Multisensory perception

Malika Auvray
Institut des Systèmes intelligents et Robotique
Sorbonne Université
CNRS UMR 7222
Paris, France

Outline

1. From sensation to perception
2. Attention
3. Spatial perception
4. Multisensory interactions
5. Sensory substitution

Criteria for a taxonomy of our senses

Dedication

Behaviour

(Morgan, 1977)

Stimuli

(Keeley, 2002)

Neurobiology

(Grice, 1962)

Properties

Qualitative experience

1. Presentation of sensory substitution devices

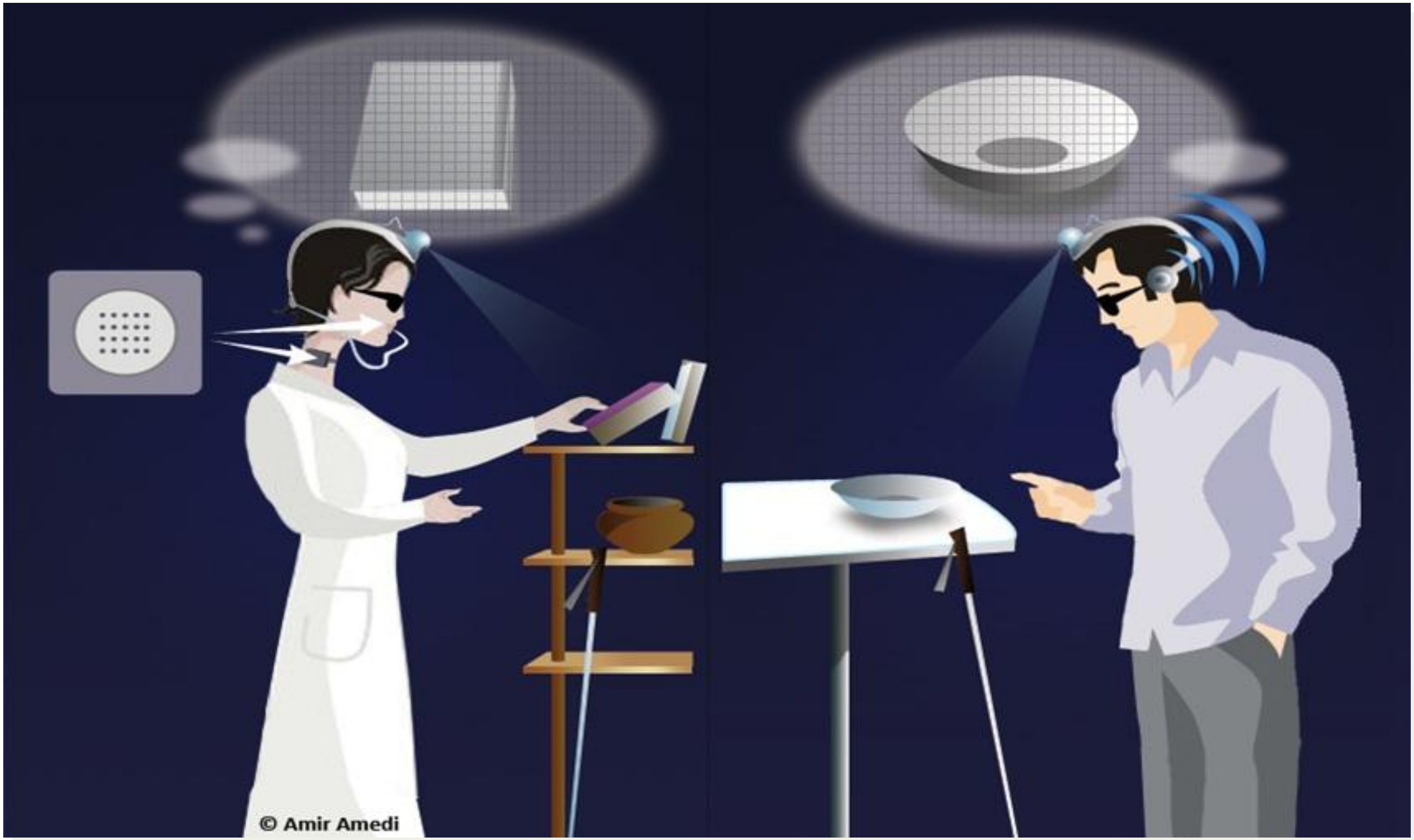
2. To see or not to see? A criterial approach

