Microsoft Research
Faculty Summit
2017

The Hearing Body: Auditory stimulation to alter perception

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Sensory systems

Monitor the surrounding environment

To obtain information and alert of significant events requiring an action. (Graziano, 2001)

- Constant margin of safety
- Guide actions

Auditory system: A warning system

(e.g. Juslin & Vastfjall, 2008, *Psych Sci*)

- It provides with a **continuous stream of information** → our ears never turn off!
- A change detector with high **temporal resolution** and high sensitivity for structured motion (range frequency response 20 Hz – 20 KHz)
- **Quick**ly orients behavior (faster than visual system).
- Informs about events all around us, even those events **outside the visual field**.
- Process several streams of information in parallel: overall impression of the environment (***soundscape***).
- Impression of **geometry and size of the space** we are in.

Tajadura-Jiménez et al (2010) *Emotion*

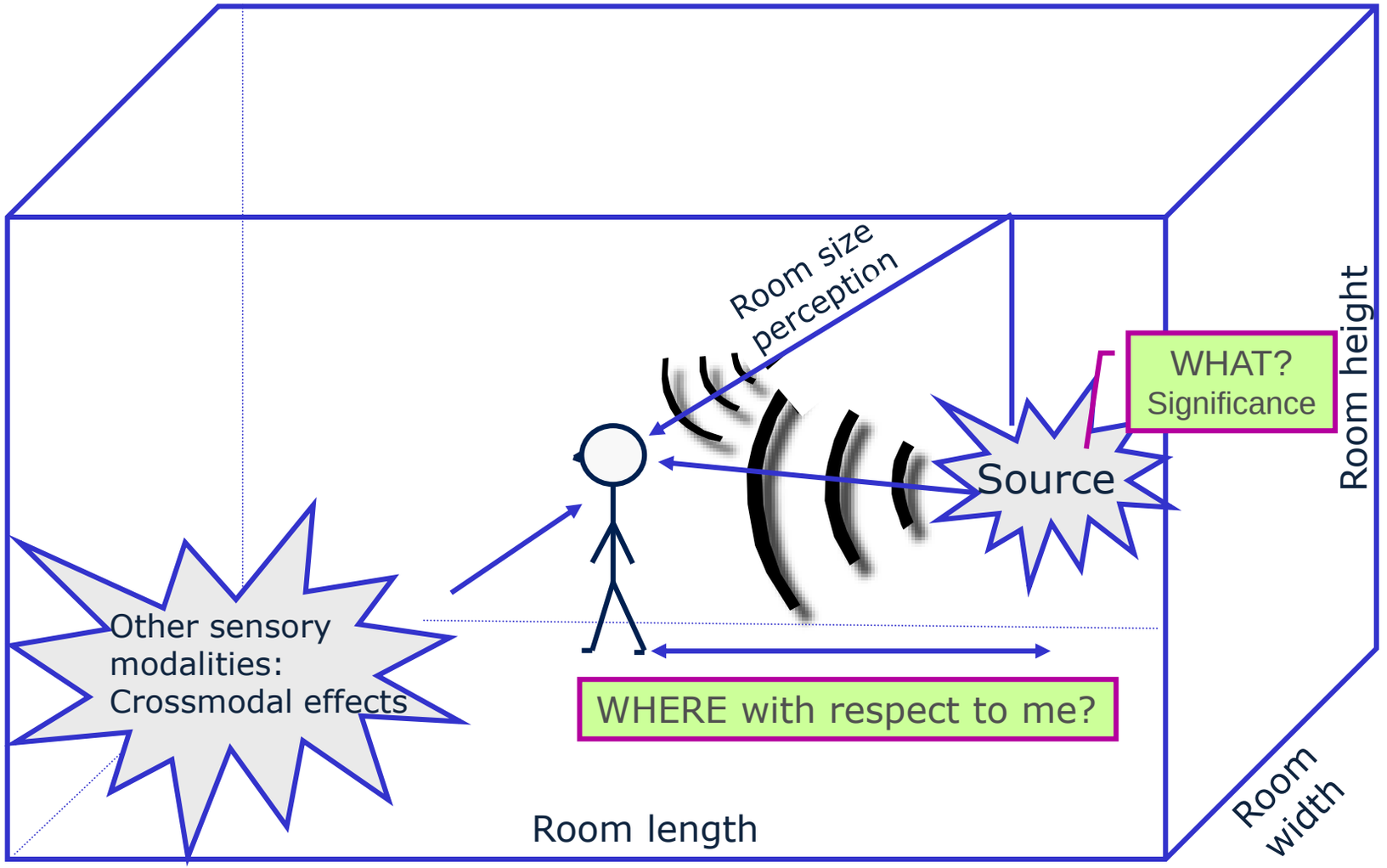
Hearing an object

Perception of material and geometry of the object from sound

- Roughness – Lederman, 1979
- Material (rubber, wood, glass or steel) - Klatzky et al., 2000
- Length - Gaver, 1988; Carello et al., 1998
- Hardness – Freed, 1990
- Shape - Lakatos, McAdams, & Caussé, 1997

Timing, what and where

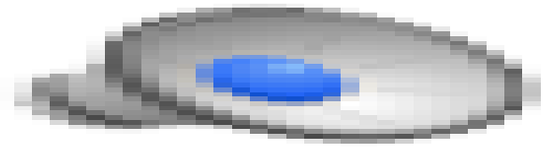
Tajadura-Jiménez et al.
CyberPsychol & Behav, 2008
Emotion, 2010a, 2010b
J. Automobile Eng, 2010



Cross-modal interaction: Evidences

The stream/bounce illusion

(Sekuler, Sekuler & Lau, 1997, *Nature*)



Video from Grove, Robertson & Harris, 2016, *Multisensory Research*

Cross-modal interaction: Evidences

The parchment skin illusion
(Jousmaki & Hari, 1998, *Curr Biol*)

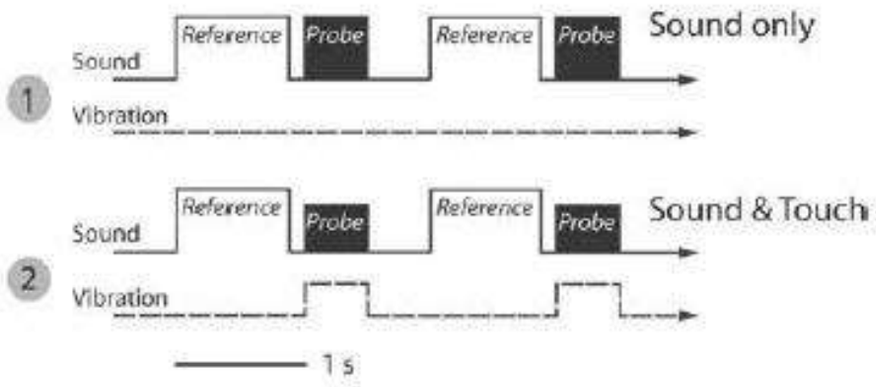
Frequency of touch sounds biases the perceived smoothness/dryness of one's skin

Cross-modal interaction: Evidences

Multisensory integration:

- allows having meaningful perceptual experiences and forming coherent representations of the external world.
- is central to adaptive behavior (E.g. Lewkowicz & Ghazanfar, 2009, *TICS*).
- often leads to enhanced behavior. E.g. smaller reaction times and thresholds.

E.g. Hands help hearing
Schurmann et al., 2004, *JASA*



Cross-modal interaction: Evidences

- Informational discrepancy → Recalibration processes.
- Sensory dominance?
  - Visual system for spatial tasks.
  - Auditory system for temporal tasks.

BUT ONE CANNOT PREDICT multisensory perception by studying senses in isolation.

