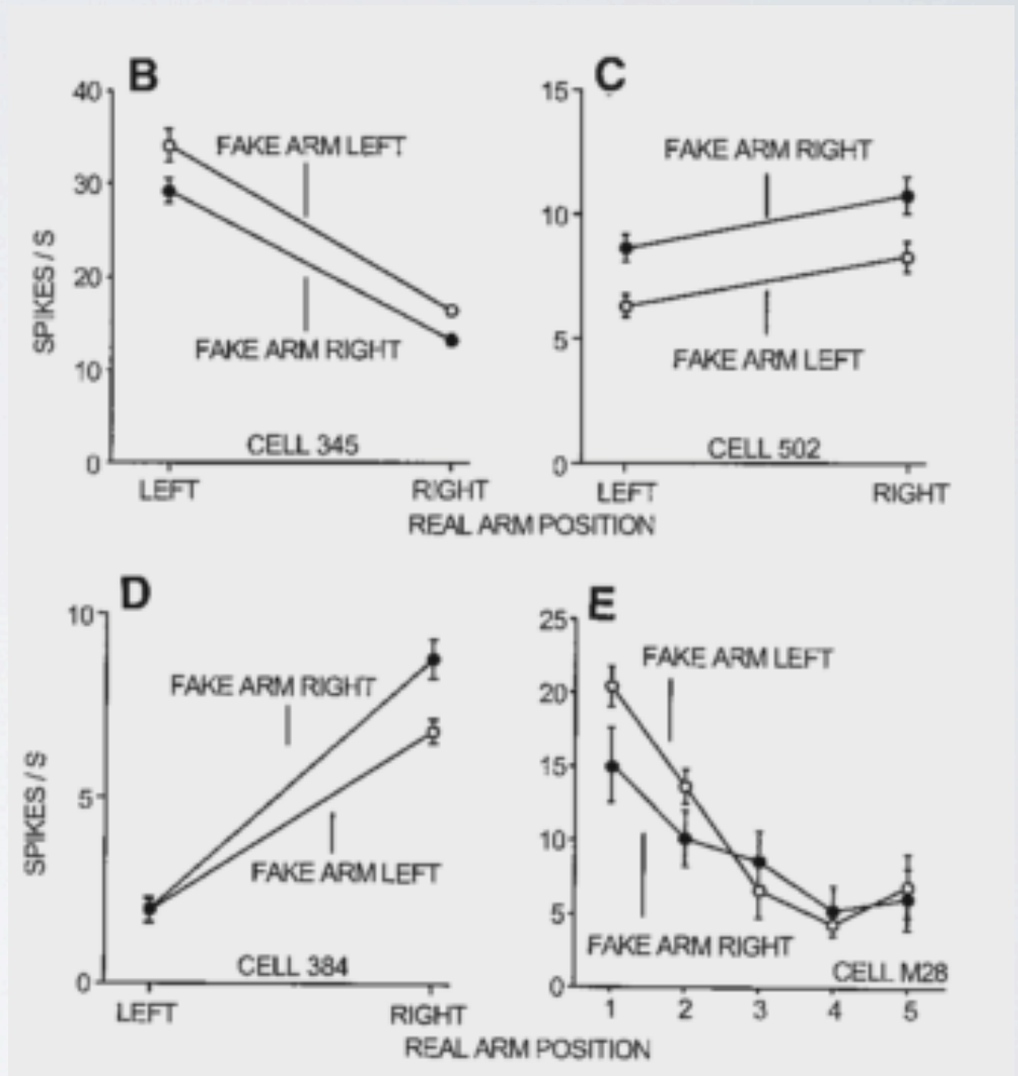


Proprioception and Vision can be decoupled using a fake arm

INTEGRATION OF VISION AND PROPRIOCEPTION

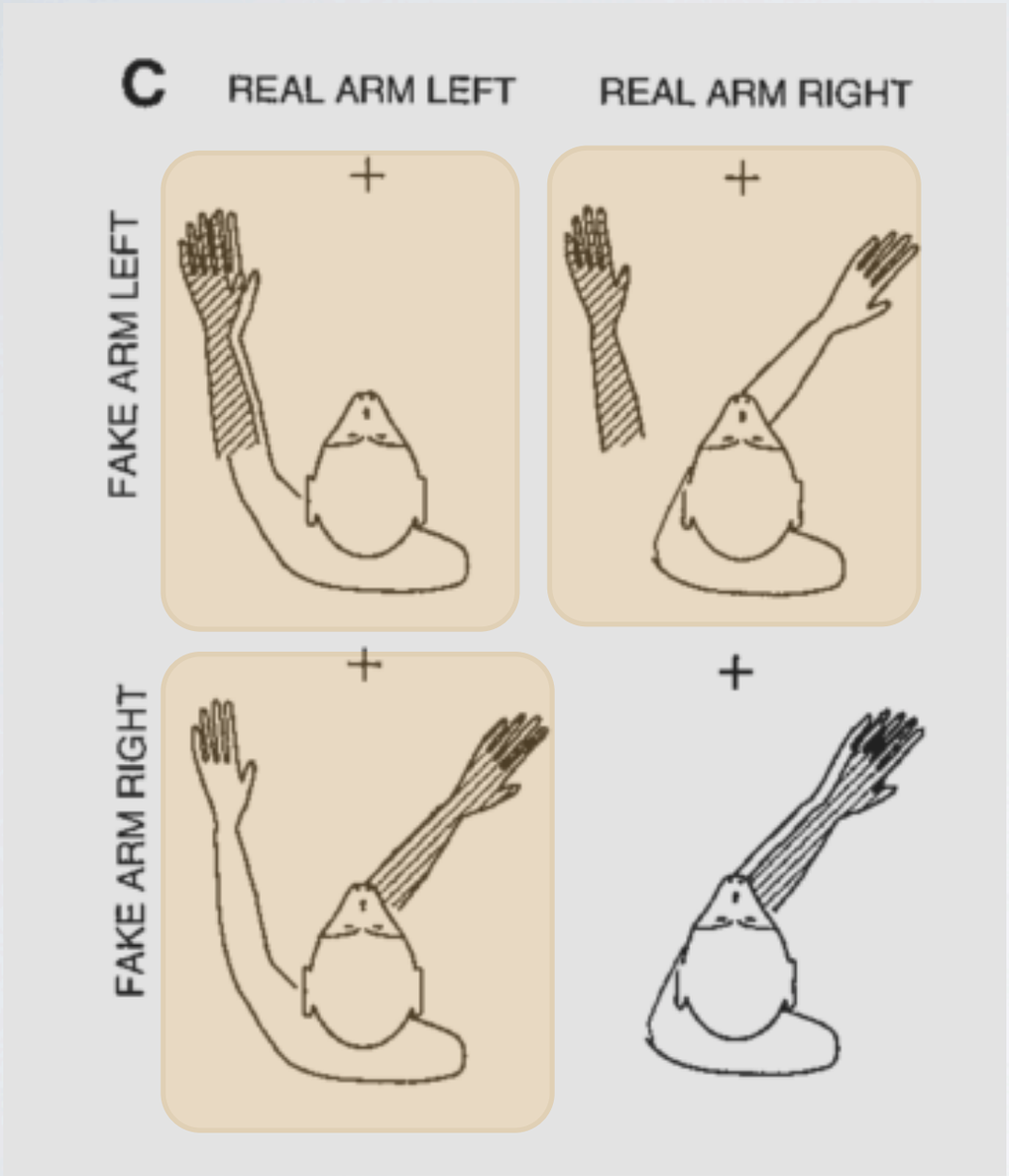
(Graziano, Cooke and Taylor, 2000)





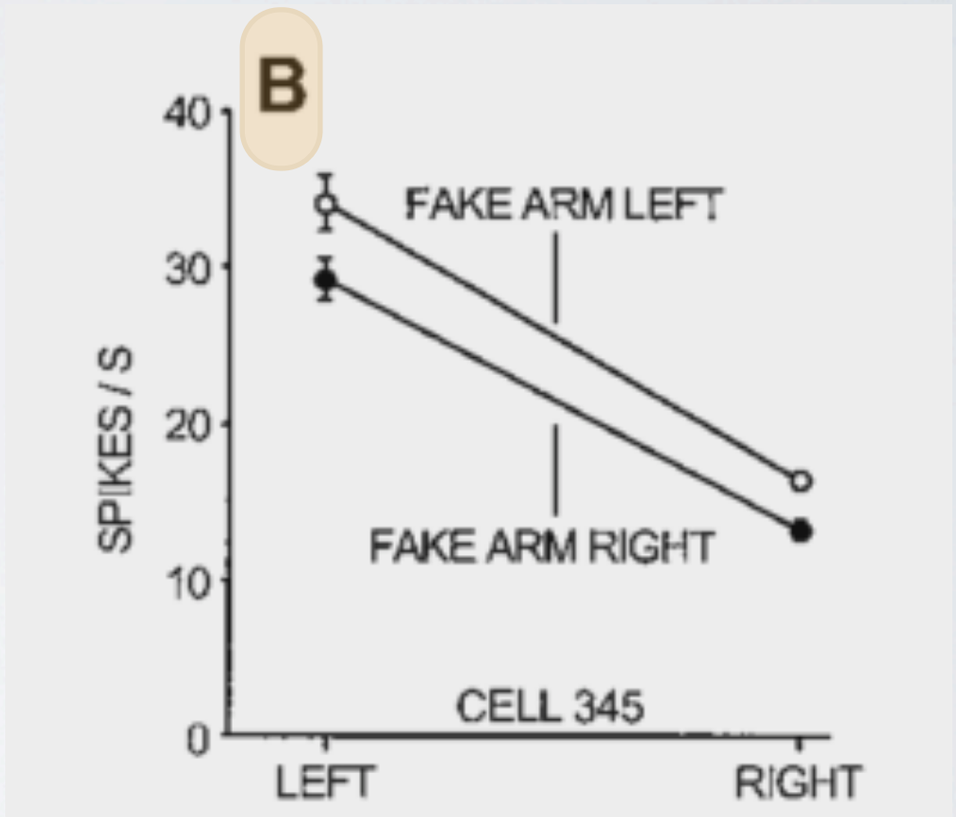
Single cell recordings show that area 5 neurons respond to both visual and proprioceptive signals about the arm location.

INTEGRATION OF VISION AND PROPRIOCEPTION



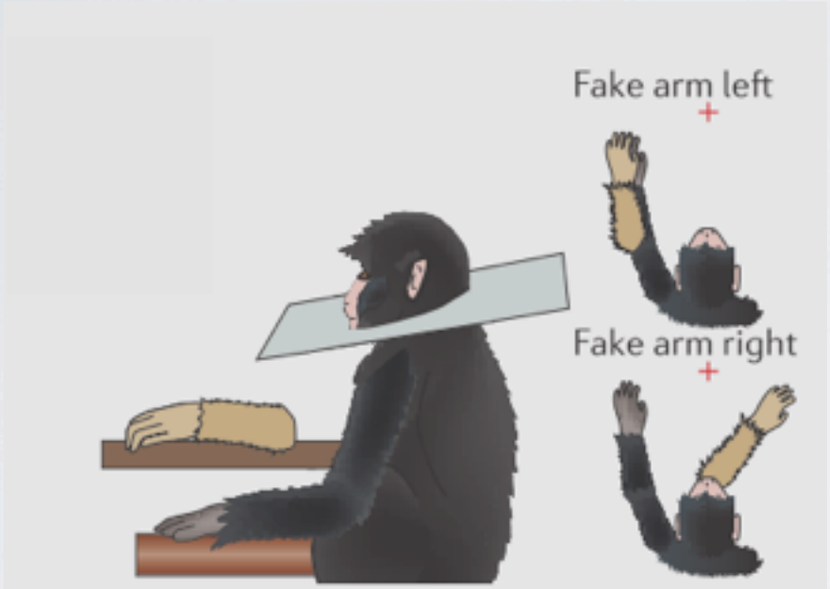
(Graziano, Cooke and Taylor, 2000)

Bimodal Neuron



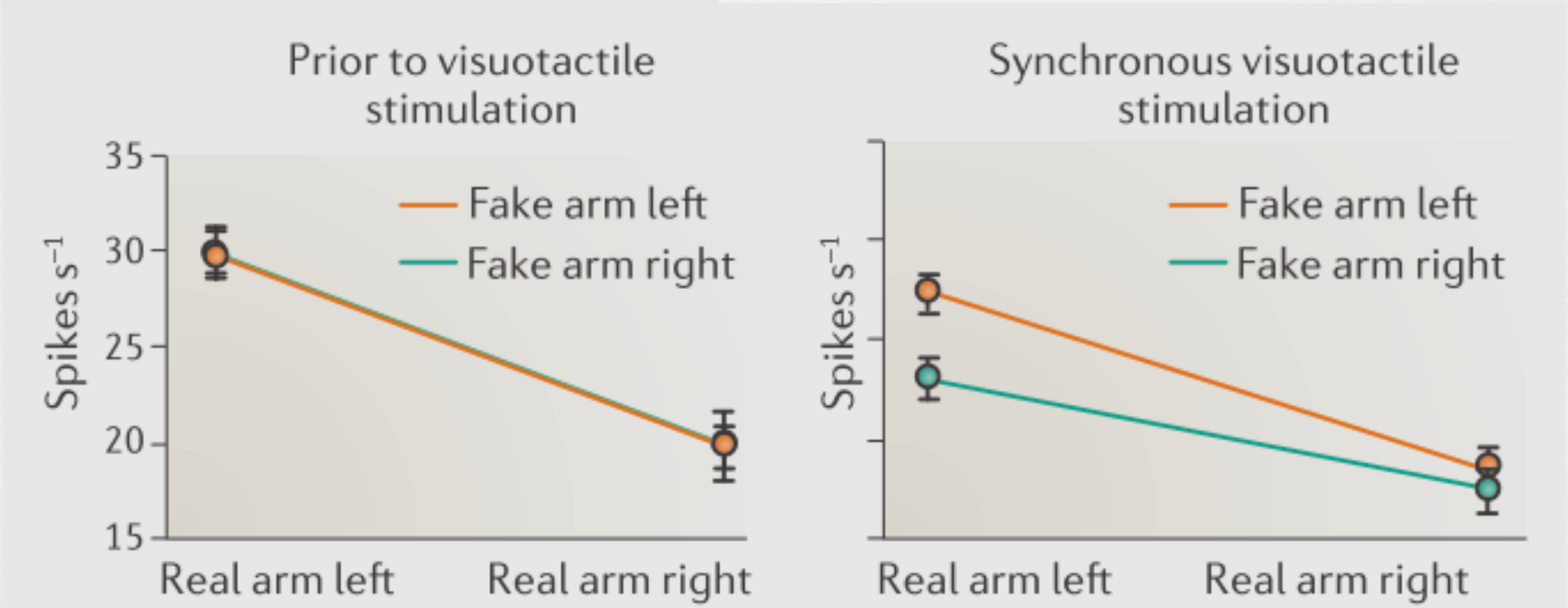
REAL ARM POSITION

INTEGRATION OF VISION, TOUCH AND PROPRIOCEPTION



Trimodal Neurons

The cell becomes sensitive to the position of the seen fake arm only after synchronous stroking



(Graziano, Cooke and Taylor, 2000; Blanke, 2012)

BODY ILLUSIONS

BODY ILLUSIONS

Why ?