3. Hasn’t the dilemma been forced on us?
SSDs beyond the perceptual assumption

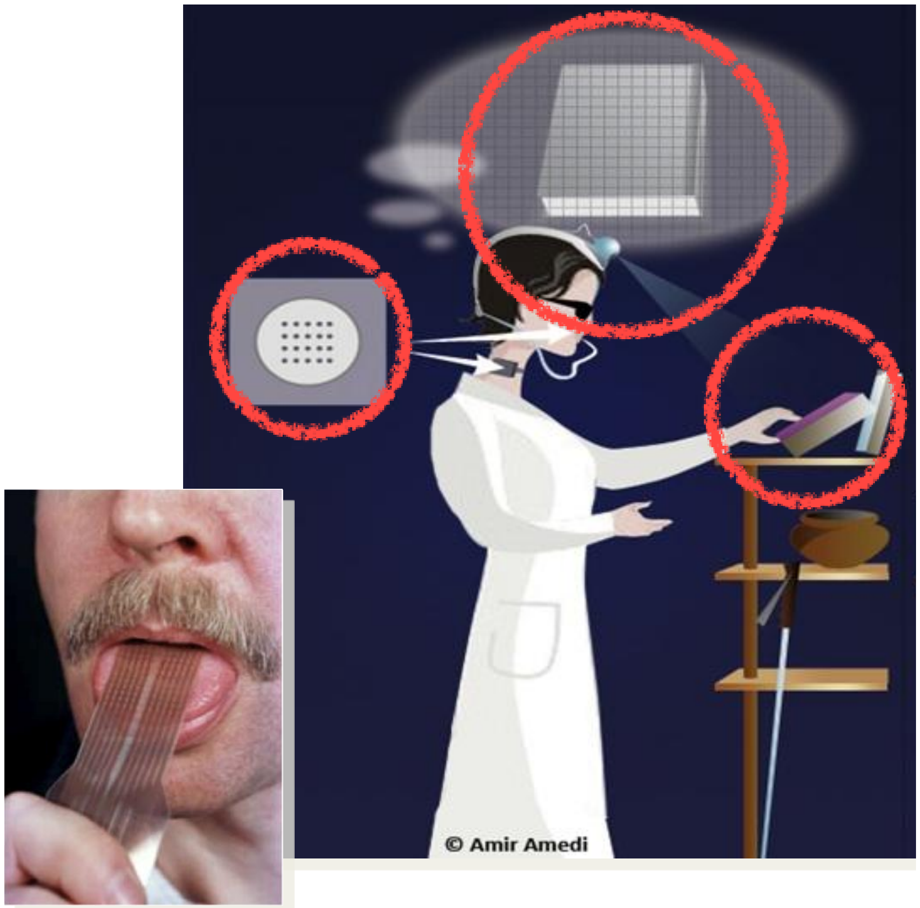
4. Optimisation of sensory substitution device: a balance between learning and intuitive coding

1. Presentation of sensory substitution devices

Sensory substitution devices



Visual-to-tactile SSDs



Tongue Display Unit (Bach-y-Rita & Kercel, 2003)