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

The Hearing Body

Using sound for altering one's body perception

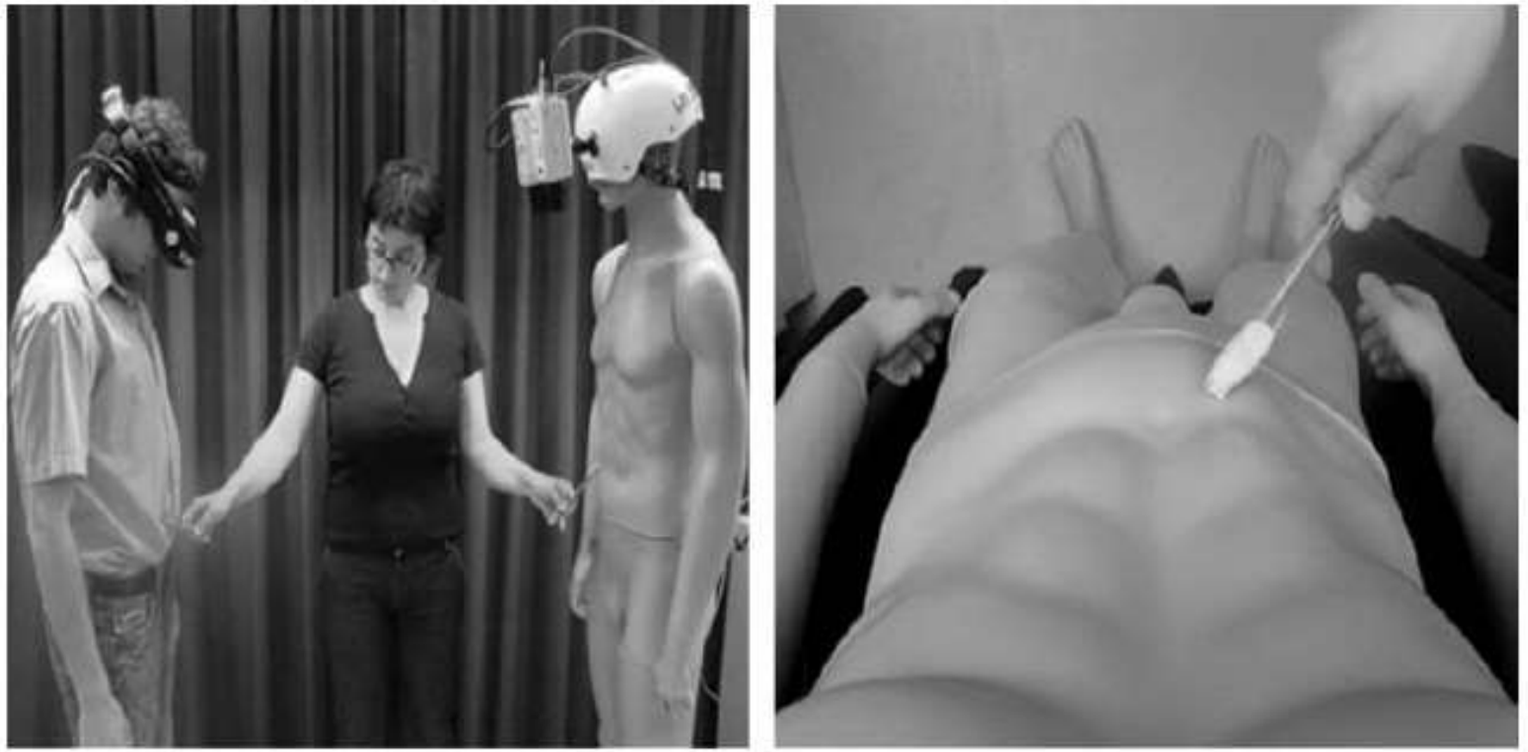
→ influences on motor behavior & emotion

Sensing the body: Neuroscience works on body representation

The sense of our physical body is not fixed. It is acquired through **sensing** and **acting**

This sense of body is crucial for emotional state, and for motor and social interactions

Changing the body through our senses



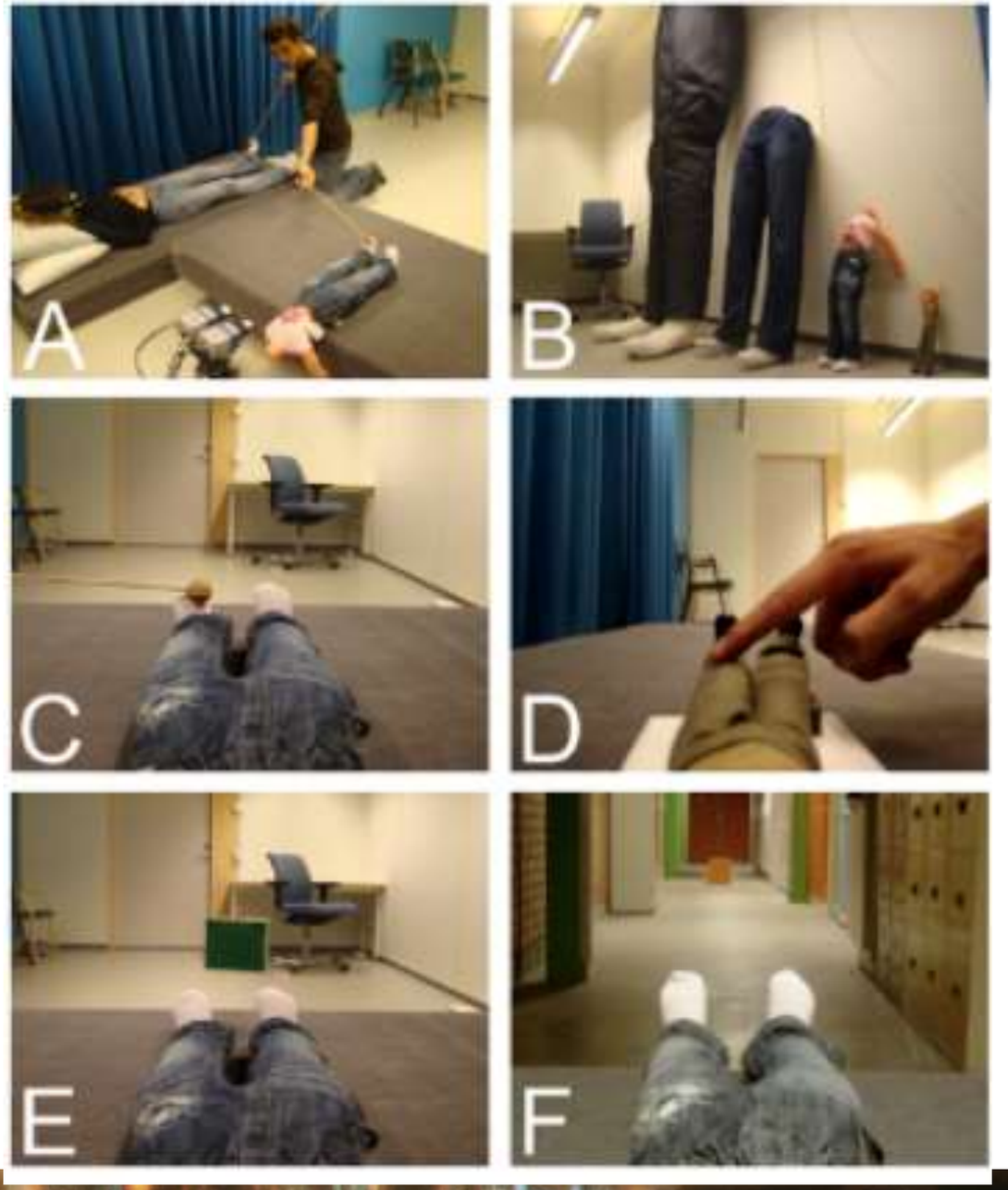
The Body-swap illusion

Petkova & Ehrsson (2008) *PLoS ONE*

Represented body size influences perceived space size

Being Barbie: The size of one's own body determines the perceived size of the world