BODY ILLUSIONS

Why ?

- BI are generated when the brain receives conflicting multisensory stimulations and tries to fit them in a coherent percept
- BI through light on the enormous plasticity of the body representation in the brain
- BI provide a controlled tool for investigating the brain mechanisms that control body perception

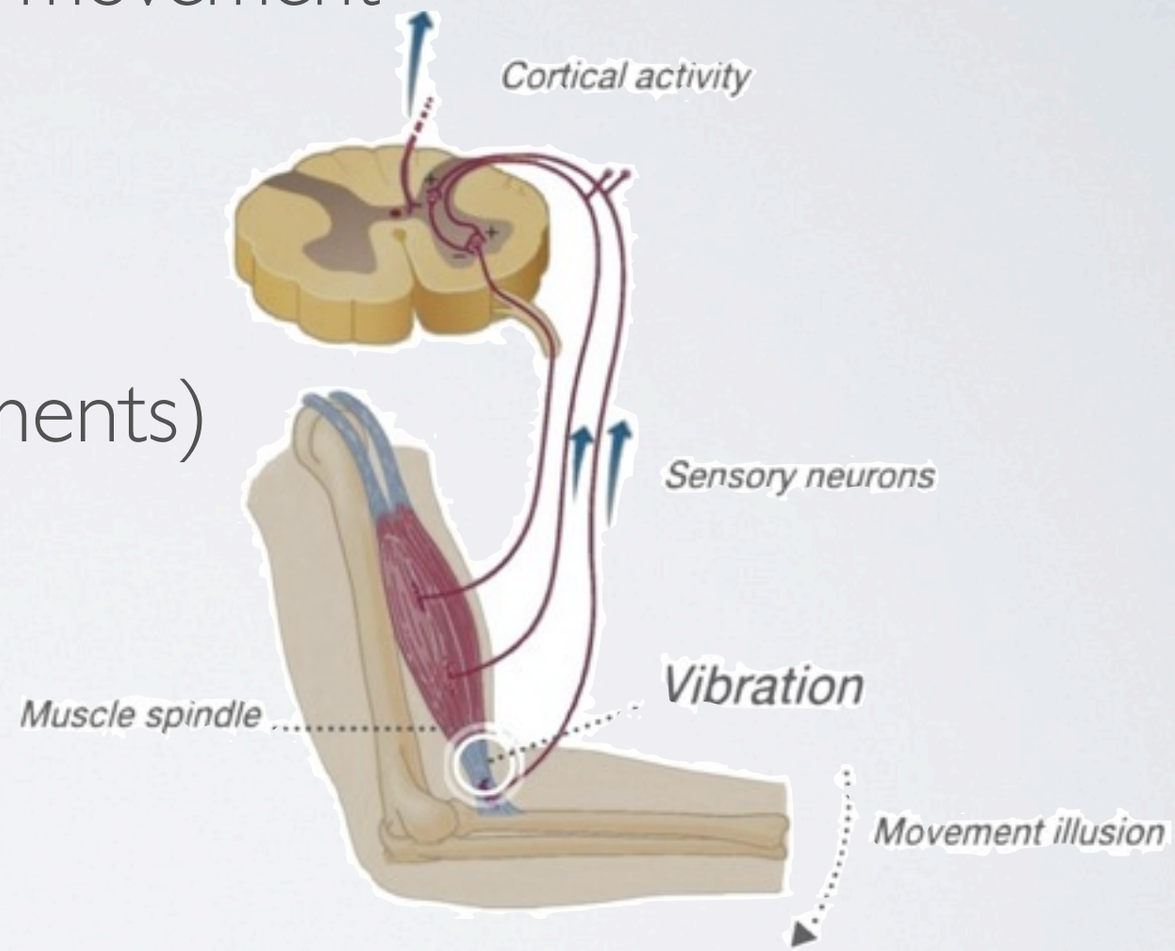
BODY ILLUSIONS

- Kinesthetic illusion (body deformations)
- Ownership Illusions
- Combination of Kinesthetic and Ownership Illusions in Virtual Reality

Illusory Movements

muscle spindles, cutaneous and joint receptors
that are activated during real movement

Kinesthesia
(perception of limbs movements)



80 Hz vibration

Movement perception
in absence of actual movement

The Pinocchio Illusion

(Lackner, 1988)

- Biceps vibration induces the illusion of elbow extension (80% subjects)
- 50% subjects experienced a **NOSE ELONGATION**
- 30% subjects experienced **FINGERS ELONGATION**
- 20% subjects experienced **NOSE and FINGERS ELONGATION**

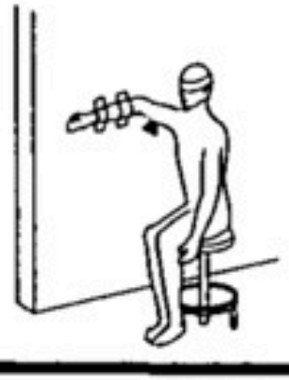
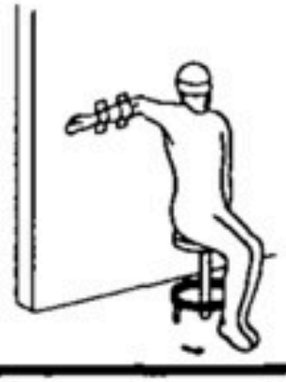
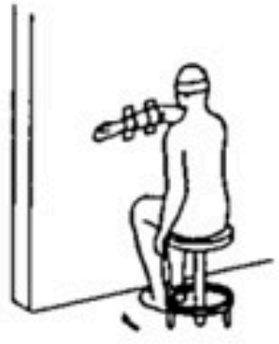
The Pinocchio Illusion

(Lackner, 1988)

The illusion results from an interaction of touch and proprioception that are integrated within the context of a known human body structure.

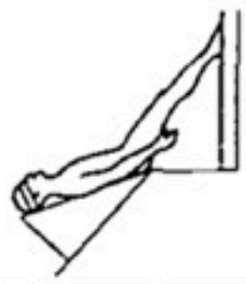
Other kinesthetic illusions

(Lackner, 1988)

	Test configuration A	Experienced pattern	Test configuration B	Experienced pattern
1				
2				
3				
4				

Other kinesthetic illusions

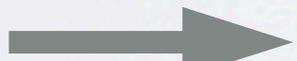
(Lackner, 1988)

	Test configuration A	Experienced pattern	Test configuration B	Experienced pattern
5				
6				
7				

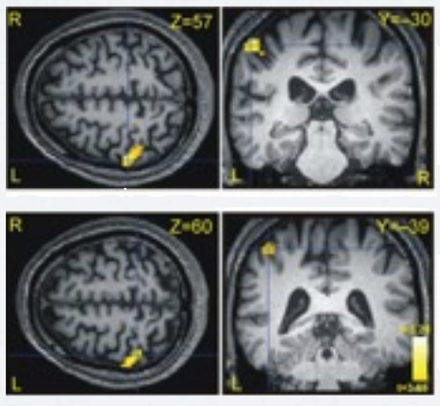
The Shrinking Waist Illusion

Illusory Motion

Primary motor cortex is activated
(even if there is no actual movement)



Wrist Shrinkage



Parietal cortex is activated
(site for the MSI of vision, touch and proprioception)

(Ehrsson et al. 2005)

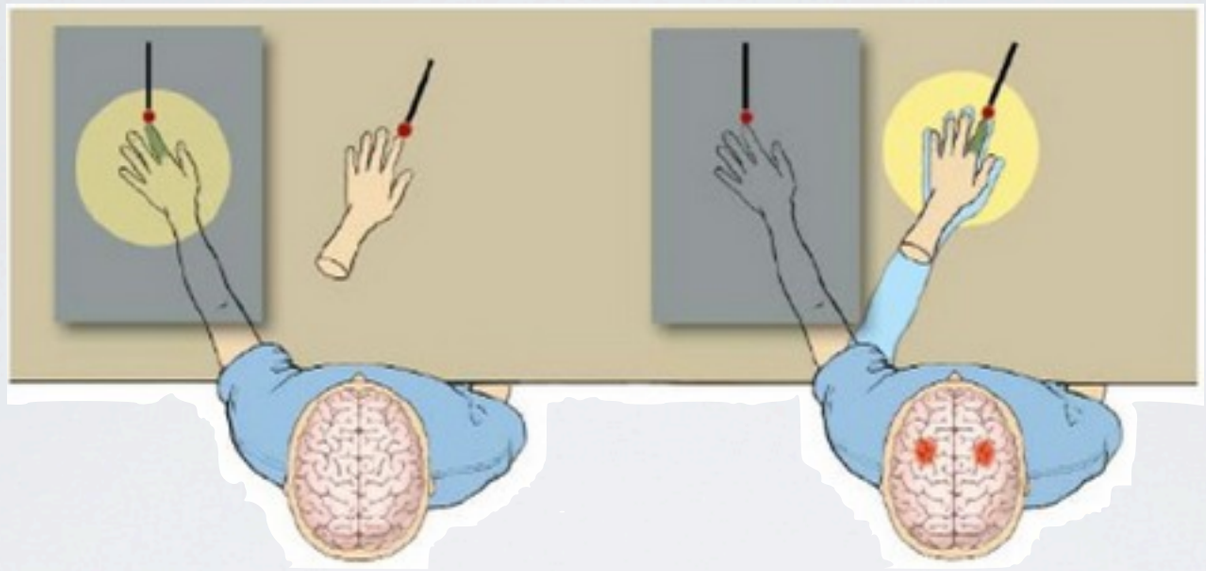
BODY OWNERSHIP ILLUSIONS

The Rubber Hand Illusion

(Botvinick and Cohen, 1998)

The Rubber Hand Illusion

(Botvinick and Cohen, 1998)



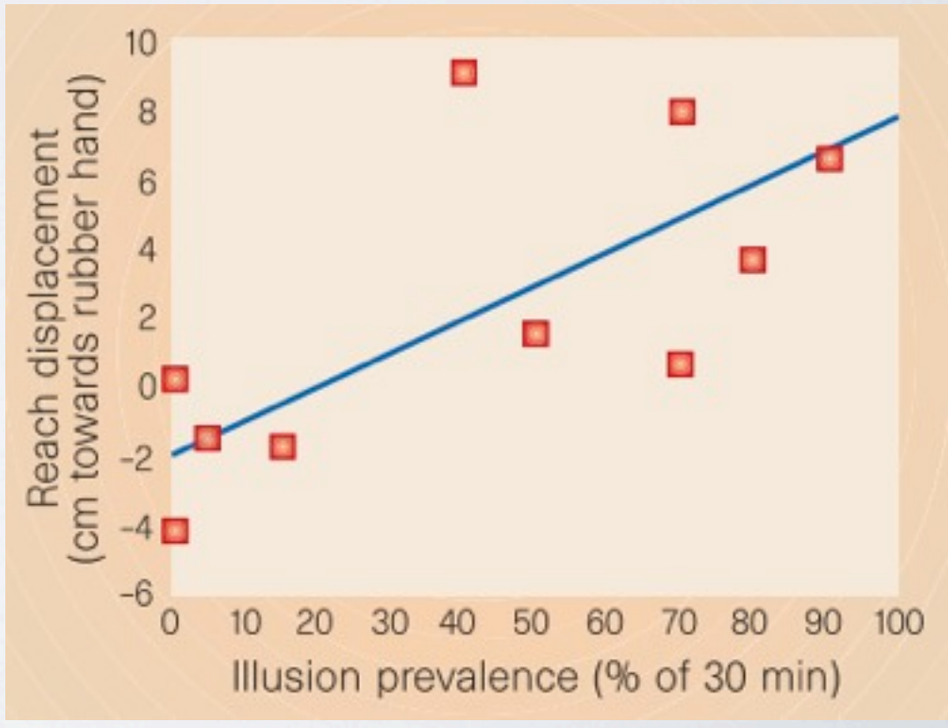
- TOUCH experienced through the rubber hand

"it seemed as if the touch I felt was caused by the paintbrush touching the RH"

- OWNERSHIP

"I felt as if the rubber hand were my hand."

- PROPRIOCEPTIVE DRIFT



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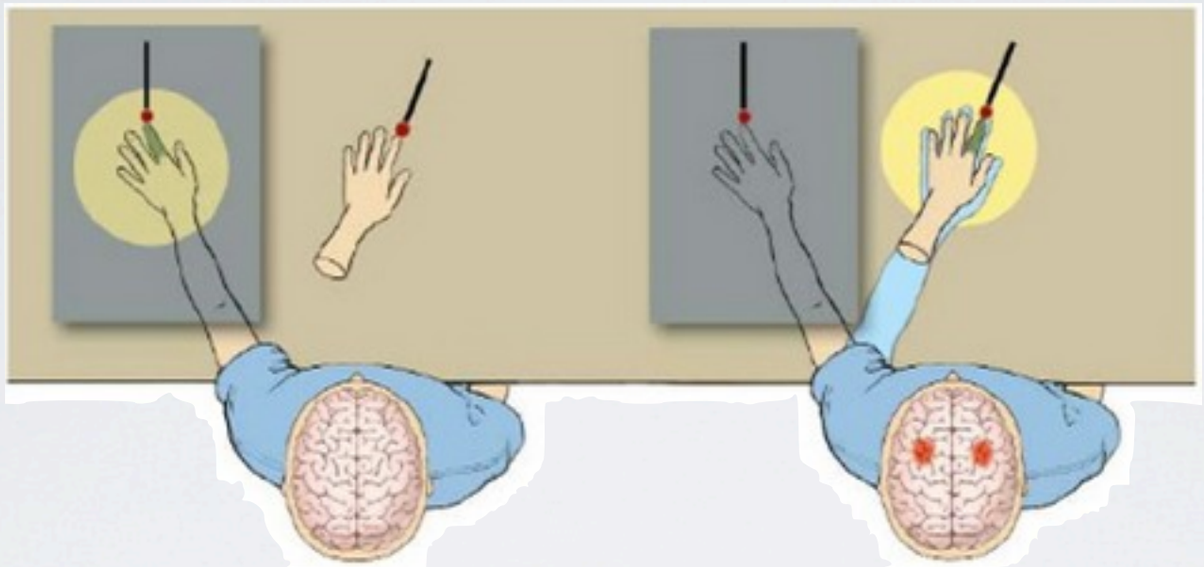
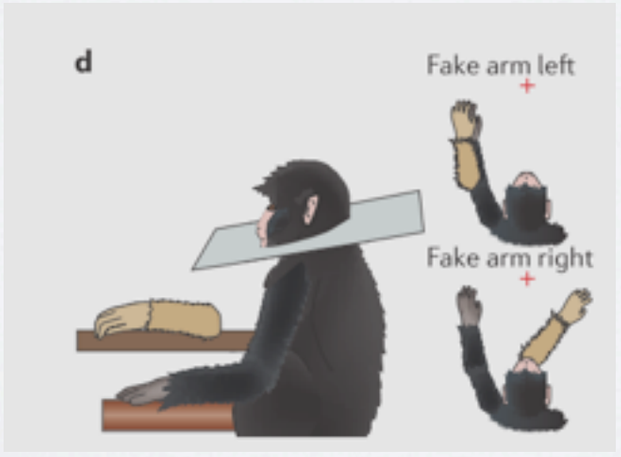
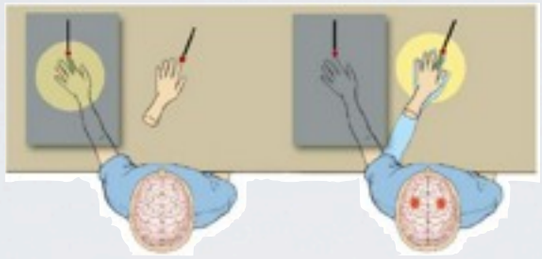
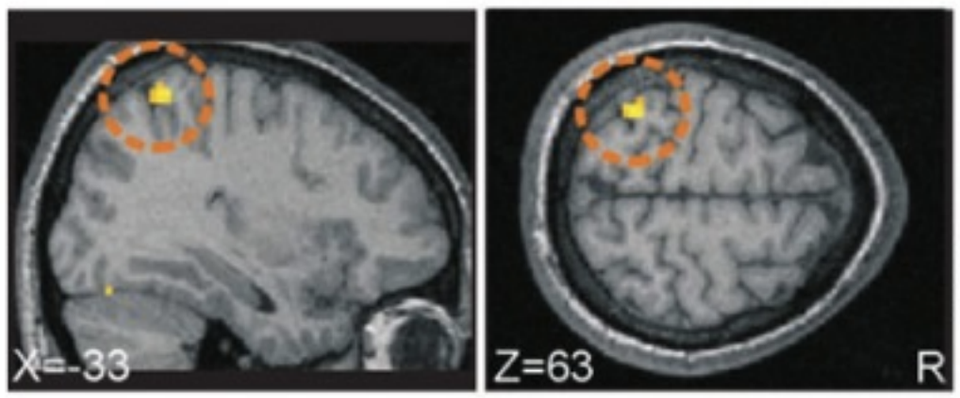