Sensor

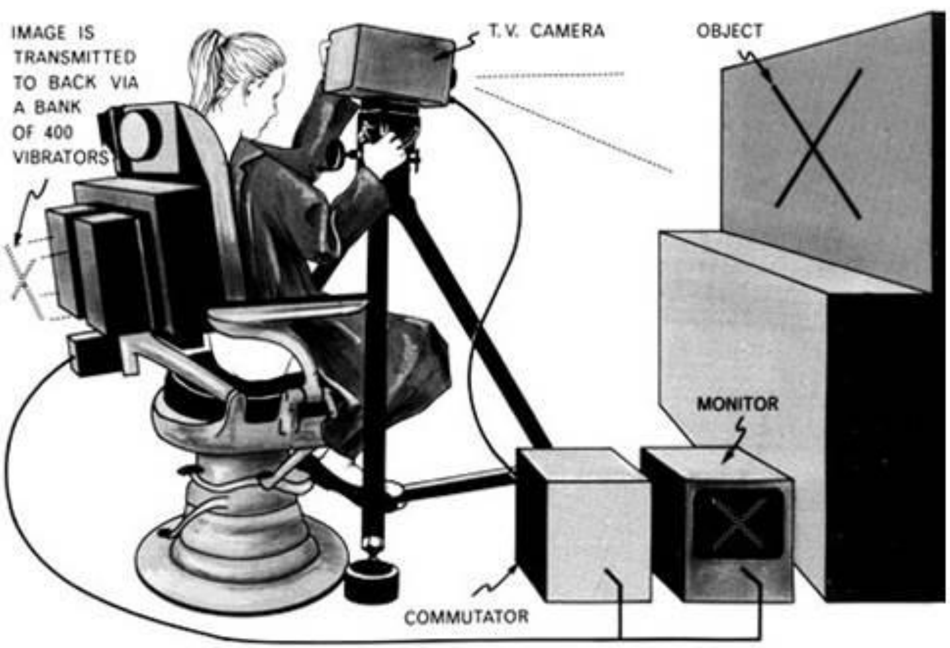
↓

Conversion device

↓

Tactile stimuli

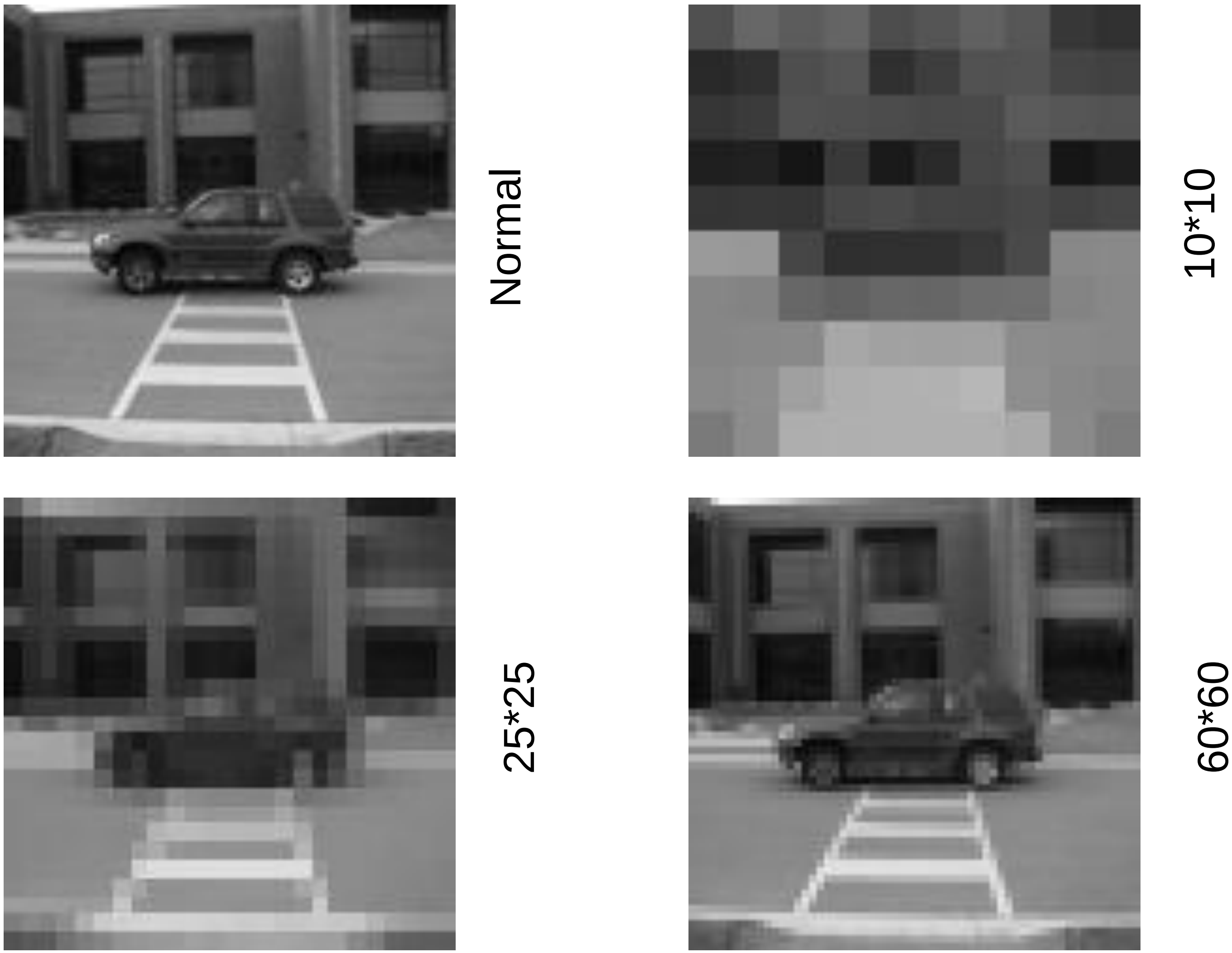
Visual-to-tactile SSDs



TVSS – V1

Tongue Display Unit

The images below demonstrate how a single frame from the video camera is represented on the skin. 10x10 grid displays 30 frames per second (wicab).



The Optacon (Optical TActile CONverter)

Telesensory Systems Inc.