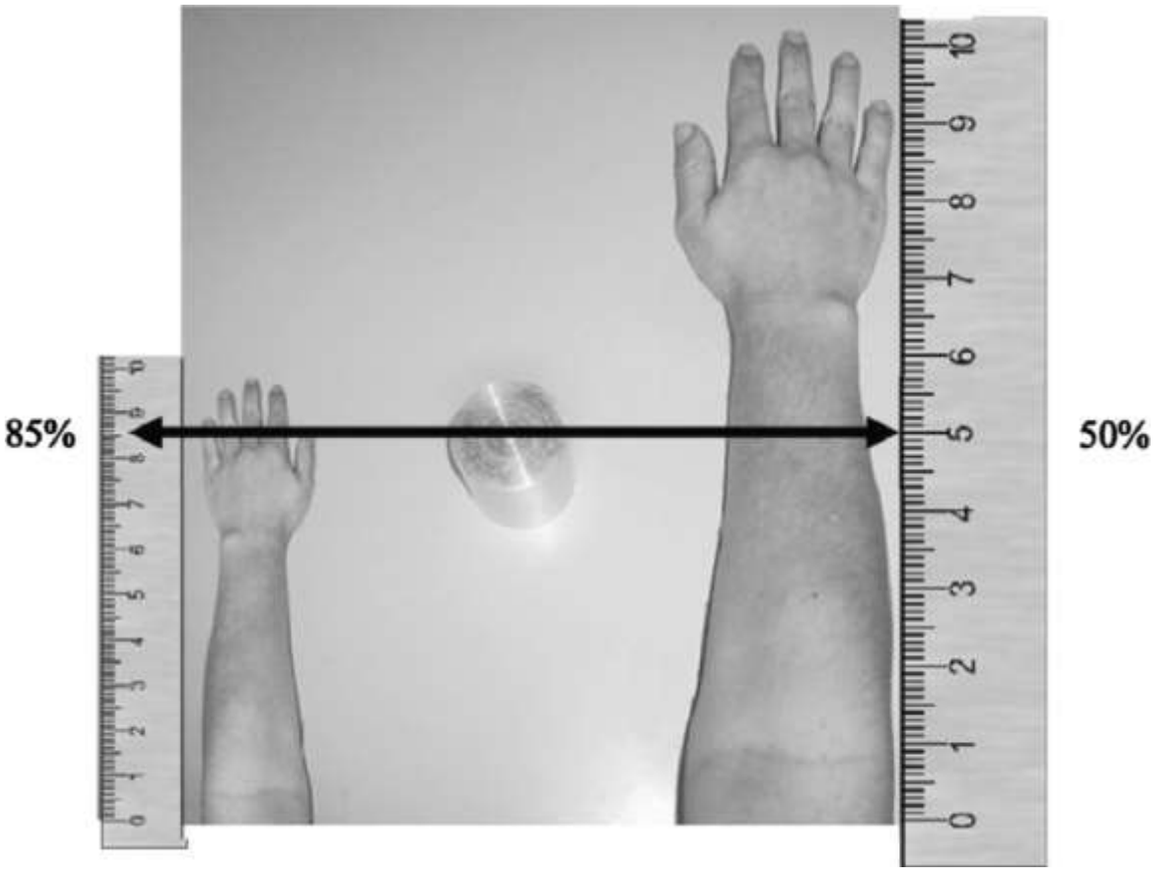
van der Hoort et al, 2013, *PLOS ONE*



One's body as a "perceptual ruler"

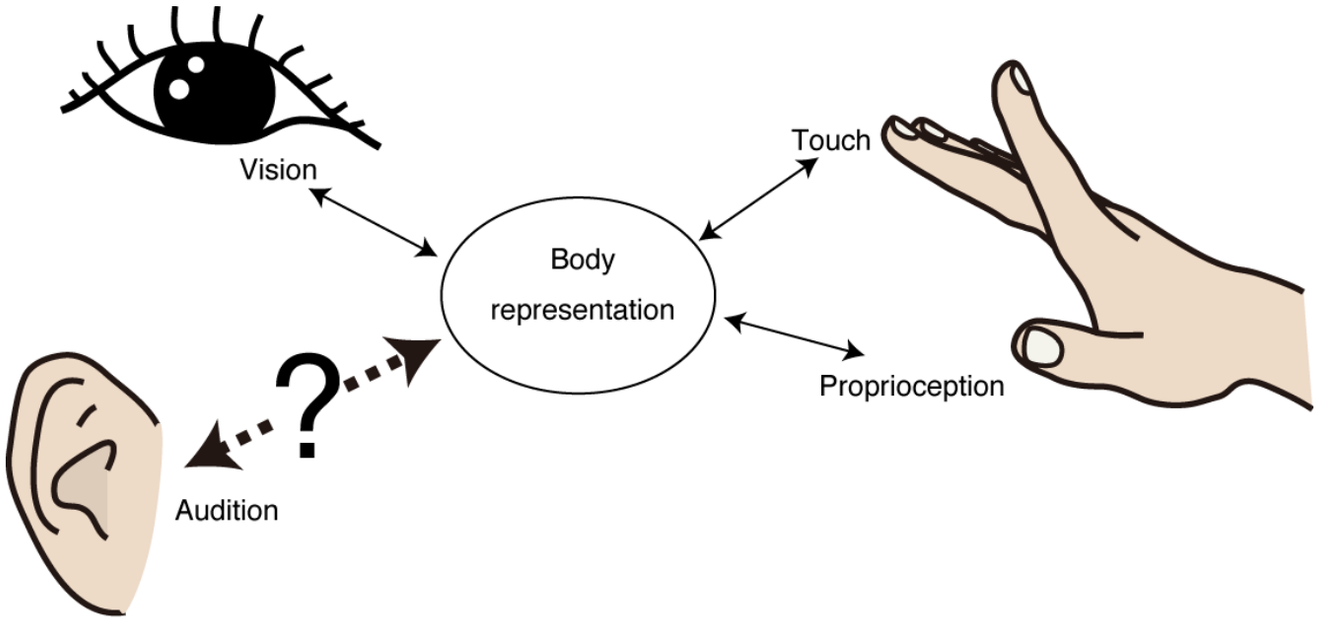
One's body is used as a "perceptual ruler" to measure object's size and distances, and to adapt behavior.

Linkenauger et al. 2011 *JEP: HPP*
Linkenauger et al. 2015 *Neuropsychologia*
Canzoneri et al. 2013 *Exp Brain Res*
Cardinali et al. 2009 *Curr Biol*



The Hearing Body

Exploring the link between audition and body-representations









Effects of sounds on the represented…

Arm length (tapping sounds)

Finger length (Auditory Pinocchio)

Body weight (footstep sounds)

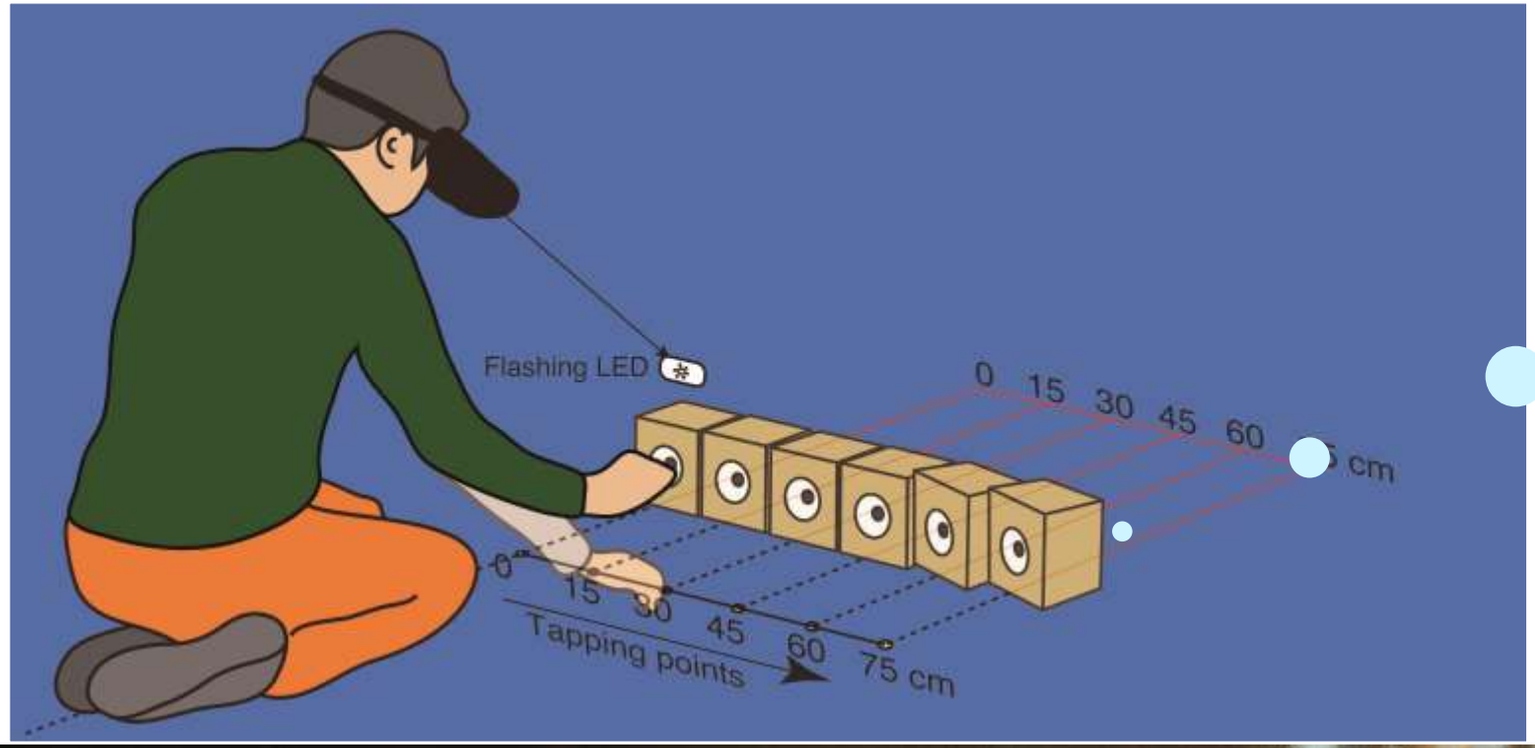
Effects of action sounds on the represented…