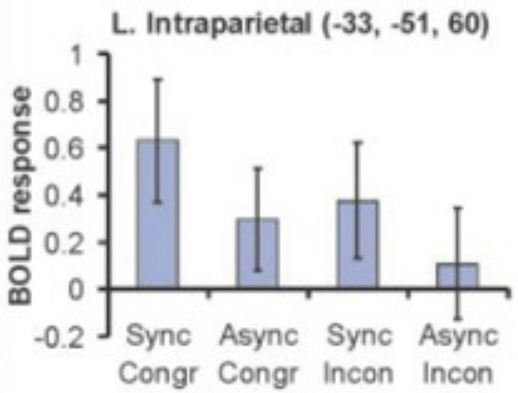
The illusion results from a "three-way interaction between vision, touch and proprioception"



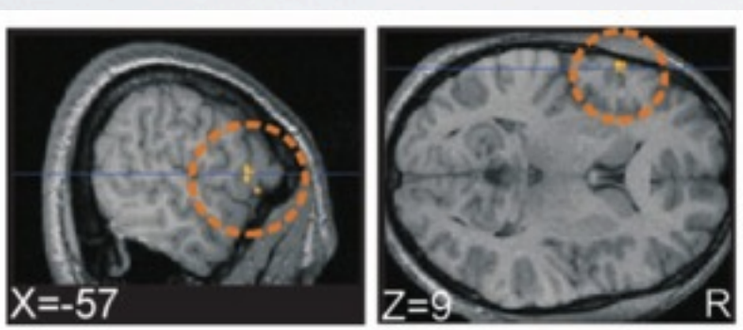
The Rubber Hand Illusion

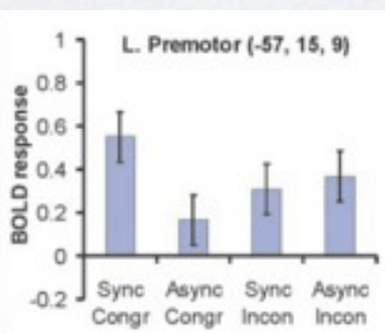




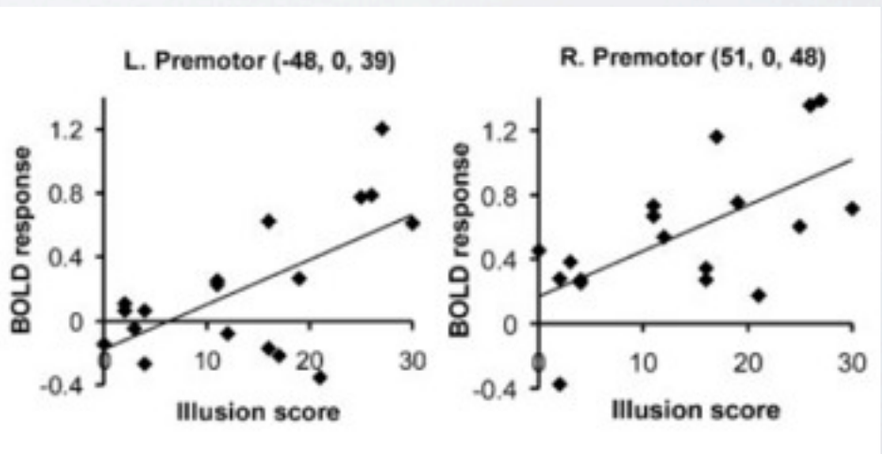


Parietal Activity
integration of vision, touch and proprioception





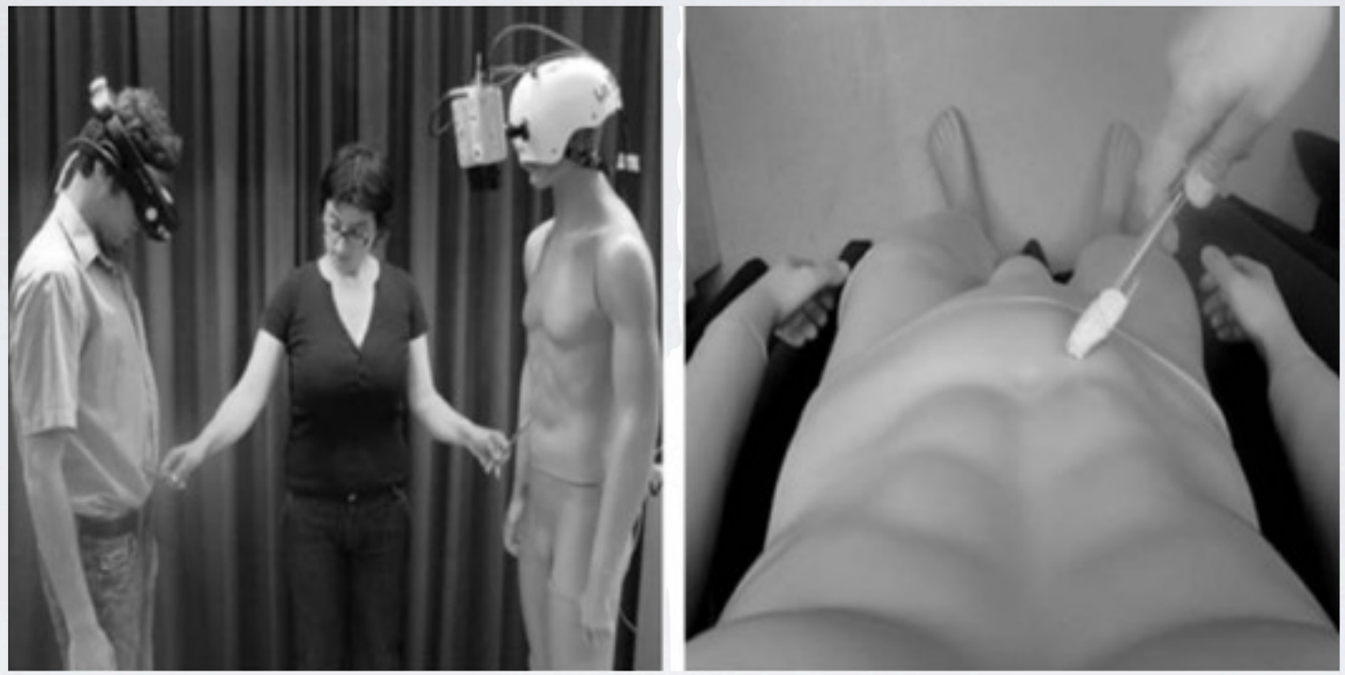
Premotor Activity
rubber hand illusion



(Ehrsson, Spence and Passingham 2004)

Full Body Ownership

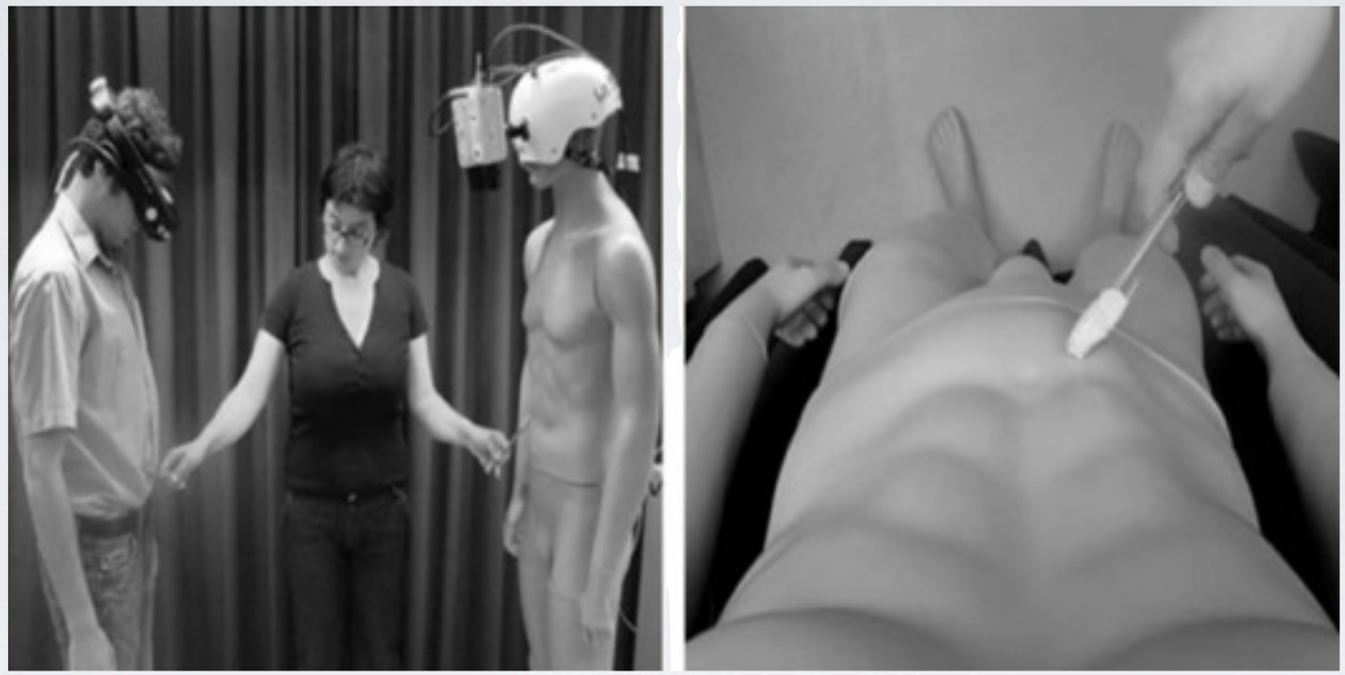
(Petkova and Ehrsson, 2008)



Ownership illusion can be experienced over a full body

Full Body Ownership

(Petkova and Ehrsson, 2008)

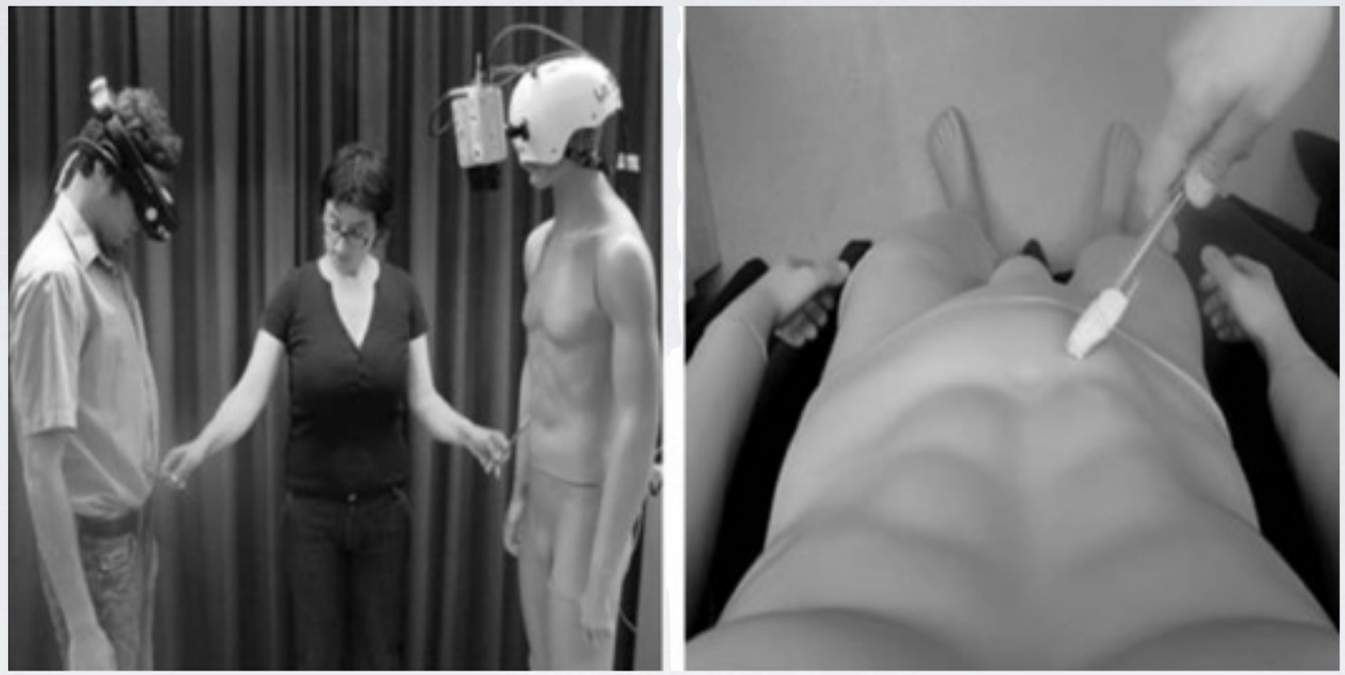


Ownership illusion can be experienced over a full body

How?