- Device for reading
- The most commercialised

The tactile stylus
(Costech, Compiegne)

- Used for the recognition of graphs in maths classes

The tactile substitution of proprioception

• Persons with bilateral vestibular damage (BVD) have little access to proprioceptive information.
They stand & walk with difficulties while making enormous conscious efforts to integrate a range of visual and tactile cues

• The brain port uses a head-mounted accelerometer and an electrotactile matrix placed on the tongue (TDU).

• Patients with BVD using the brain port are able to adapt to the new source of data in few seconds. Head motion studies showed that the stability they obtain approaches that of persons with normal vestibular functions (Tyler et al., 2003).

The substitution of pain

- Patients suffering from leprosy do not feel anything in their leprosed members and the absence of pain results in self-generated damages.

- Brand & Yancey (1993) built a system that alerts their users of damaging activities in their leprosed limb thanks to pressure sensors located in an intact part of the body.

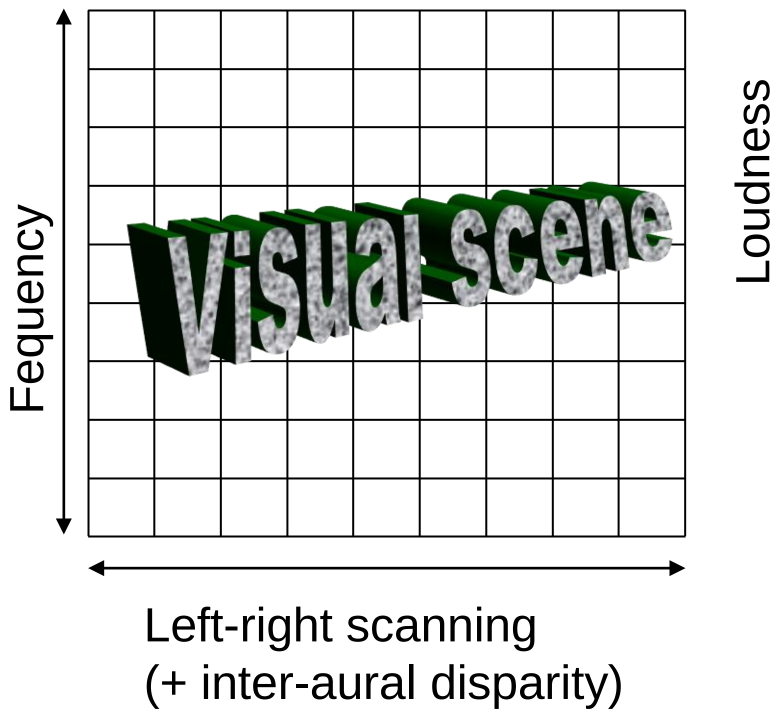
→ The use of such a device did not prove that useful: The patients, having access only to abstract information, were not forced to react and come to ignore the signals.

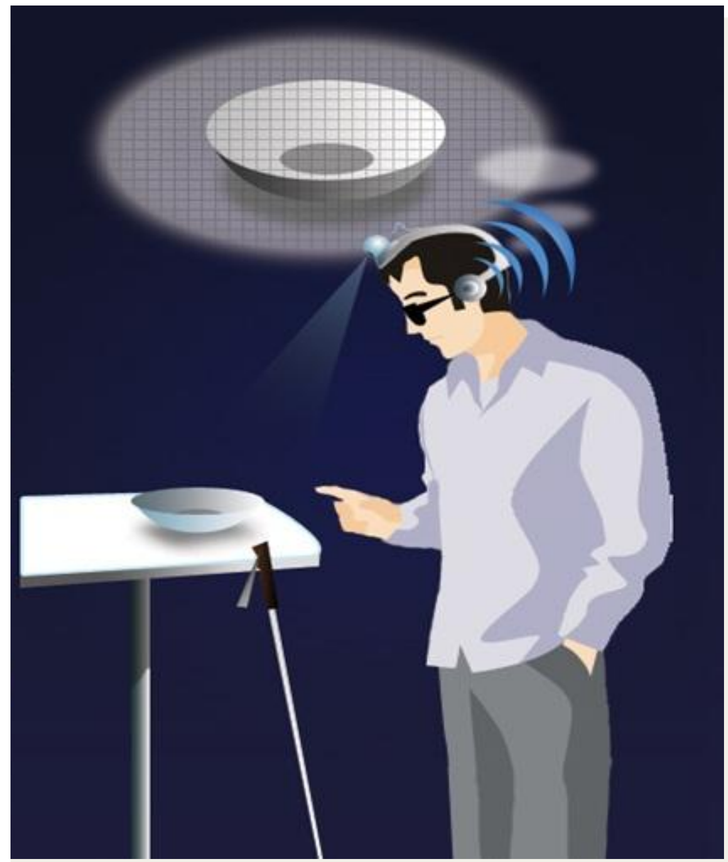
When the alerting signal consists of a painful high-voltage and low current electric shock displayed on an intact part of the body:

1- The patients involuntarily interpreted the signal less as a danger to avoid than as a kind of punishment.