Arm length (tapping sounds)

Audio-tactile adaptation

Zero distance condition:

the tapping sound originates at the tapping location



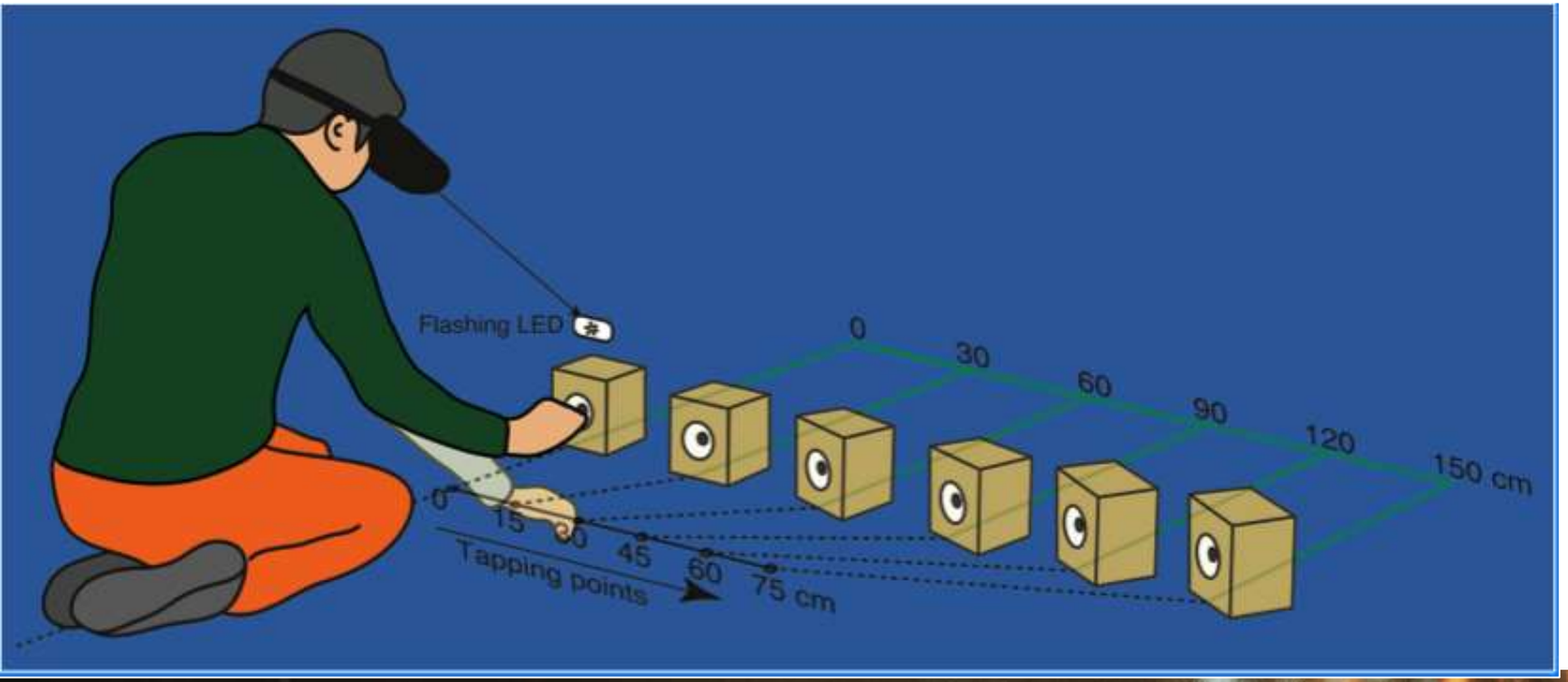
Speakers hidden from participants

Tajadura-Jiménez et al, 2012, *Current Biology*

Audio-tactile adaptation

Double distance condition:

the tapping sound originates at double the distance to the tapping location

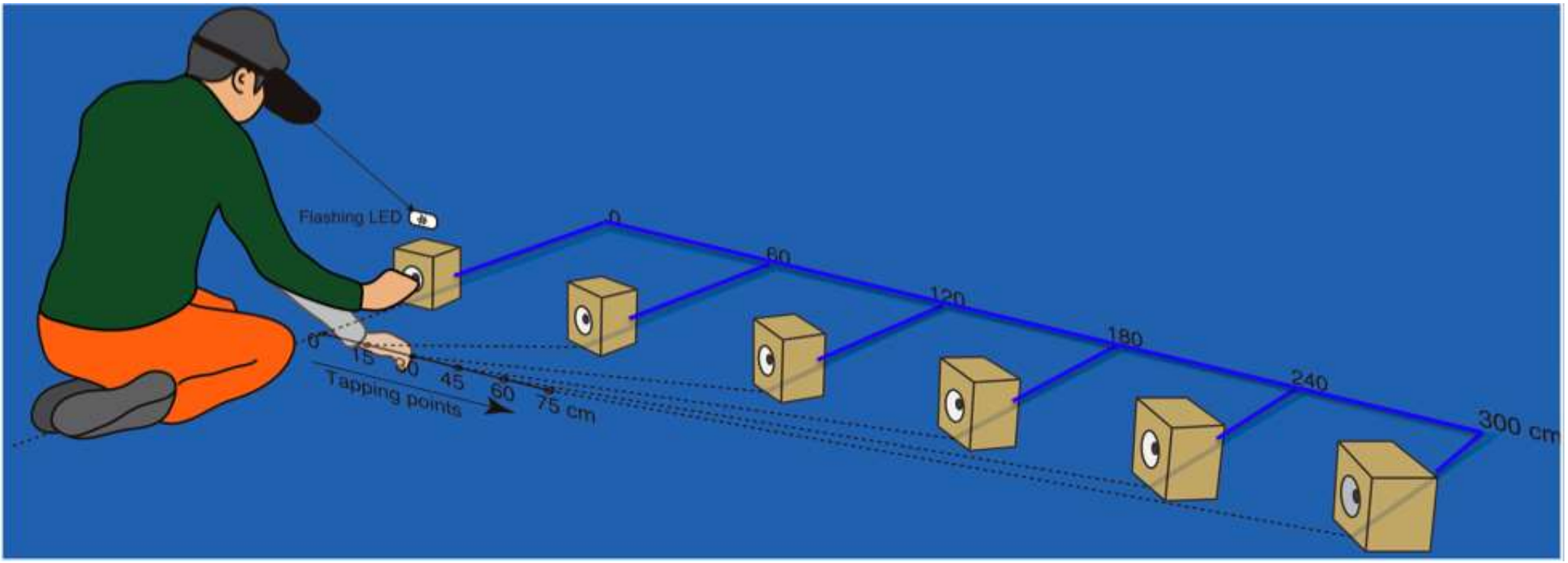


Tajadura-Jiménez et al, 2012, *Current Biology*

Audio-tactile adaptation

Quadruple distance condition:

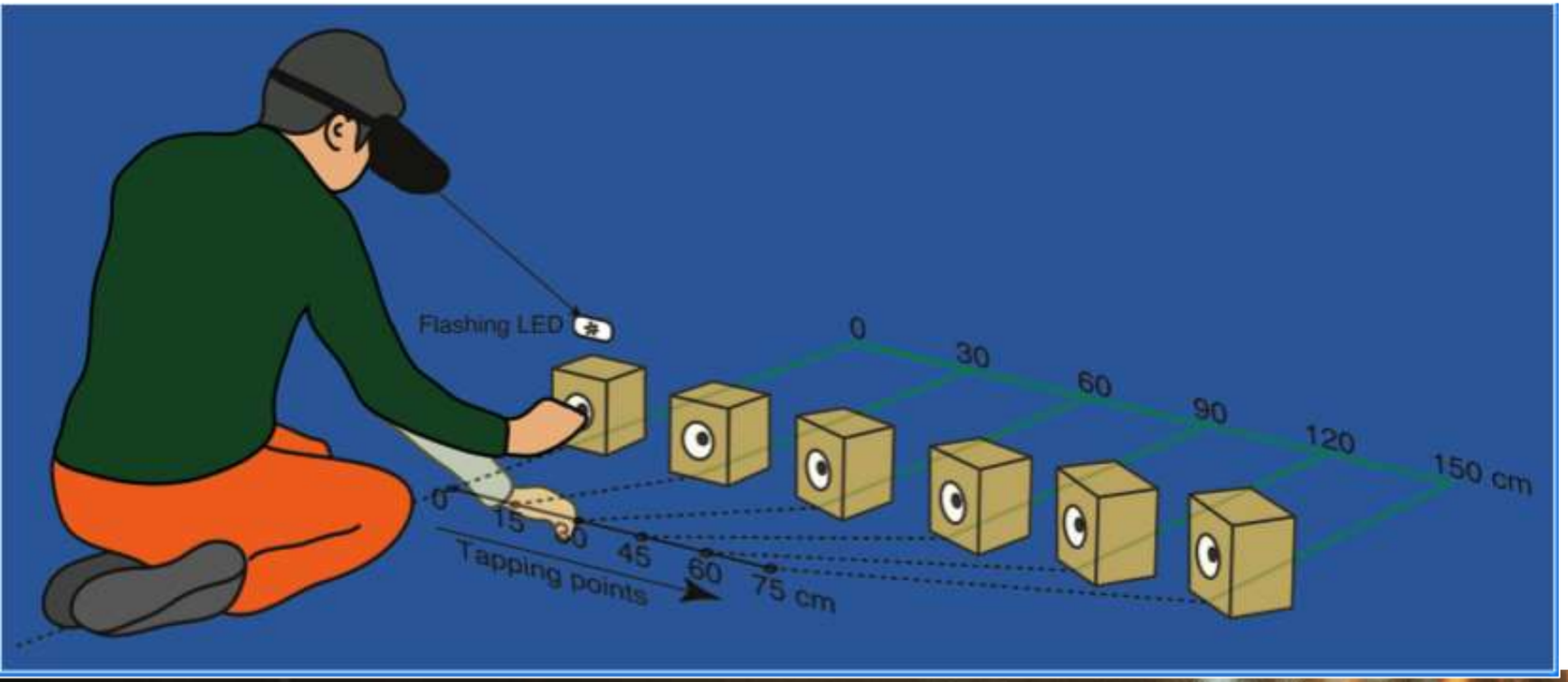
the tapping sound originates at quadruple the distance to the tapping location



Audio-tactile adaptation

Double distance ASYNCHRONOUS condition:

delay (300–800 ms) between the participant's taps and the tapping sounds



Tajadura-Jiménez et al, 2012, *Current Biology*

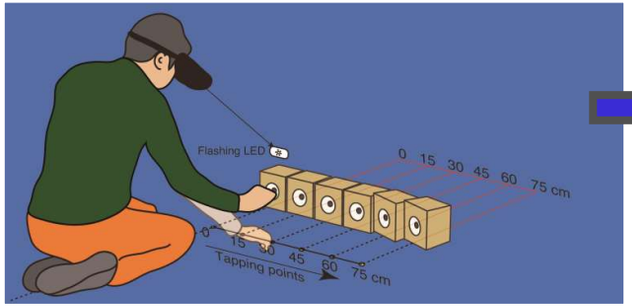
Quantifying changes in body-representation

Adapted from previous studies on bodily illusions

Pre-test:

Arm-extent

criterion baseline



Post-test:

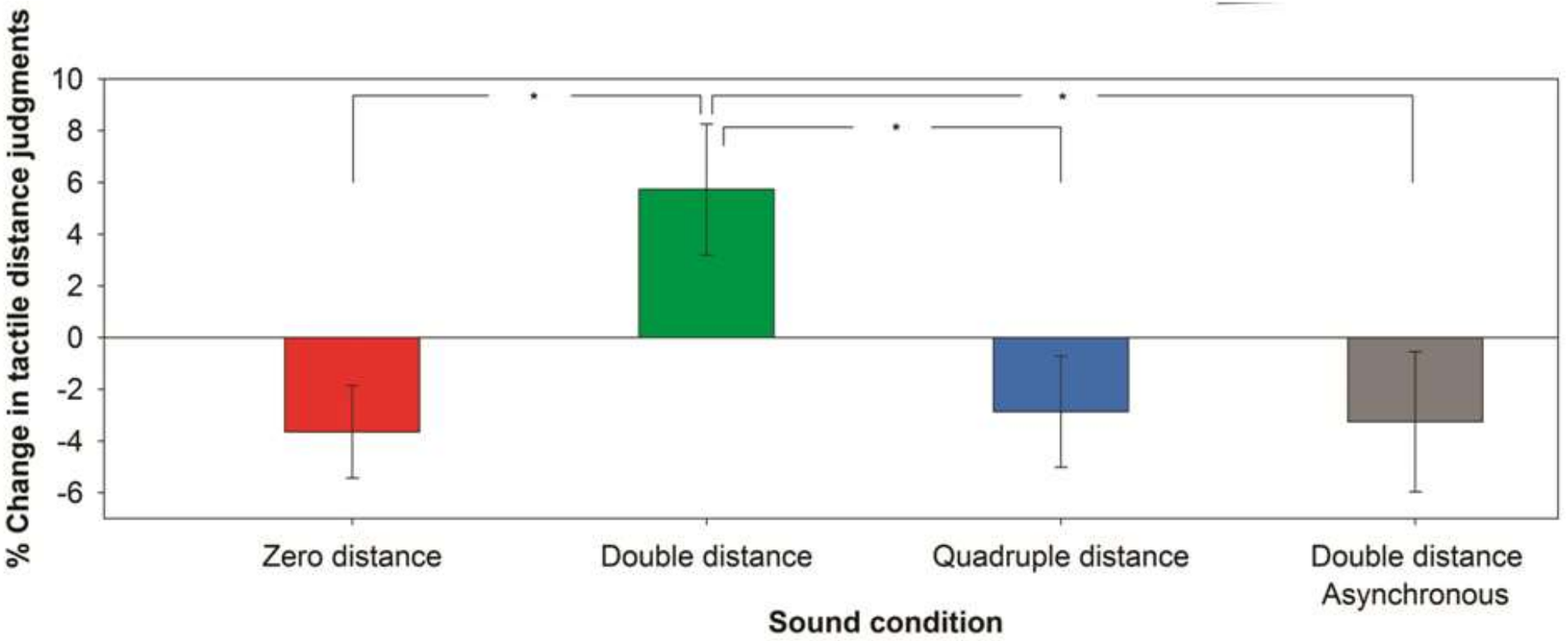
Arm-extent

Distance task for dual tactile stimuli presented in the arm
(adapted from de Vignemont et al, 2005, Current Biology)