Full Body Ownership

(Petkova and Ehrsson, 2008)



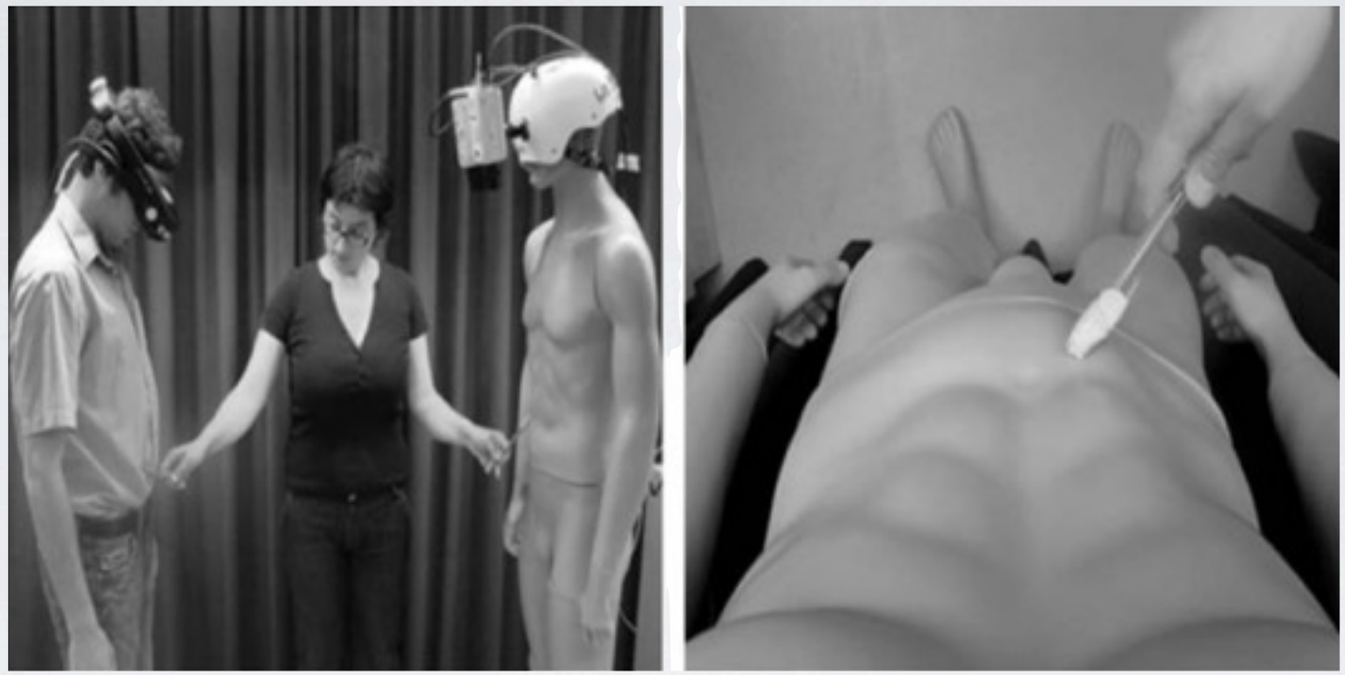
Ownership illusion can be experienced over a full body

How?

- First person perspective (1PP)

Full Body Ownership

(Petkova and Ehrsson, 2008)



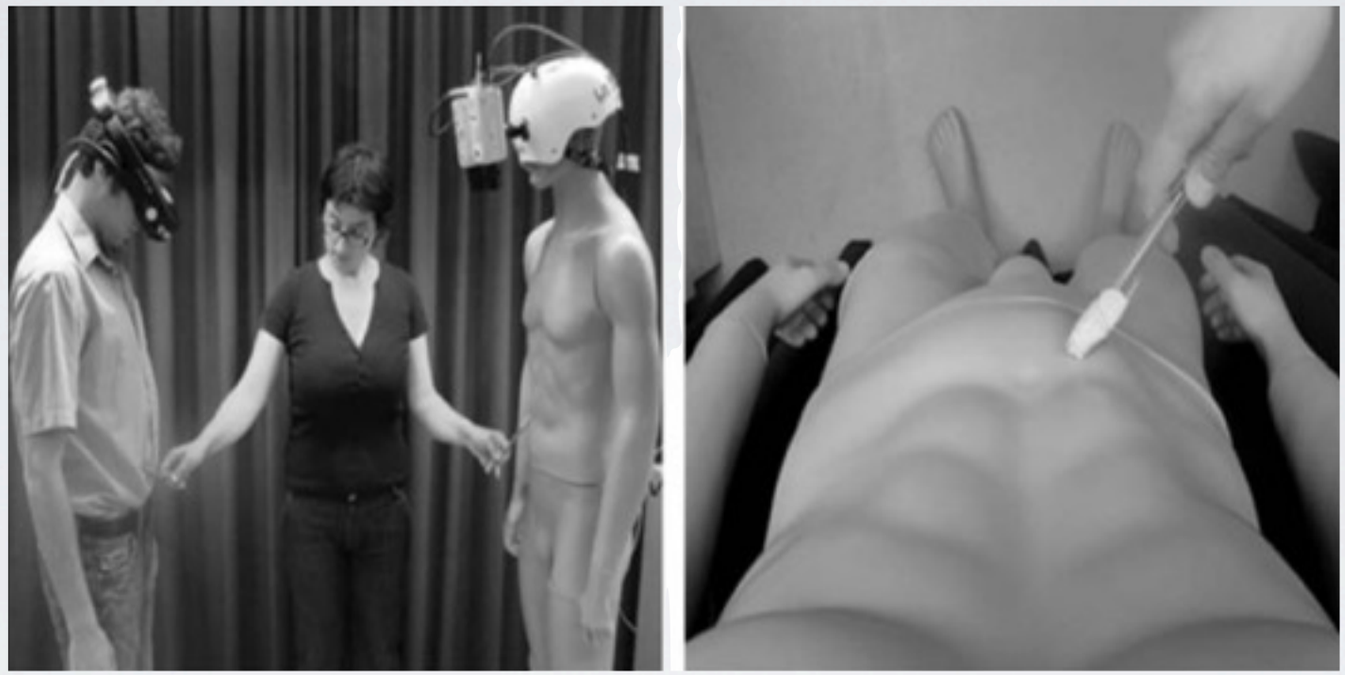
Ownership illusion can be experienced over a full body

How?

- First person perspective (1PP)
- .... over a humanoin body

Full Body Ownership

(Petkova and Ehrsson, 2008)



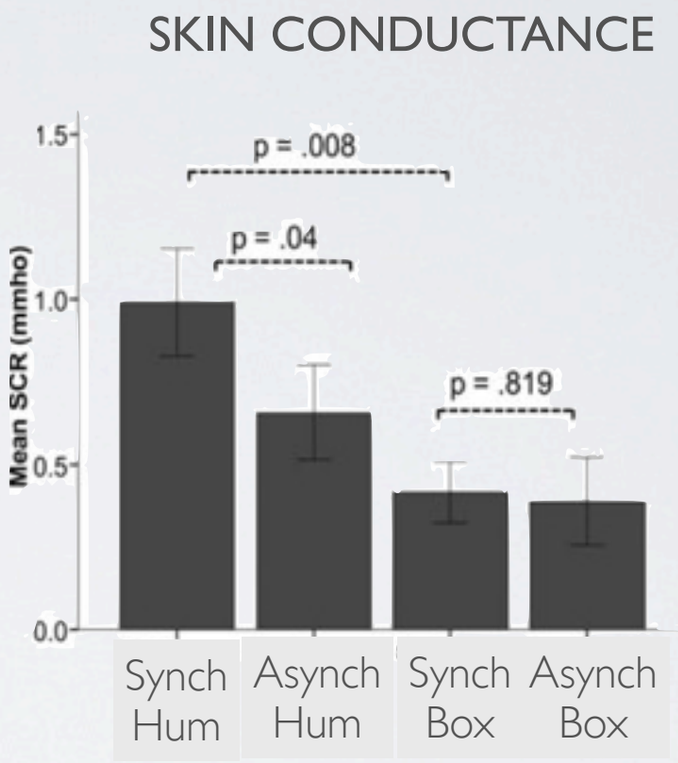
Ownership illusion can be experienced over a full body

How?

- First person perspective (1PP)
- .... over a humanoin body
- Synchronous visuotactile stimulation

Full Body Ownership

(Petkova and Ehrsson, 2008)

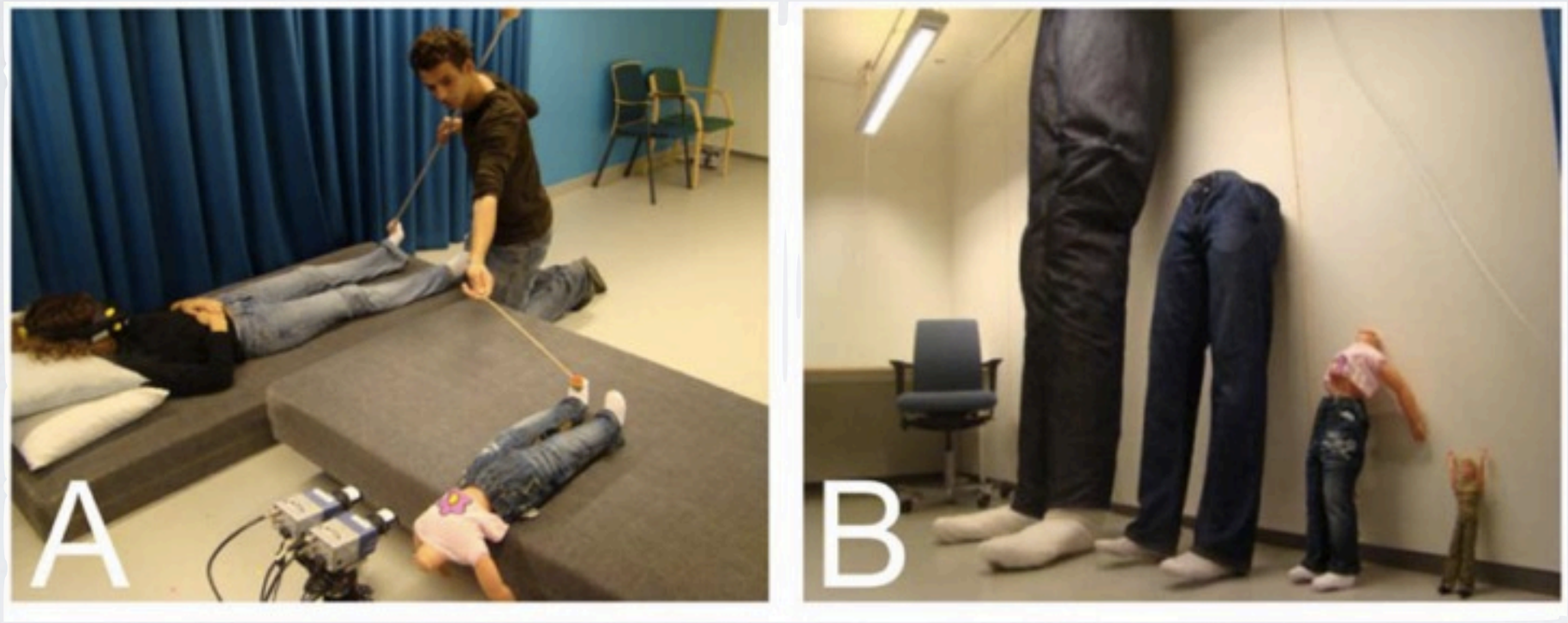


Stronger reactions to threat toward the fake body in the synchronous + humanoid body condition

Full Body Ownership

of small and big bodies

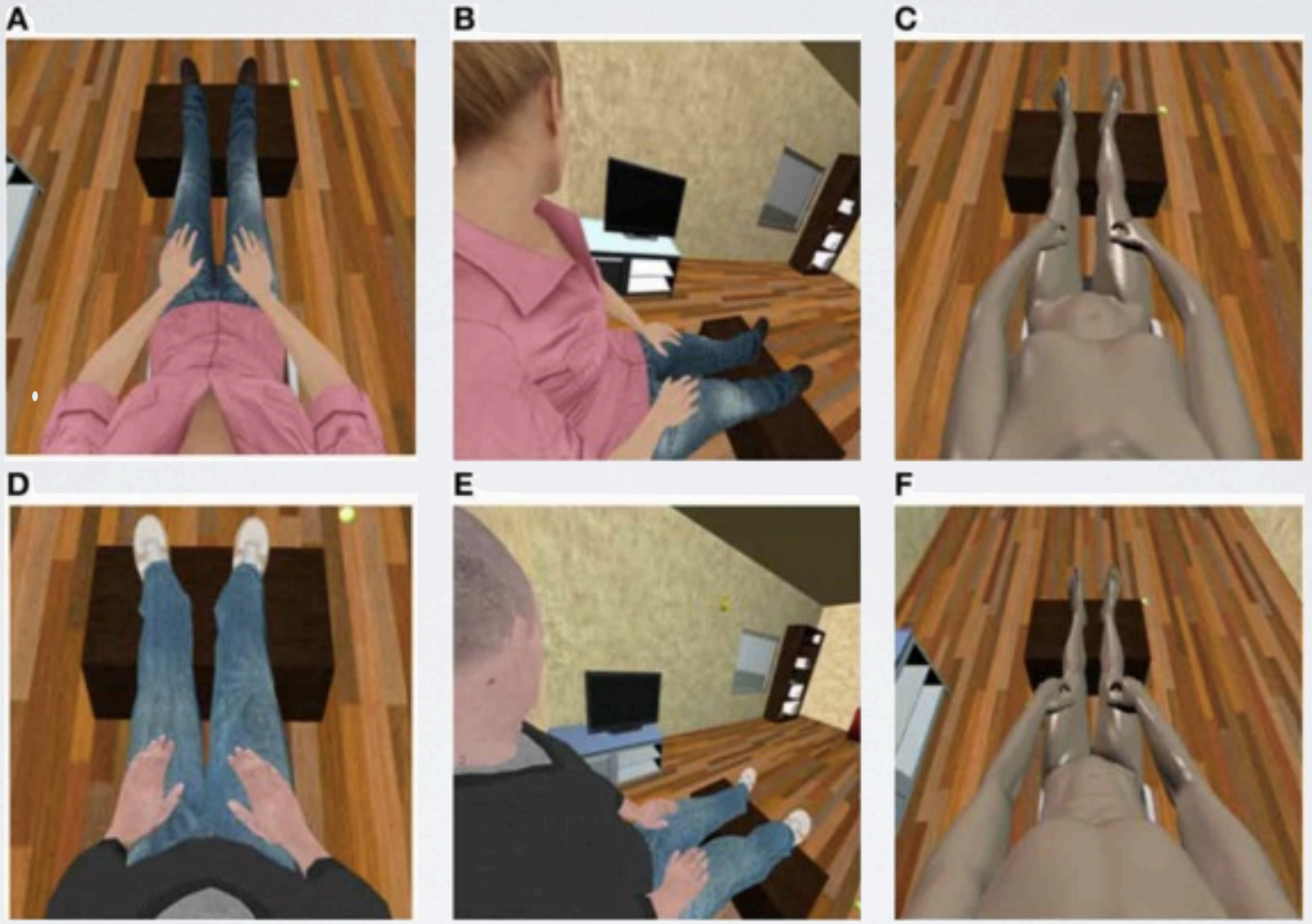
(van der Hoort et al. 2011)