2- The system remained under the patients' control who could always switch it off, especially if the signal lasted long; whereas natural pain cannot be switched off and persists as long as the danger threatens.

Visual-to-auditory SSDs

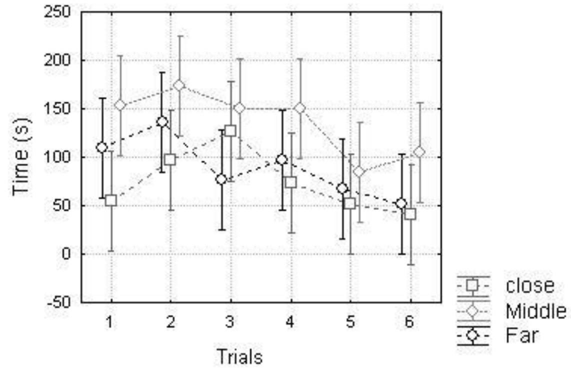


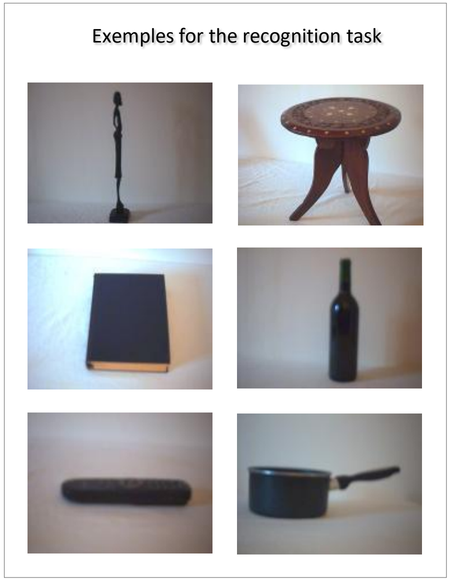


Meijer, 1992

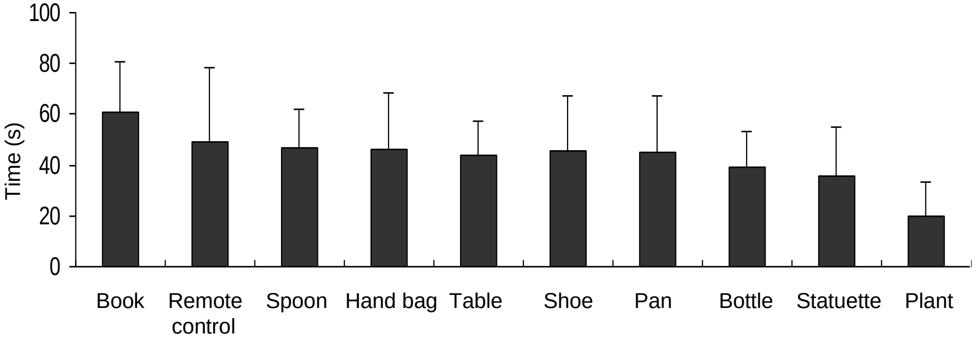
Learning to perceive with the Voice (Auvray et al., 2007)

Displacement and pointing





Recognition and categorization



Echolocation devices

Sonic glasses et Sonic torch (Kay, 1985)