Tajadura-Jiménez et al, 2012, *Current Biology*

Results: Effect of condition

Tajadura-Jiménez et al, 2012,
Current Biology



Interim summary – Effects of sound on…

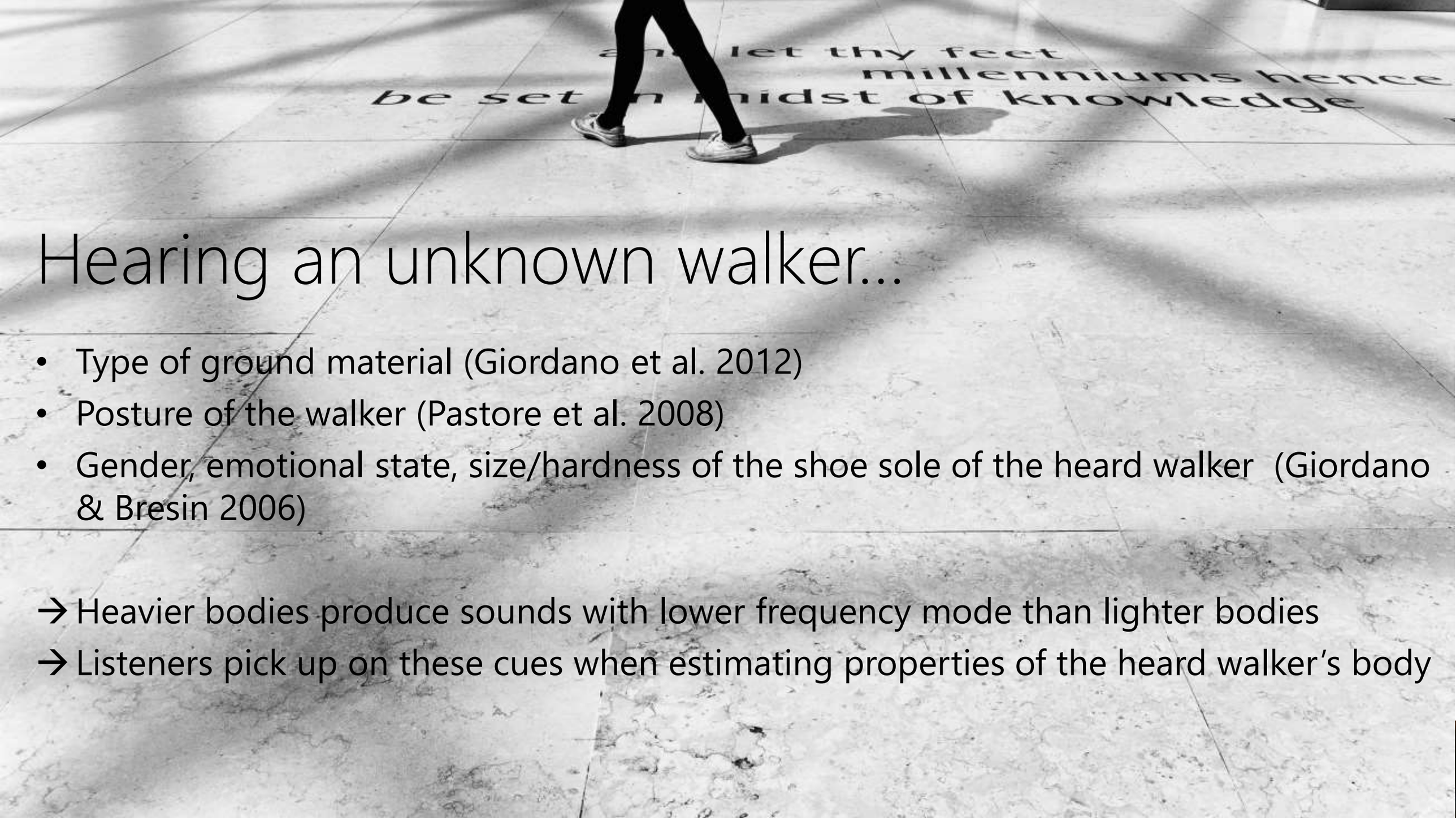
Represented arm length (tapping sounds)

Quantified by looking at:

- Perceived tactile distance
  Tajadura-Jiménez et al. (2012) *Current Biology*
- Subjective feelings of arm elongation
  Tajadura-Jiménez et al. (2015) *Frontiers Psychol*
- Kinematics of reaching movements
  Tajadura-Jiménez et al. (2016) *Frontiers Psychol*

Effects of action sounds on the represented…

Body weight (footstep sounds)



Hearing an unknown walker…

- Type of ground material (Giordano et al. 2012)
- Posture of the walker (Pastore et al. 2008)
- Gender, emotional state, size/hardness of the shoe sole of the heard walker (Giordano & Bresin 2006)

→ Heavier bodies produce sounds with lower frequency mode than lighter bodies

→ Listeners pick up on these cues when estimating properties of the heard walker's body

Our shoe-based prototype

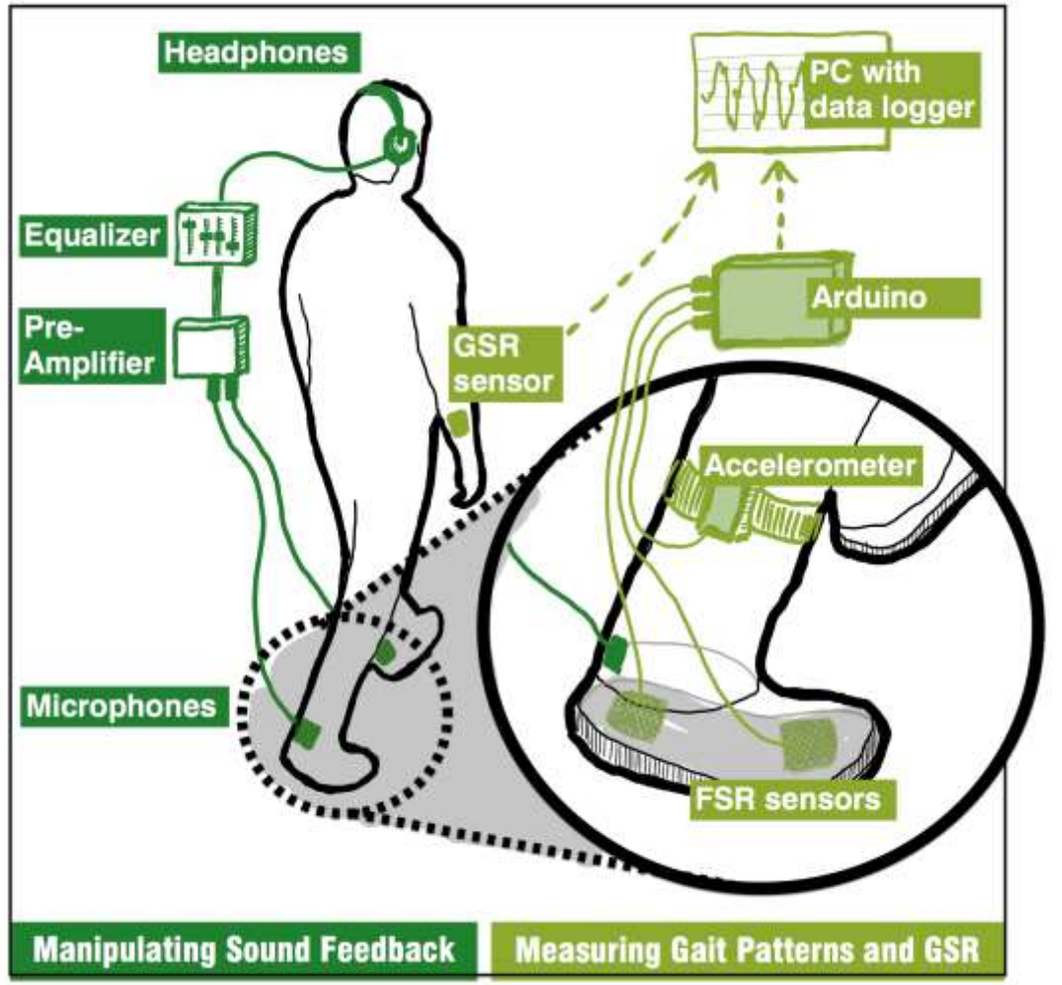
Tajadura-Jiménez et al, 2015, *CHI*

How about our own walking sounds? Do they affect the perception of our body?

As Light as your Footsteps:

Changing in real-time the frequency spectra of one's walking sounds to alter:

- Perceived body weight
- Emotional state
- Gait



Our shoe-based prototype

Tajadura-Jiménez et al, 2015, *CHI*

3 sound conditions
- high frequency
- low frequency
- control

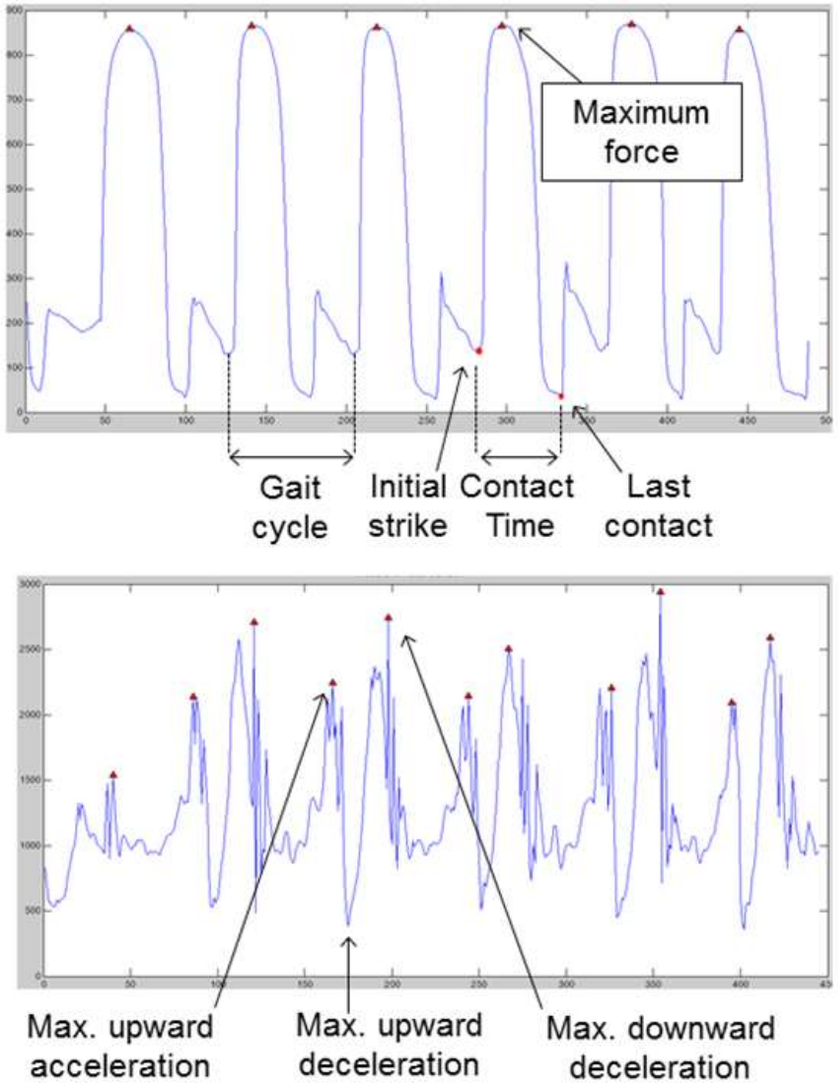
Rationale behind: Heavier bodies produce sounds with lower frequency mode than lighter bodies