... and the world looks smaller/larger
when you own a big/small body

Full Body Ownership

(Maselli and Slater 2013)



- First person perspective (1PP) over a realistic body
- Vision and Proprioception in spatial register are sufficient, i.e. synchronous visuotactile stimulation is not necessary

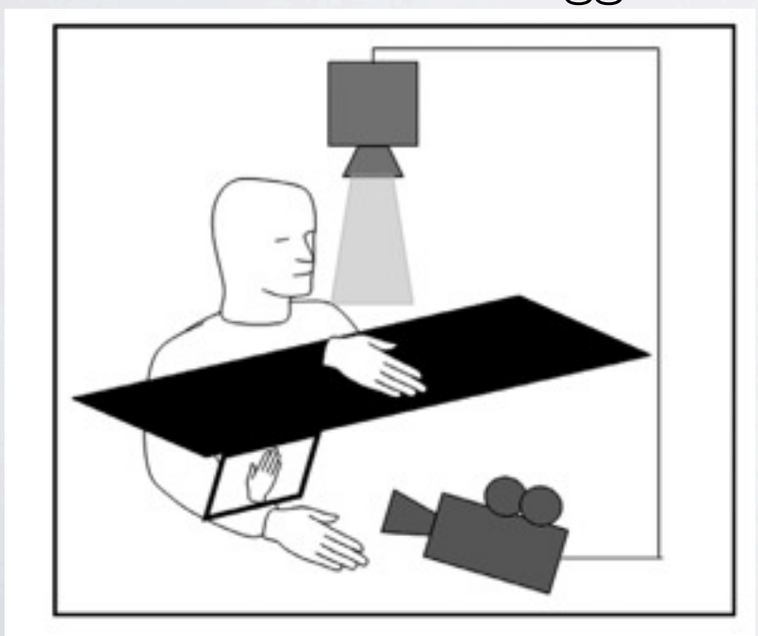
Ownership Illusions

originate when experiencing congruent multisensory correlations of stimuli from the real and virtual body

Ownership Illusions

(Kalckert and Ehrsson, 2008)

(Tsakiris, Prabhu and Haggard 2006)



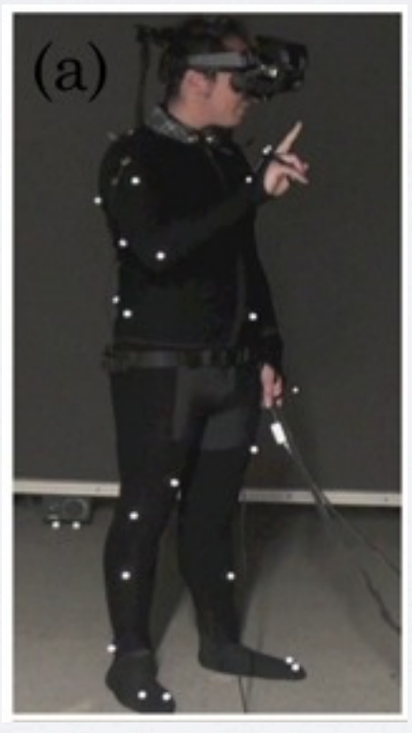
The RHI can be induced through **visuomotor correlations**

Body Illusions in VR

Virtual Reality is an ideal tool for manipulating sensory information

Head Tracking

Full Body Tracking



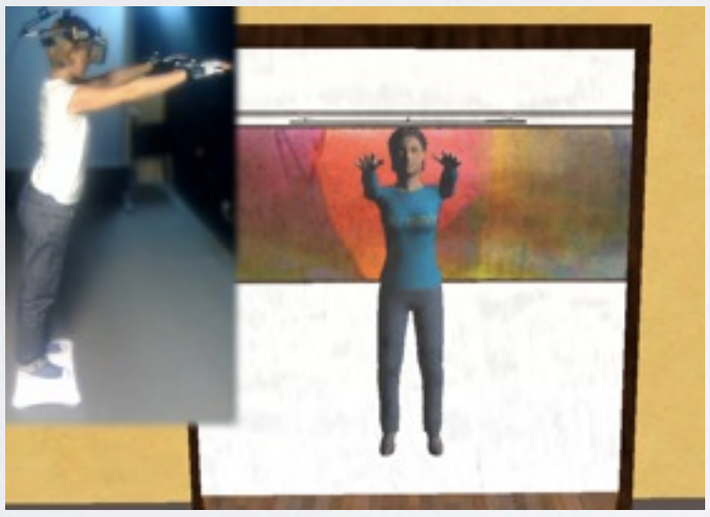
Haptic Devices

PRESENCE in VR

Head-tracked Stereo
wide field-of-view

Visual perception through
natural sensorimotor
contingencies

Events are realistic
and correlate with
your actions



Plausibility Illusion:
Strong illusion that
events are real

Place Illusion:
Strong illusion
to be there

PRESENCE

(Slater, 2009)

Body Ownership in VR

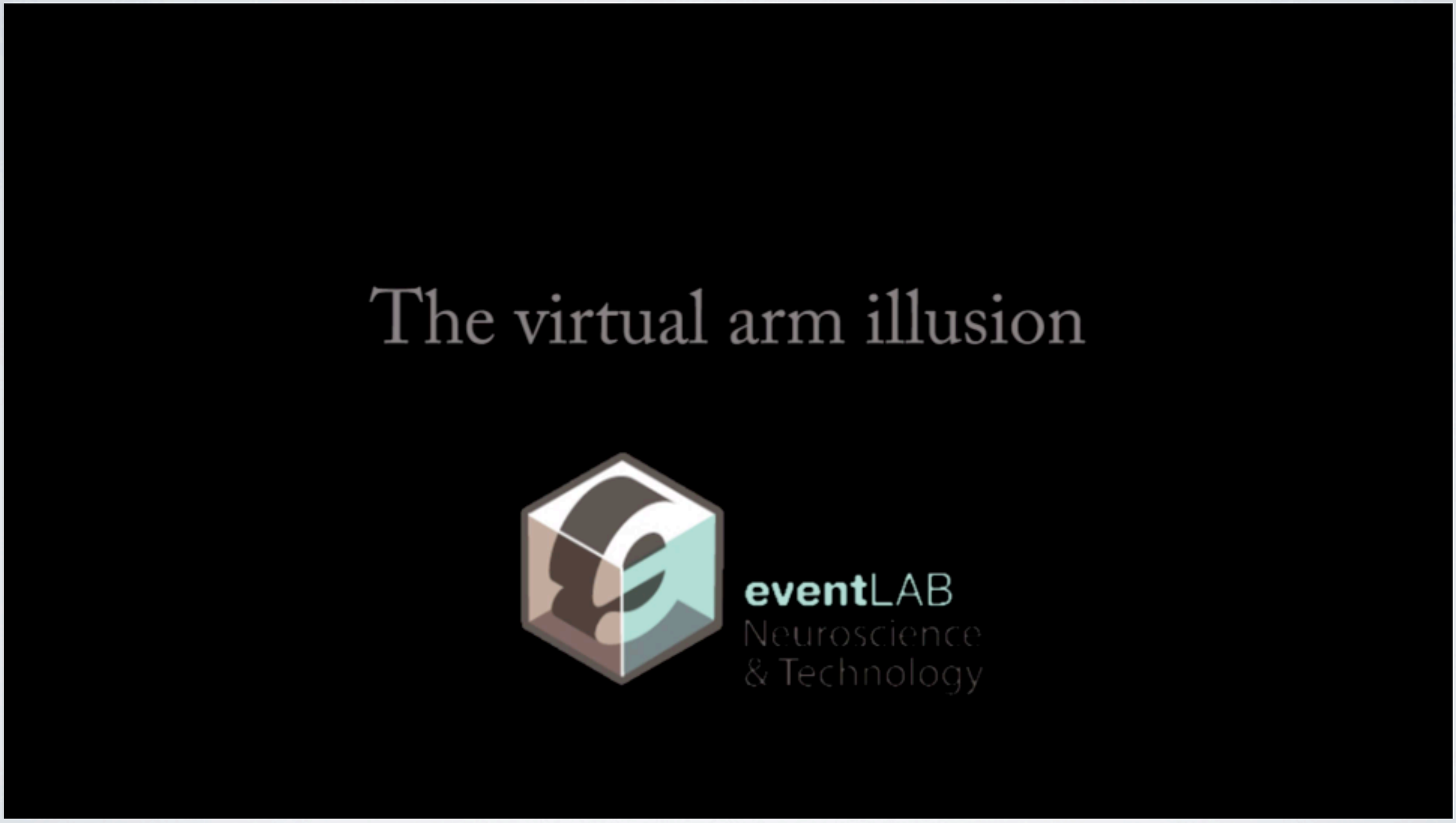
Rubber Hand Illusion in VR

(Slater et al. 2009)

PowerWall - 1PP view of the hand

Illusion induced with both visuotactile and visuomotor correlations

Rubber Hand Illusion in VR



(Slater, Perez-Marcos, Ehrsson and Sanchez-Vives 2009)

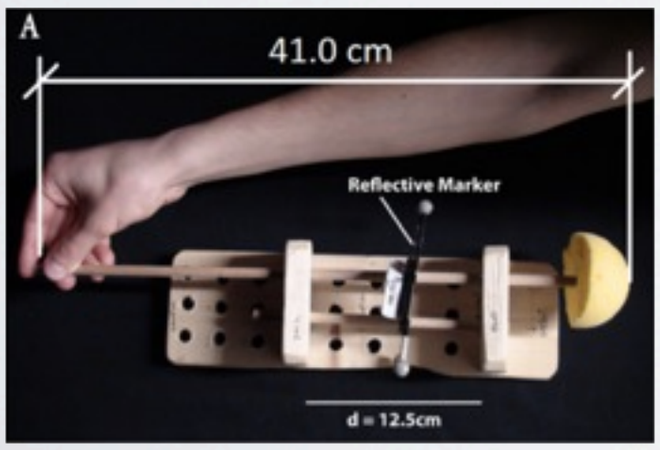
Ownership of deformed bodies

- The brain tolerates body deformations (as from kinesthetic illusions)

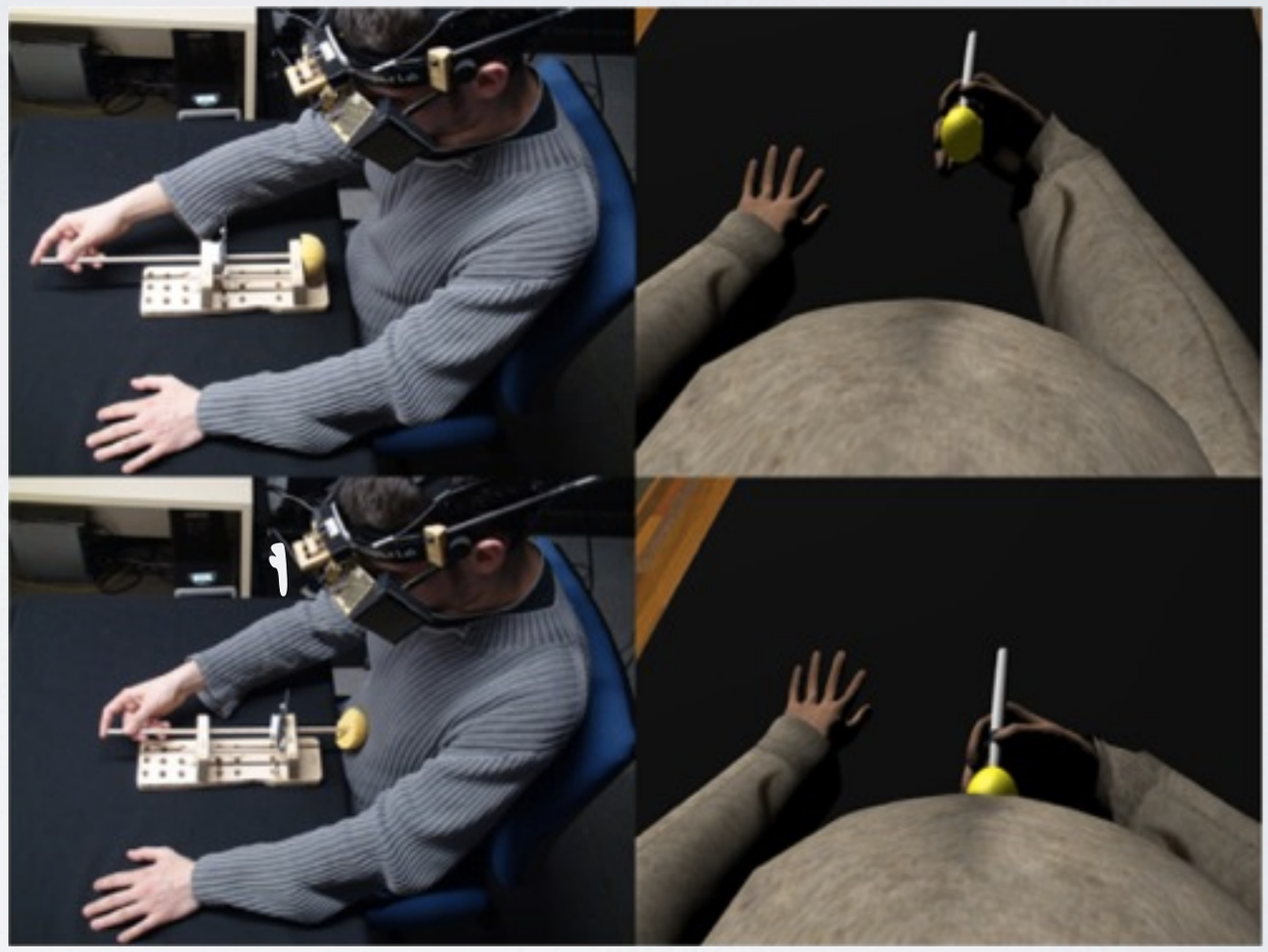
- In VR it is possible to add visual information of body deformations that can be assimilated

The Big Belly Illusion

(Normand et al. 2011)