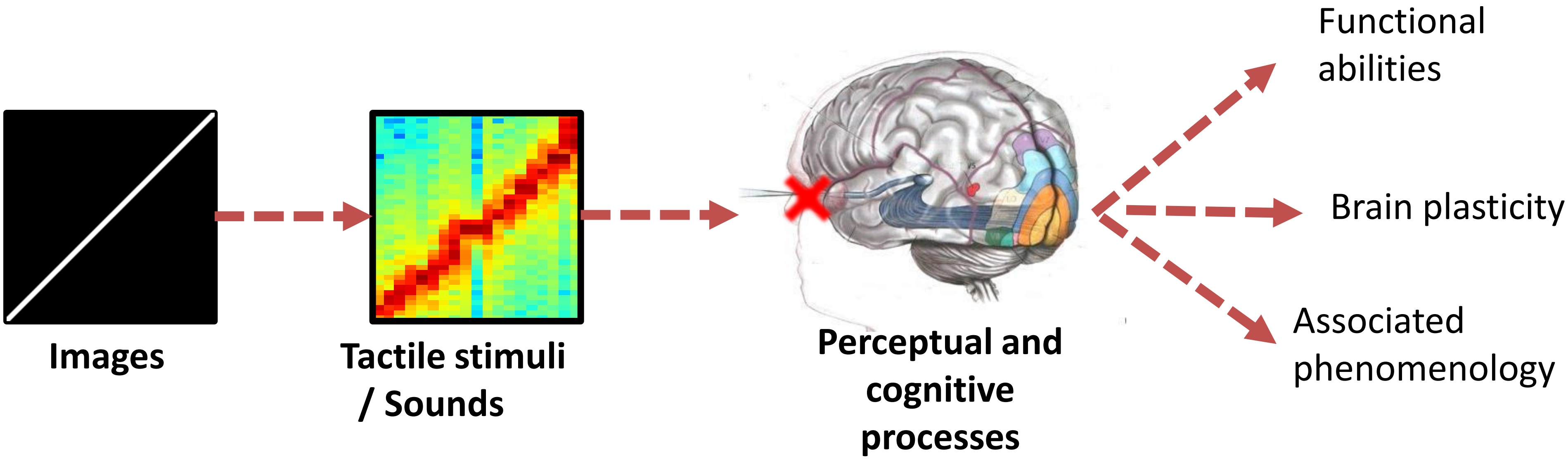
Eye cane (Amedi, 2012)

- Same principles as sonar. An ultrasound source/receptor emits a stream of FM signals. Receptors use telemetry calculating the time taken by an ultrasonic signal to reach an object and return by reflection to the generator.

- The distance between the source and the obstacle is then converted into sounds (such as frequency or delay) to provide information about the distance and position of a distant object.

2. To see or not to see? A criterial approach

Sensory substitution devices



To see: Visual model dominates the psychological literature

- White, B. W., Saunders, F. A., Scadden, L., Bach-y-Rita, P., & Collins, C.C. (1970). Seeing with the skin. Perception & Psychophysics, 7, 23-27.

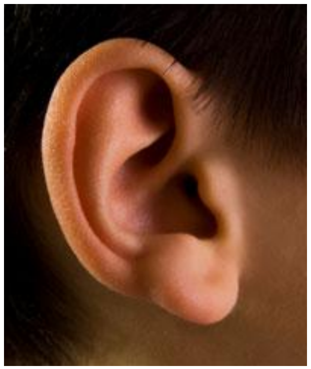
- Bach-y-Rita, P., Tyler, M. E., & Kaczmarek, K. A. (2003). Seeing with the brain. International Journal of Human-Computer Interaction, 2, 285-295.

To see: The visual model in the press & philosophy

- “Sensory hijack: rewiring brains to see with sound. A new device that restores a form of sight to the blind is turning our understanding of the senses upside down” (New Scientist, 17.08.2010).

- “A person making intelligent use of a TVSS (Tactile Vision Sensory Substitution) may be said to be seeing (though perhaps only dimly) features of his environment.” (Heil, 1983, p.16).

Visual processes?



Dominance

- Perception remains in the *substituting* modality
- Auditory (e.g., with the Voice) or tactile (e.g., with the TVSS)
- Humphrey, 1992; Keeley, 2002; Block, 2003; Prinz, 2006

Deference

- Perception goes to the *substituted* modality
- Visual (e.g., with the Voice or the TVSS)
- Cole, 1990; Dennett, 1991; O'Regan & Noë, 2001; Hurley & Noë, 2003

Functional data

- **Visual-to-tactile substitution devices**

Localization tasks (Janson, 1983; Lemaire, 1999)

Simple form recognition (Kaczmarek & Haase, 2003; Sampaio et al., 2001)

Reading (Bliss, et al., 1970; Craig, 1981, 1983; Loomis, 1974, 1981).

- **Visual-to-auditory substitution devices**

Object localization (Prloux et al., 2008; Renier et al., 2005)

Navigation tasks (Maidenbaum et al., 2014)

Form recognition (Arno et al., 1999, 2001; Auvray et al., 2007; Brown et al., 2014; Cronly-Dillon et al., 1999, 2000; Pollok et al., 2005)

Complex shapes and natural images recognition (Striem-Amit et al., 2012)

Texture recognition (Stiles & Shimojo, 2015)

Partially overlapping shapes (Reich & Amedi, 2015)