NewScientist
Sonic shoes change the way you walk

Multi-measurement approach

- Gait patterns:
  -Exerted force
  -Foot acceleration

Tajadura-Jiménez et al, 2015, *CHI*



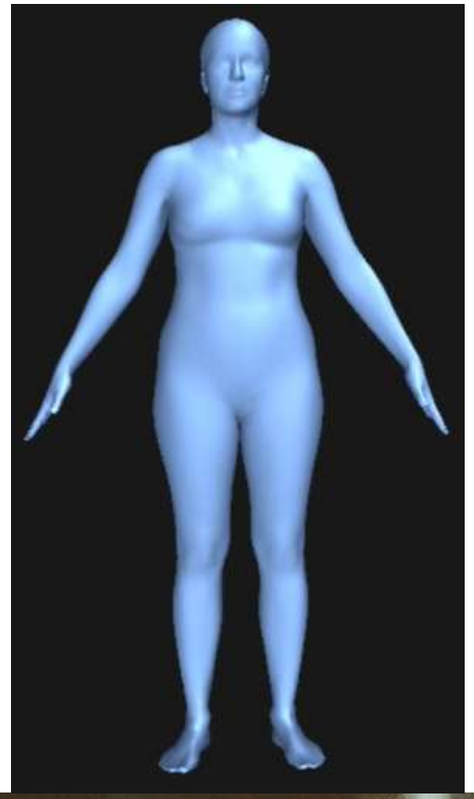
Multi-measurement approach

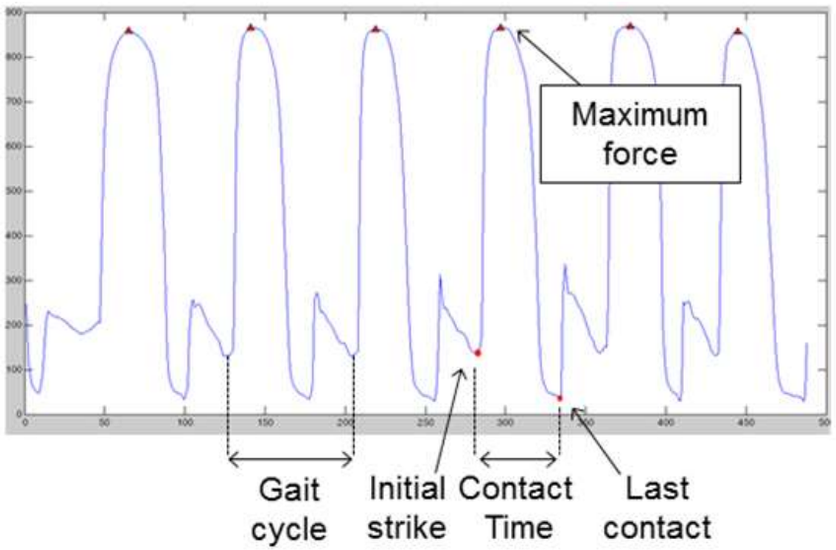
Tajadura-Jiménez et al, 2015, *CHI*

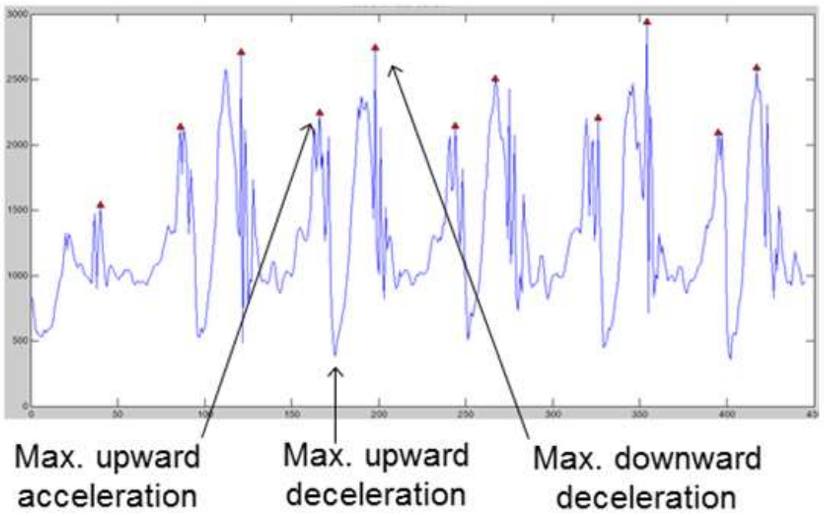
- Gait patterns:
  -Exerted force
  -Foot acceleration

- Emotional responses
  -GSR sensor
  -Questionnaires

- Perceived body weight (avatar)







Interim summary – Effects of sound on…

- Augmenting high frequencies of self-produced walking sounds results in:
  - A perceived lighter body
  - Feeling more positive & aroused
  - Feeling faster and more able to localize their feet
- Sound frequency changes also impact on gait patterns
- Our findings relate to enhanced emotional state and better predisposition for physical activity

Represented body weight/size

Tajadura-Jiménez et al, 2015, *CHI*

Applications

These findings open opportunities to design audio-based body-centred applications to support wellbeing.

Aim: Make people feel good about their bodies & motivate them toward physical activity.

MagicShoes

www.magicshoesproject.com
@magicshoes_proj

2017-2019, I+D+I Project SOCIETAL CHALLENGES

Changing sedentary lifestyles by altering mental body-representation using sensory feedback

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Effects of non-action sounds on the represented…

Finger length
(Auditory
Pinocchio)

Using non-action sounds

Tajadura-Jiménez et al, 2017, *Scientific Reports*

How about sounds that do not naturally occur?
Could they also affect the representation of our body?