IPP over an avatar with a large belly

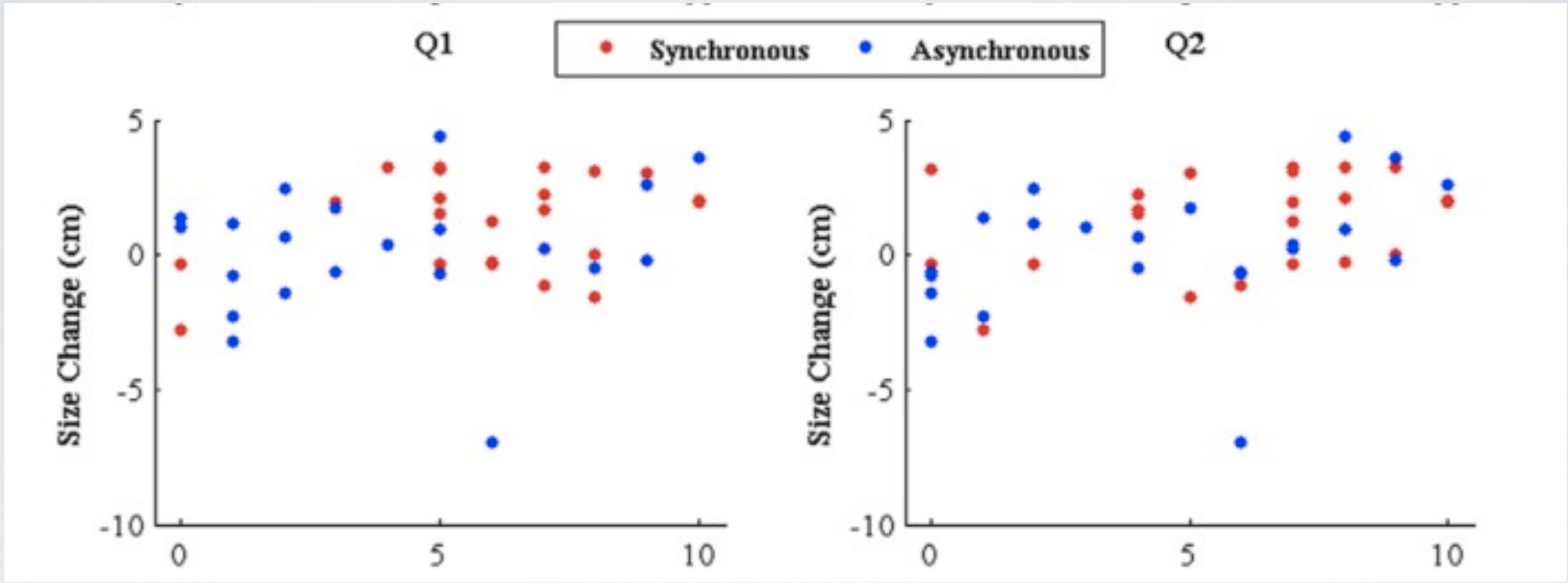


Use a tracked rot to touch the virtual/real belly

The Big Belly Illusion

(Normand, Giannopoulos, Spanlang and Slater et al. 2011)

The Big Belly Illusion



questionnaire scores
ownership

questionnaire scores
belly-size

(Normand, Giannopoulos, Spanlang and Slater et al. 2011)

The Big Belly Illusion

- Participants that experienced the illusions through IPP and congruent visuomotor plus visuotactile correlations

- Participants overestimate the size of their belly after the experiment

- Strong correlation among ownership scores and overestimations of the belly size

(Normand, Giannopoulos, Spanlang and Slater et al. 2011)

A very long Arm Illusion

- How much can you have the illusion of ownership over a highly non-symmetrical body ?

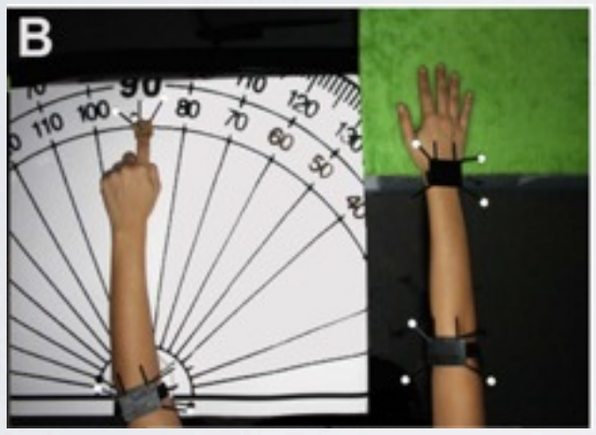
- How long can your arm be before you reject it as not being part of your body?

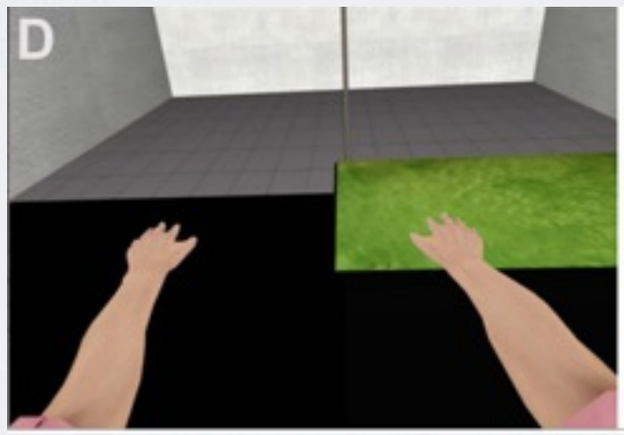
(Kilteni, Normand, Sanchez-Vives and Slater 2012)

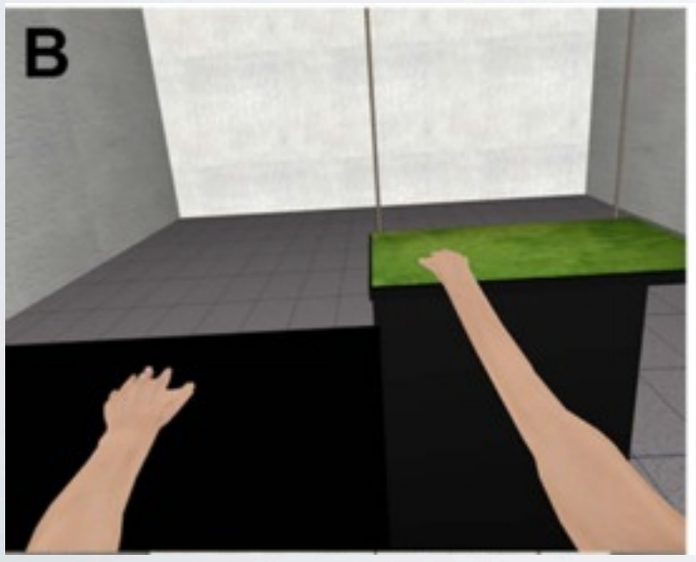
A very long Arm Illusion

(Kilteni et al. 2012)

- Subjects have a 1PP over a virtual body
- They can control the arms movements
- They touch two boxes both in physical and virtual reality

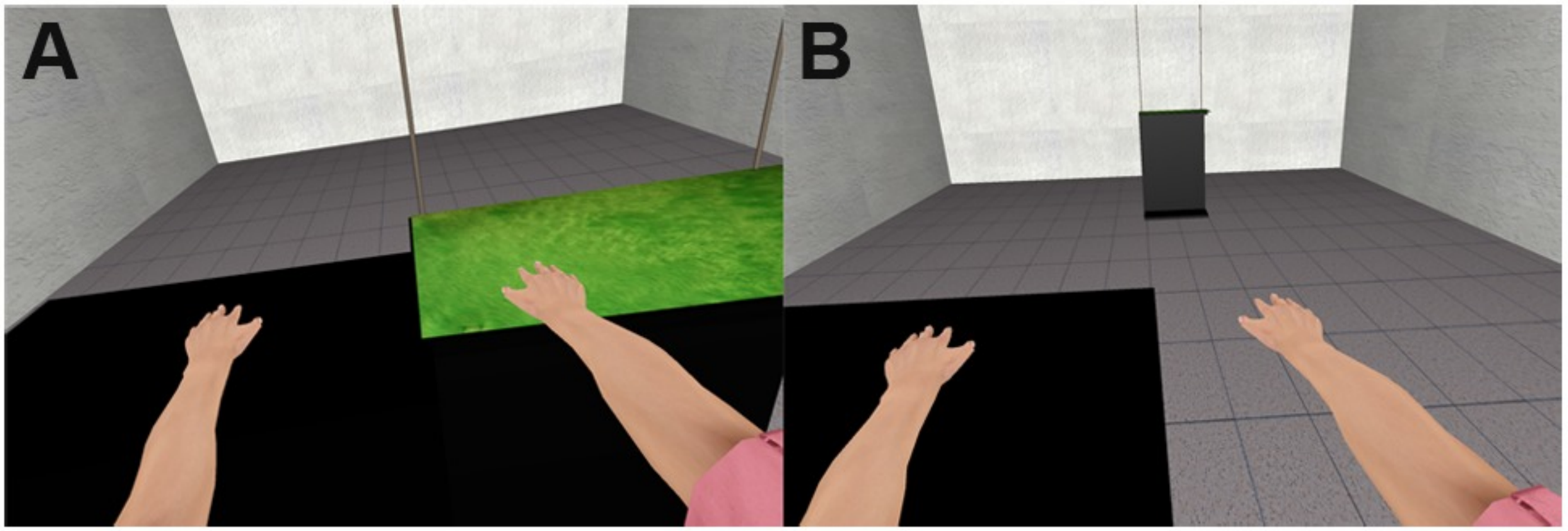






- While they experience touch the virtual box move away and the virtual arm elongates.
- This create the illusion of an elongating arm

A very long Arm Illusion



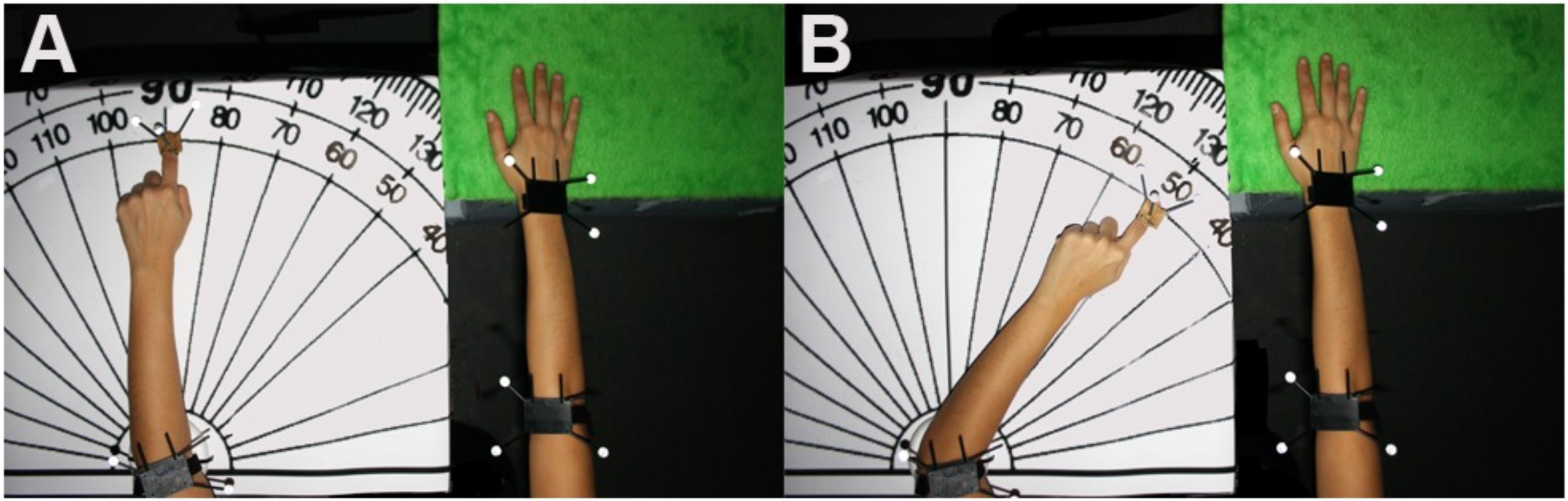
Congruent

The virtual hand touches the box in the same way as the real one

Incongruent

The virtual hand does not reach the box but the real one does.

A very long Arm Illusion



Measuring drift angle

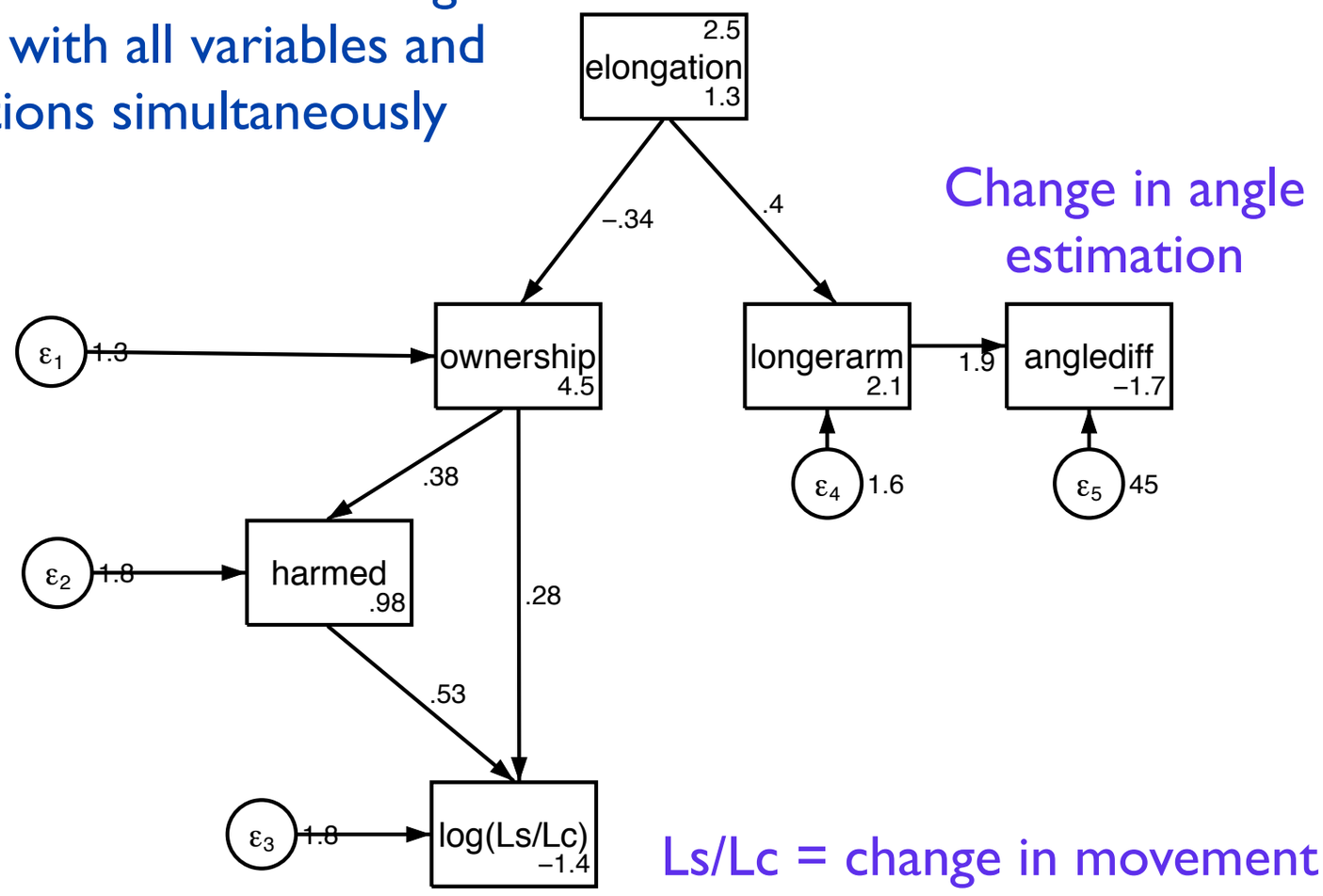
A very long Arm Illusion

(Kilteni, Normand, Sanchez-Vives and Slater 2012)

RESULTS

Path Analysis

Path analysis has the advantage of dealing with all variables and equations simultaneously



Change in angle estimation

Ls/Lc = change in movement in response to the threat

RESULTS

- No significant difference between Congruent and Incongruent conditions for length = 1
  - this probably reflects the dominance of IPP
  - + visual-motor synchrony
- The virtual arm is integrated into body ownership strongly up to length 3, and less so length 4

Ownership Illusions: Recap

Ownership illusions can be induced providing multisensory correlated stimuli

- body parts
- full bodies
- ... with non realistic sized and proportions
- the illusion brings along a set of perceptual correlates (e.g. size, posture, autonomic responses, etc.)