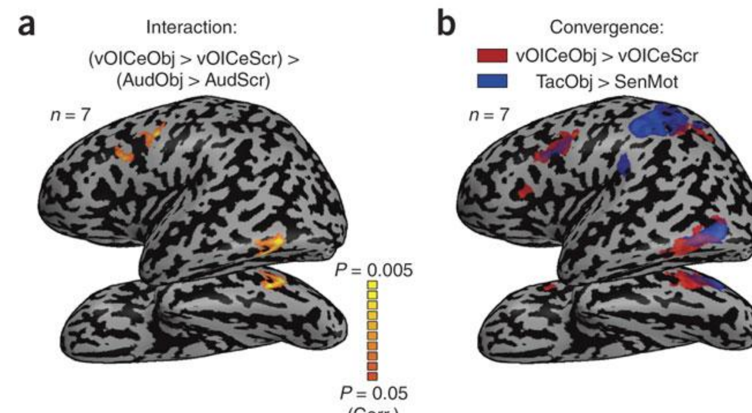
Sensitivity to visual illusions (Renier et al., 2006)

Brain imaging data

Increased activation of V1 after practice with visual-to-auditory (e.g. De Volder et al., 1999; Renier et al., 2005) and visual-to-tactile substitution devices (e.g. Ptito & Kuppers, 2005; Ptito et al., 2005).

However, one brain area can sustain different functions in blind and sighted. TMS on V1 before and after practice. Some participants report tactile sensations on the tongue (3 / 8 EB and 1 / 5 LB). The subjective experience associated with an activity in the visual cortex after sensory remapping can be tactile and not visual (Kupers et al., 2006).

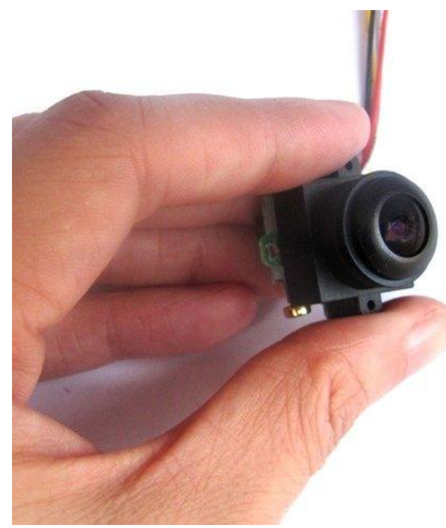
Activation beyond primary sensory areas (Amedi et al., 2007).



Stimulus

	Vision	Audition
Receptors		
Stimulus	Lightwave	Soundwave
Proper object	Distant coloured shapes	Sounds
Subjective character	Images	Auditory

Proximal source



Distal source

Same distal source of information

Properties: distant perception

	Vision	Audition
Receptors		
Stimulus	Lightwave	Soundwave
Proper object	Distant coloured shapes	Sounds
Subjective character	Images	Auditory

Option 1: Incomplete visual object (distant shape but no colour)

Option 2: Non canonical auditory object (e.g. we can hear the size of a dog behind the fence)

Option 3: Shape as amodal

Distant perception?

Properties: distant perception

- Contrast between the distal character of vision and the proximal character of touch. Distal attribution as a criterion of device integration.

> “Very soon after I had learned how to scan, the sensations no longer felt as if they were on my back, and I became less and less aware that vibrating pins were making contact with my skin. By this time objects had come to have a top and a bottom; a right side and a left; but no depth - they existed in an ordered two dimensional space.” (Guarniero, 1974, p. 104 - quoted by Leon, 2011, p. 165; Heil, 1983; 2003, p. 228, 2011, p. 288; Peacocke, 1983, p. 15)

- After training users of the TVSS no longer feel tactile stimulation on the skin bus directly localize object as being in front of them.