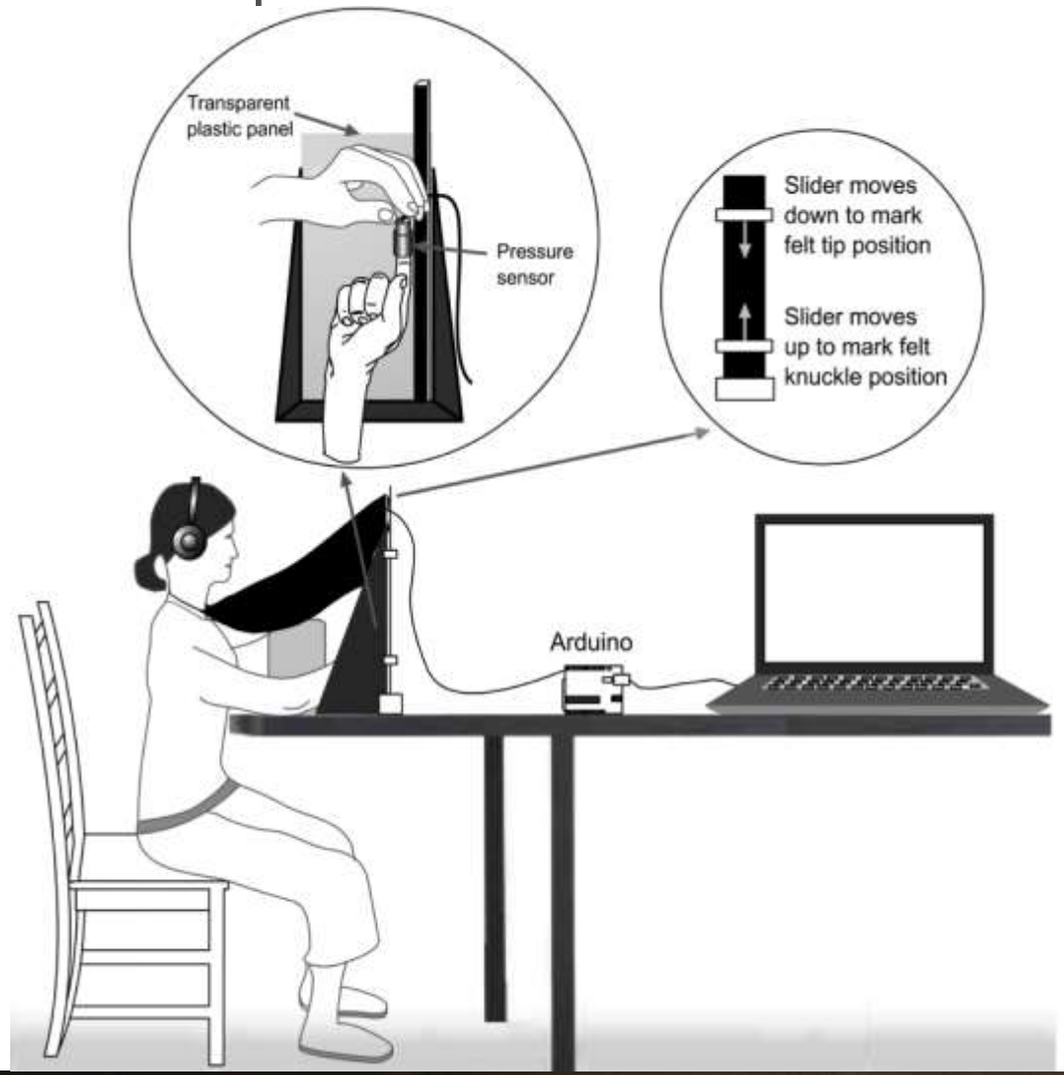
Auditory Pinocchio:

Using tones rising/falling in pitch to alter the length of a represented body part

Drawing on the well-known capacity of changes in pitch to elicit impressions of motion and of changes in object size (E.g. Deroy & Spence, 2013, *Cons & Cog*)

The experiment

Tajadura-Jiménez et al, 2017, *Scientific Reports*

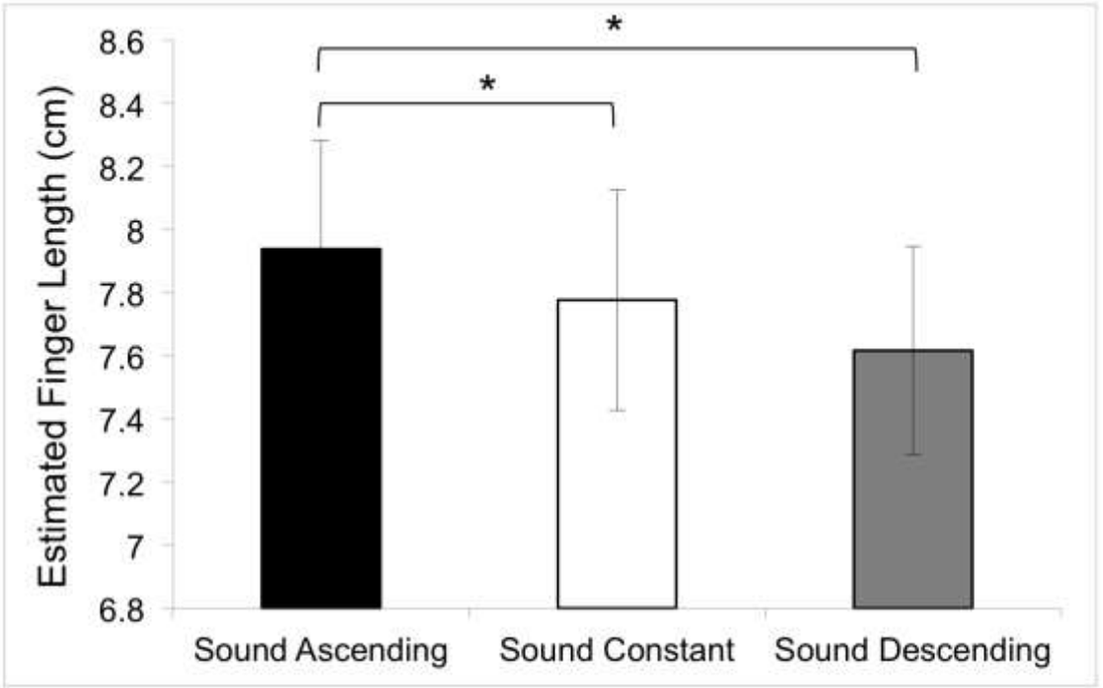


Sound Type

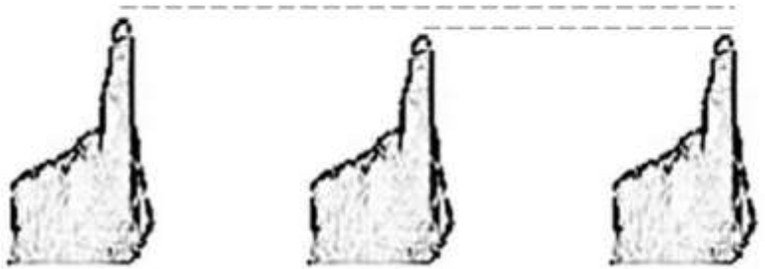
- 'ascending' tone: 700 to 1200 Hz
- 'descending' tone: 700 to 200 Hz
- 'constant' tone: 700 Hz

Results

Tajadura-Jiménez et al, 2017,
Scientific Reports



Typical visual matches



Interim summary – Effects of sound on…

- Previous research has found that body representations are flexible.
- They can be modified by visual or tactile cues, and by sound cues (our previous work), but these are most often realistic.
- Finding the effect with an arbitrary association with sound shows how ready we are to refer available information to ourselves.

Represented finger length

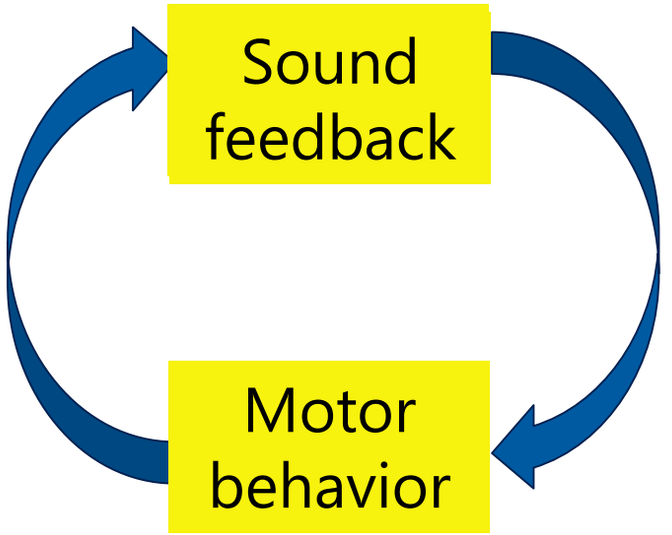
Tajadura-Jiménez et al, 2017, *Scientific Reports*

To take away: Multisensory perception & plasticity of mental representations

- Human perception is **multisensory and plastic**.
- Multisensory integration is central to **adaptive behavior**.
- Studies on multisensory perception can **inform the design of intelligent systems**, that can:
  - Form accurate representations of the world.
  - Act better.
- Body-representation depends on auditory and other sensory information. **Body-representation is supramodal.**
- Changes in body-representation connect to changes in behaviour & emotion → **framework to study body-representation.**

To take away: Sensory-motor loops

- Similar principles apply to object perception during body-object interactions.
- Surface interaction sounds can alter object-representation, and influence motor behavior and emotion.
- **Sensory-motor loops**: planning actions, sensory expectations and discrepancies leading to adapt behavior (E.g. Wolpert and Ghahramani, 2000, *Nat. Neurosci.*).



It's not just what we touch but also how we touch it
Bianchi-Berthouze & Tajadura-Jimenez, 2014, *CHI*.

Thank you for your attention! Questions?

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