Ownership Illusions: What's Next

There is growing evidence that in ownership illusions the type of body carries with it a set of **attitudinal and behavioral correlates**

- A casual body appearance makes you drum better
- A dark-skin body decreases your racial body
- A child body changes the way you perceive the environment and yourself

Drumming Experiment

(Kilteni et al. 2013)

- The hypothesis was that the form of the virtual body would make a difference to how they played.
- All did a baseline condition where they were represented only by white hands.
- 16 were embodied in a 'casual' looking body and16 in a body of 'formal' appearance.
- Motion capture recorded 30 upper body movement variables during a baseline time (white hands only) and experiment time.

Drumming Experiment

Drumming Experiment

Results

- Response variables
    - Subjective body ownership scores (questionnaire)
    - Responses about the body scores (questionnaire)
    - Dimensionality of the motion capture data (principle components analysis)
- Hypothesis → higher movements dimensionality for the casual group

(Kilteni, Bergstrom and Slater 2013)

Drumming Experiment

Results

- The l**evel of body ownership was the same and high** for both groups (median 5 or 6 out of max score of 7 with low IQR).

- The **casual body was judged as significantly more expressive and appropriate** for the task than the formal body. (Remember - between-groups).

(Kilteni, Bergstrom and Slater 2013)

Drumming Experiment

The **movement dimensionality was significantly higher for the casual body group**

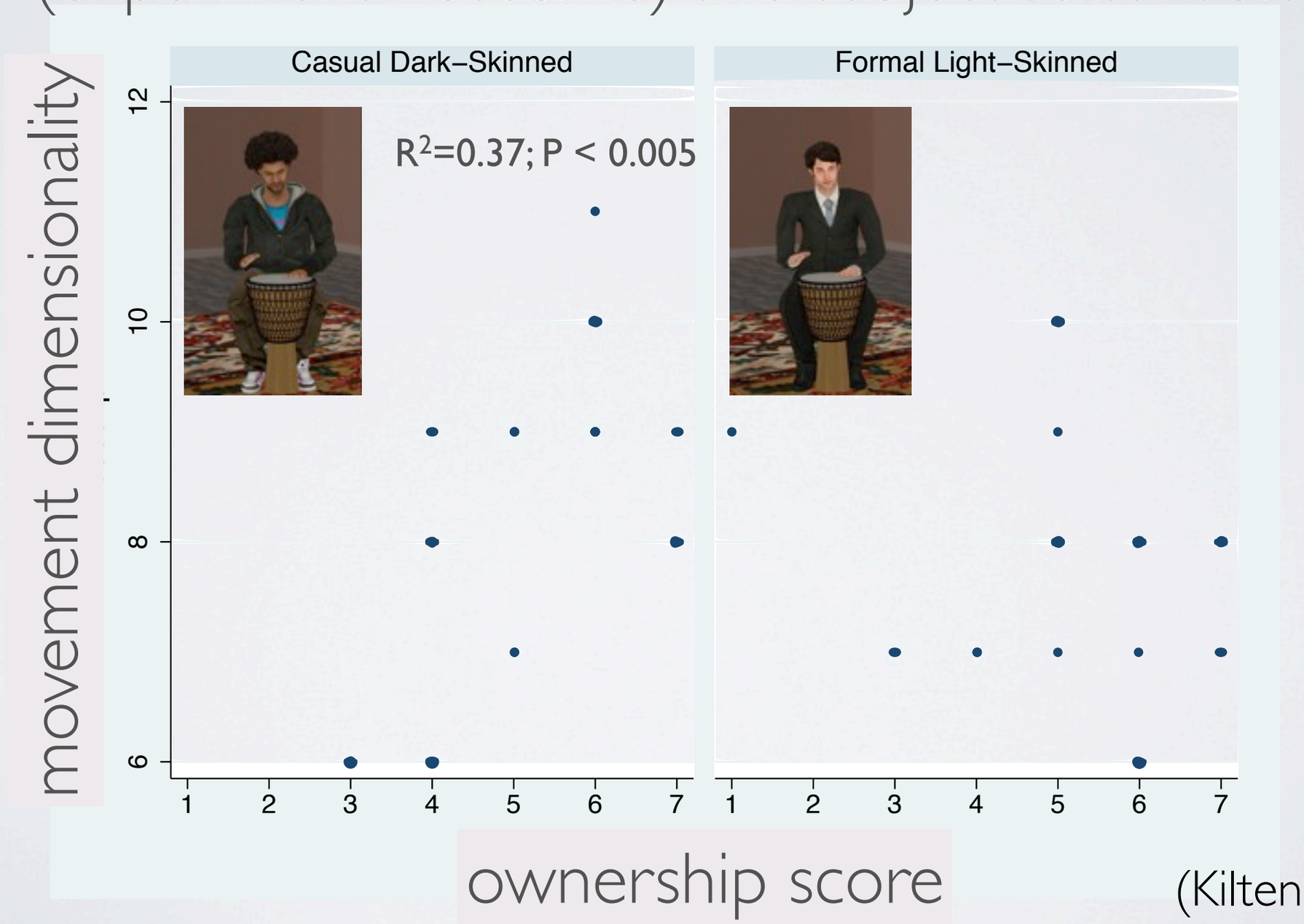
Mean ± SD of no. eigenvalues >= 95% of variance

Group	Mov. Dimens. Before	Mov. Dimens. After	Paired t-test
Casual	7.4 ± 0.23	8.5 ± 0.29	0.0002
Formal	7.5 ± 0.38	7.5 ± 0.27	0.90
t-test	0.90	0.013	

(Kilteni, Bergstrom and Slater 2013)

Drumming Experiment

Correlations between dimensionality difference (experiment - baseline) and subjective variables.



(Kilteni et al. 2013)

Drumming Experiment

Conclusions

The body shapes the way we play

Full body ownership illusions can lead to substantial behavioral and probably cognitive changes in the context of musical performance

(Kilteni, Bergstrom and Slater 2013)

IMPLICIT RACIAL BIAS

Motivations

- People tend to categorize others into in-groups and out-groups

- Racial categorization is apparently a deep seated example.

- Others have shown that racial categorization can be simply overcome by shifting coalitional alliances (Kurzban et al 2001).

- **Can embodiment techniques be used to obtain a similar result?**

(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

- Experimental design: between-groups
  - 15 embodied dark-skin (ED)
  - 15 embodied light-skin (EL)
  - 15 not embodied - but dark skin in mirror with asynchronous movements (ND)
  - 15 embodied purple/alien skin (EA).

(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

- Days before the experiment participants completed an ‘implicit association test’ for racial bias.

(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

- Days before the experiment participants completed an 'implicit association test' for racial bias.
- This asks participants to quickly pair
  - Dark faces with negative words + light faces with positive words
  - Dark faces with positive words + light faces with negative words

(Peak, Seinfeld, Aglioti and Slater 2013)

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

(Peak, Seinfeld, Aglioti and Slater 2013)

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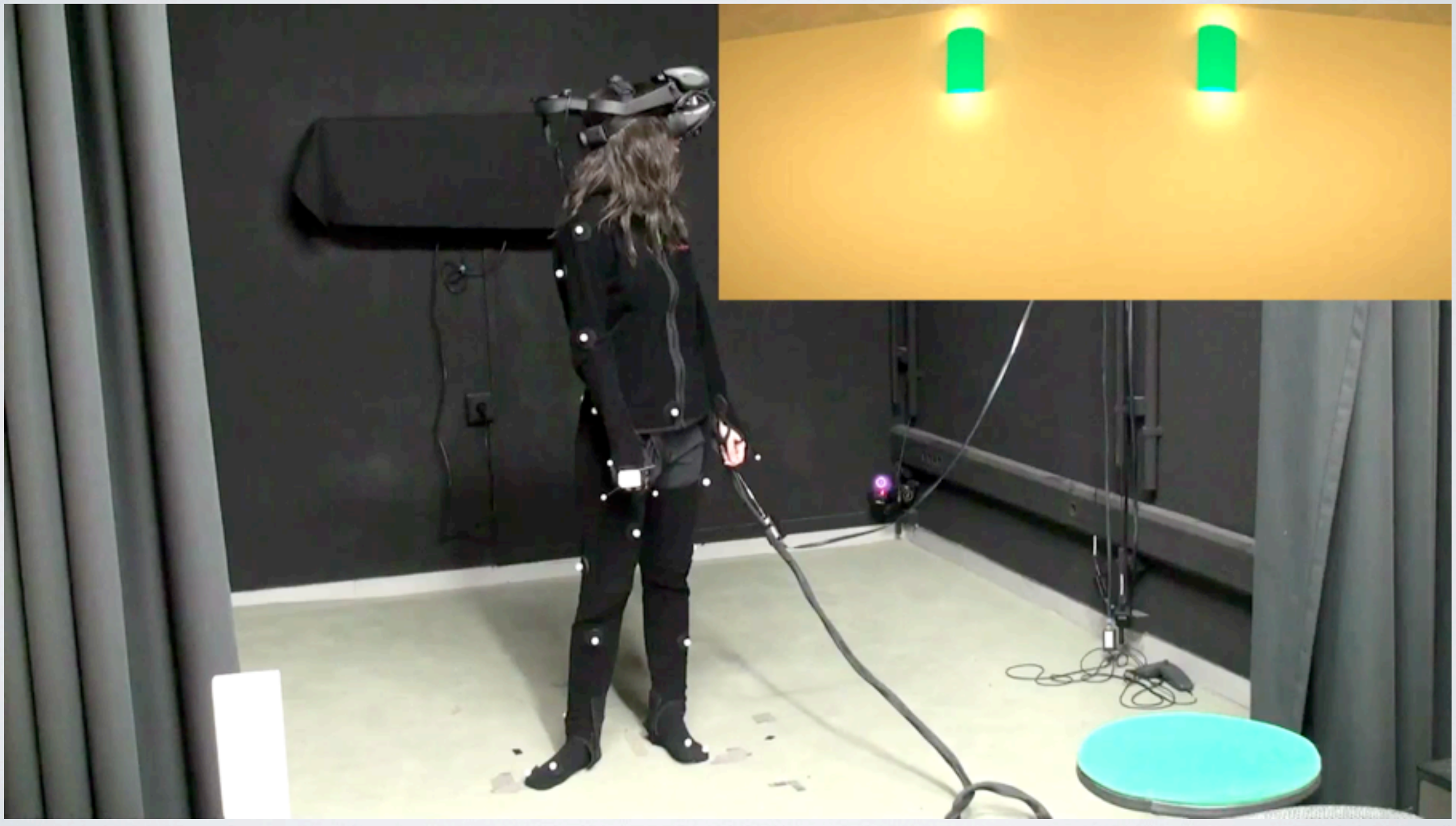
- https://implicit.harvard.edu/implicit/demo/

(Peak, Seinfeld, Aglioti and Slater 2013)

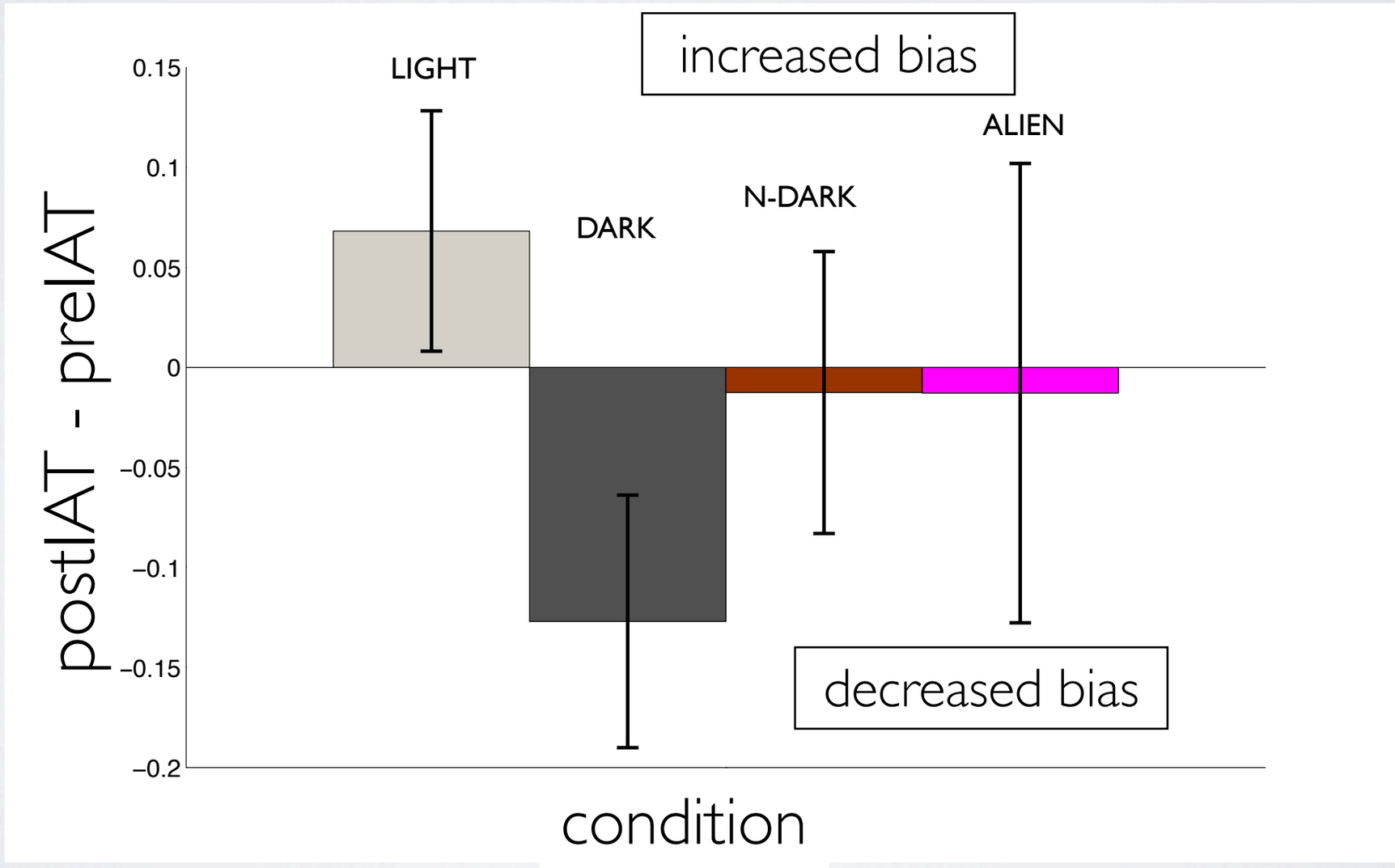
IMPLICIT RACIAL BIAS



(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

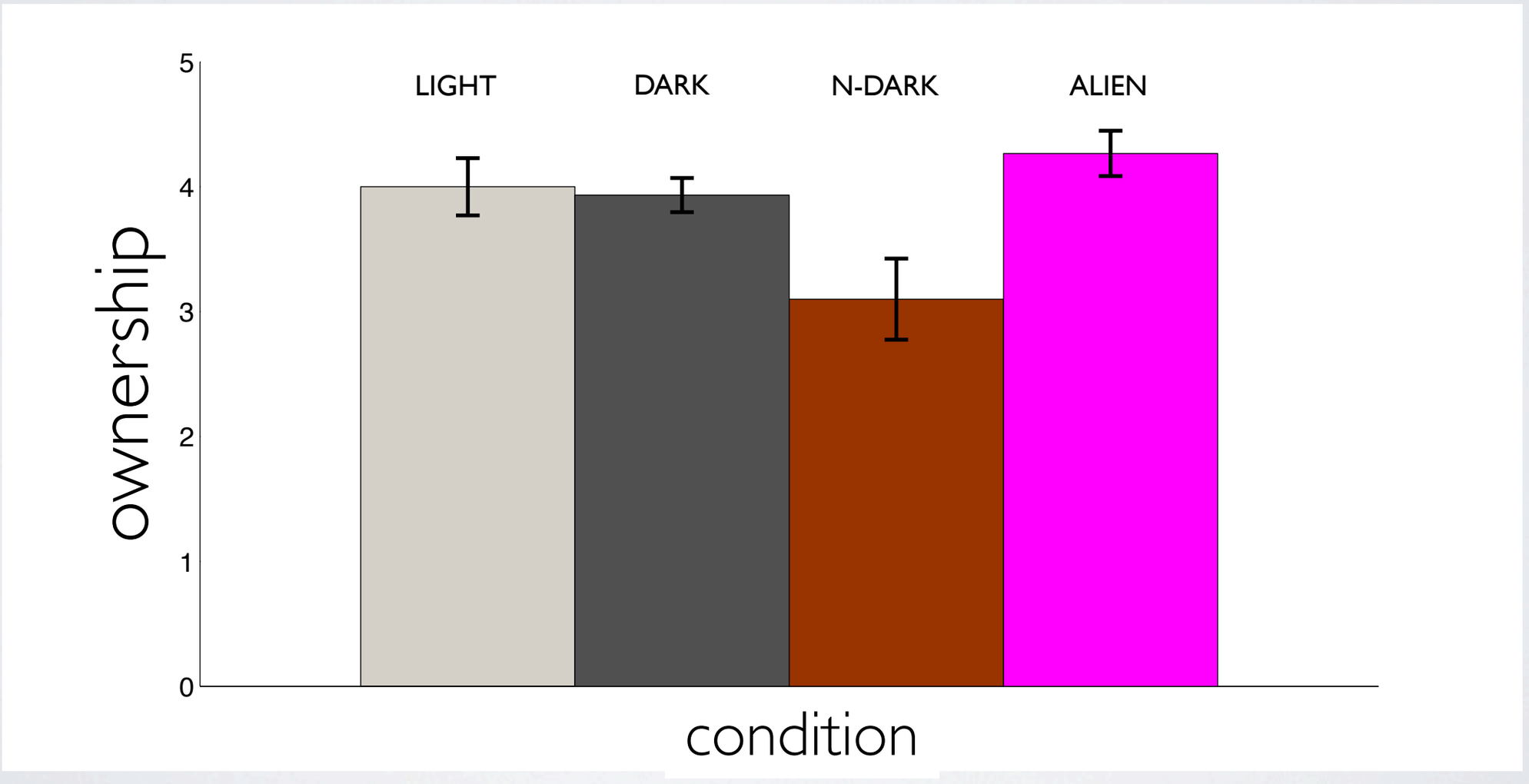
After their VR exposure they have the Implicit Association Test (IAT) test again.



(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

The illusion of body ownership was the same for all three embodied groups.



(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

Conclusions

(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

Conclusions

- Remarkable how few minutes exposure to ‘being’ in the ‘out-group’ can influence deep-seated processes

(Peak, Seinfeld, Aglioti and Slater 2013)

IMPLICIT RACIAL BIAS

Conclusions

- Remarkable how few minutes exposure to 'being' in the 'out-group' can influence deep-seated processes

- Similar results found using a dark rubber hand illusion (Farmer et al. 2013)

(Peak, Seinfeld, Aglioti and Slater 2013)

THE CHILD EXPERIMENT

Motivations

(Bakanou, Groeten and Slater 2013)

THE CHILD EXPERIMENT

Motivations

- Previous results showed that the experience of ownership over a bigger/smaller body affects the way sizes and distances are perceived (van der Hoort et al. 2011)

(Bakanou, Groeten and Slater 2013)

THE CHILD EXPERIMENT

Motivations

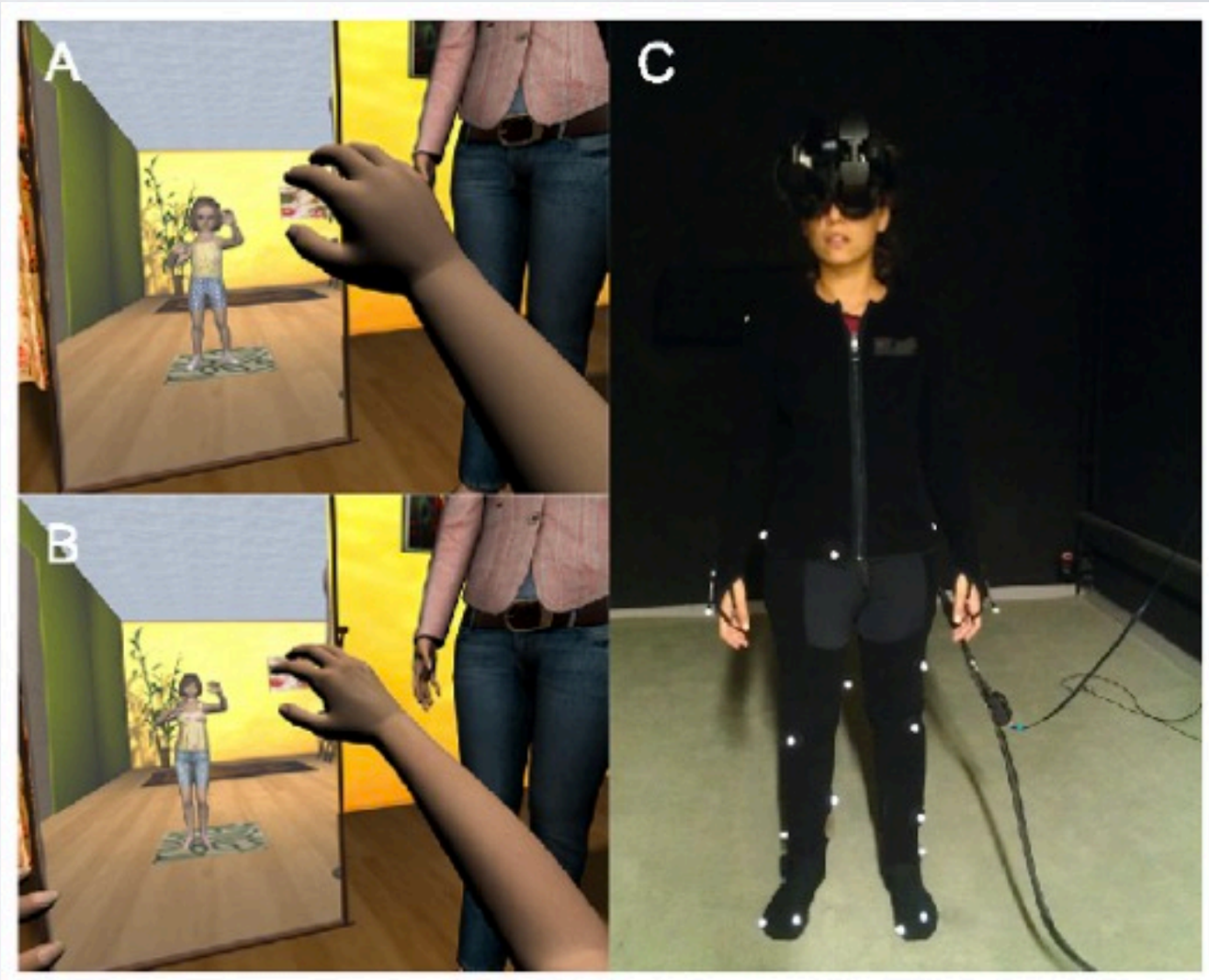
- Previous results showed that the experience of ownership over a bigger/smaller body affects the way sizes and distances are perceived (van der Hoort et al. 2011)

- **Can other factors, such as the type of body you own, affect size perception and the way you experience and categorize your self?**

(Bakanou, Groeten and Slater 2013)

THE CHILD EXPERIMENT

- Within-groups experiment
- Embodiment in a child body or in a scaled adult body
- Embodiment through synchronous visuomotor correlation
- Response Variables:
    - questionnaires
    - object size estimation
    - implicit association test (adult vs child)



(Bakanou, Groeten and Slater 2013)

THE CHILD EXPERIMENT

(Bakanou, Groeten and Slater 2013)

THE CHILD EXPERIMENT

Results

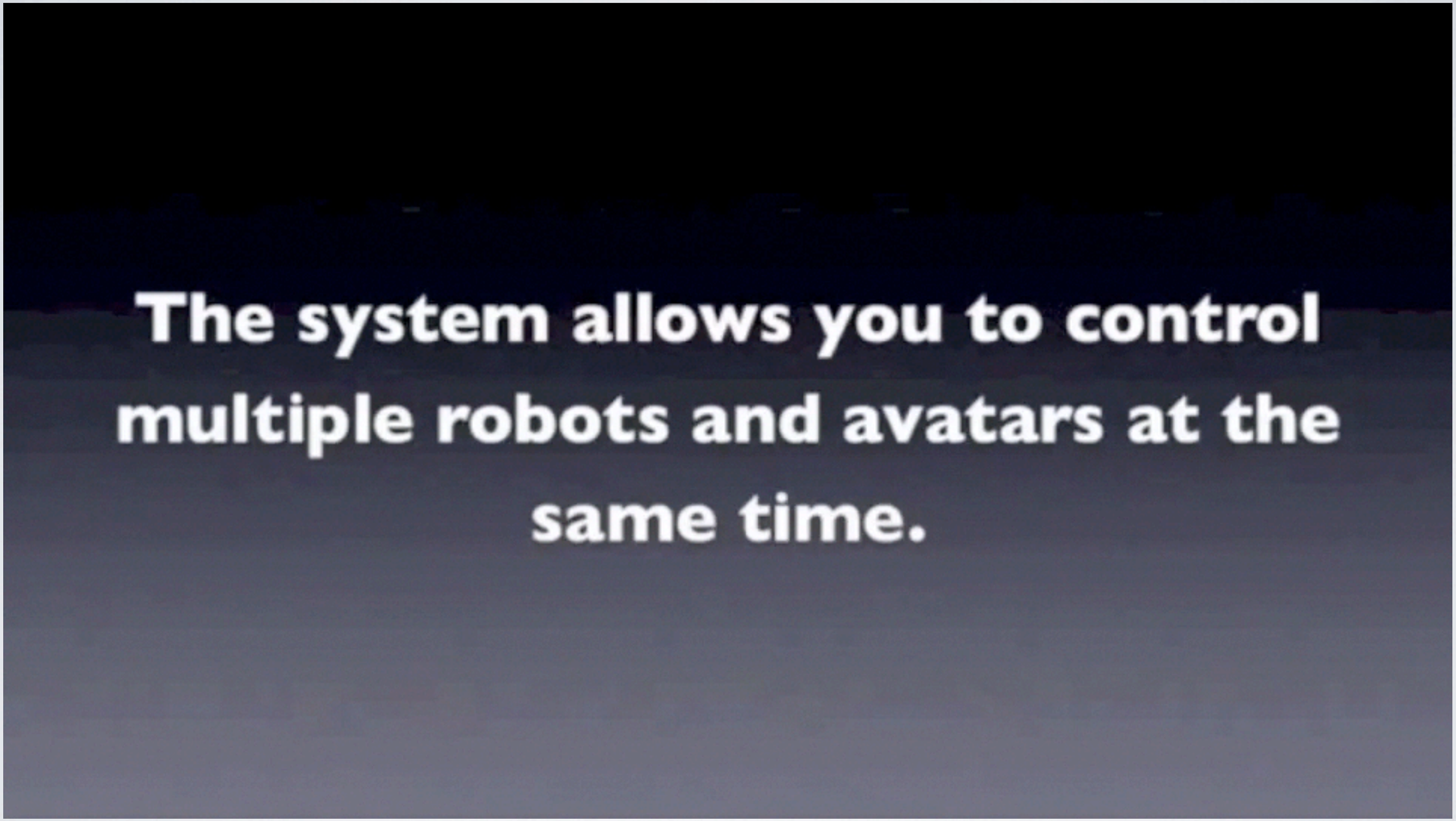
- Ownership can be induces toward a child body
- Object size estimation is affected non only by the size of the owned body, but also by its shape and meaning content (adult shape vs child shape)
- Self-categorization is modulated by the type of body you own

(Bakanou, Groeten and Slater 2013)

What about

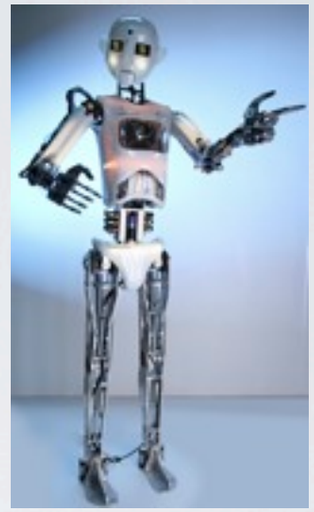
BEING A ROBOT ?

Embodiment into a ROBOT



Embodiment into a ROBOT

BCI



Allow disabled persons to interact with the world through an avatar or a robot

....from Ownership to Telepresence

BEAMING

The process of instantaneously transporting **visitors** from one physical place to another destination, allowing them to interact with **local** people there

BEING A ROBOT

Ownership of a robot *000s km away
from your real body!

BEING A ROBOT

000s km away from your real body!

BEING A ROBOT

000s km away from your real body!

BEING A PATIENT

*000sm away from your doctor!

BEING A PATIENT

*000sm away from your doctor!

CREDITS


eventLAB
Neuroscience
& Technology









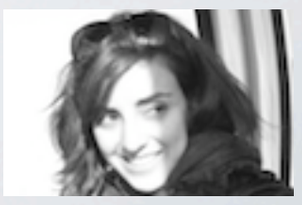










FOUNDING

TRAVERSE

FP7 ATT

FP7 FET

FP7

FP6 FET

THANKS!!