Distal attribution – Siegle & Warren, 2010

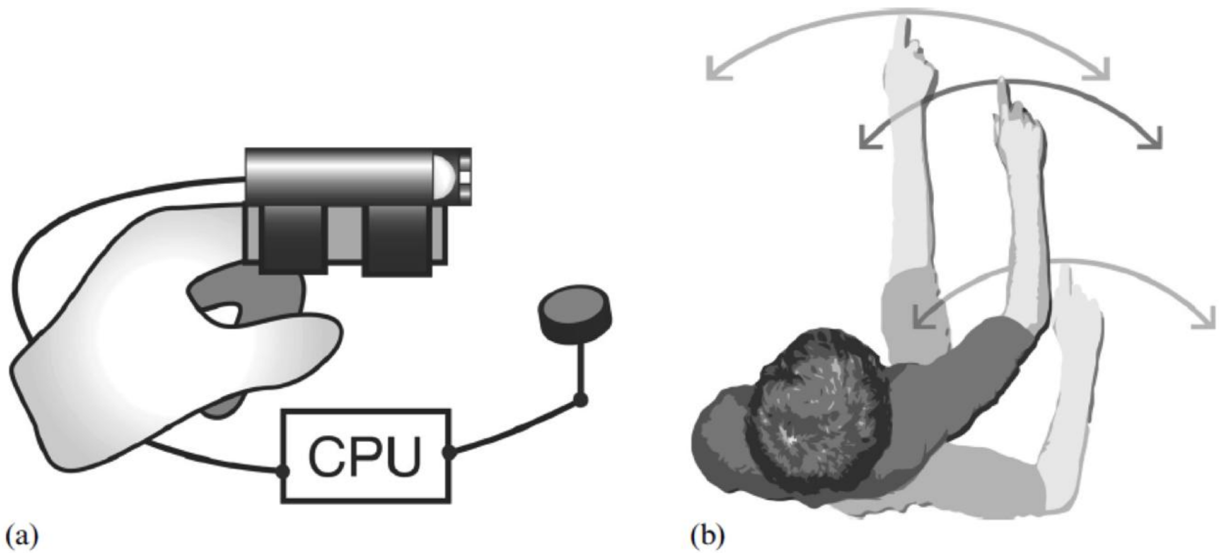


Figure 2. (a) The sensory substitution device used in the experiment. Photodiode on the index finger transduces light from the target and drives a circular vibrating motor on the subject's back. (b) Pattern of arm movements participants were instructed to make when exploring the target.

✓ Investigation of distal attribution based on a perceptual strategy

✓Blindfolded participants observed a target light using a device consisting of a finger-mounted photodiode that drives tactile vibration on the back.

✓ With the blindfold off and the target removed, participants moved a reference object to match the perceived egocentric distance of the target.

Distal attribution – Siegle & Warren, 2010

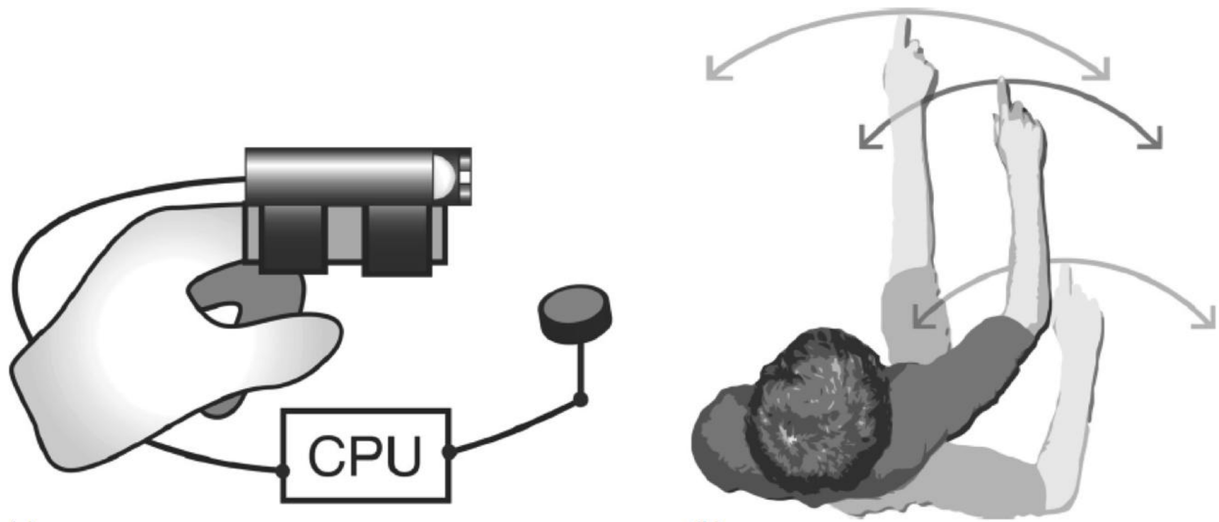


Figure 2. (a) The sensory substitution device used in the experiment. Photodiode on the index finger transduces light from the target and drives a circular vibrating motor on the subject's back. (b) Pattern of arm movements participants were instructed to make when exploring the target.

✓ Better performance for participants instructed to attend to the distal target vs. proximal variables.

✓ "The results experimentally confirm that distal attribution can occur in sensory substitution, based on a perceptual strategy rather than on an explicit cognitive strategy" (Siegle & Warren, 2010, p. 208).

✓ Nota: differences in task difficulty.

Qualitative experience

	Vision	Audition
Receptors		
Stimulus	Lightwave	Soundwave
Proper object	Distant coloured shapes	Sounds
Subjective character	Images	Auditory

Phenomenological data

- Visual phenomenology / acquired synesthesia? (Ward & Meijer, 2010, 2 blind Ps).

- Not necessarily associated with a visual nor with an auditory experience + task dependent (Auvray et al., 2007, 6 sighted Ps).

	Localization tasks	**Recognition and categorization tasks**
P 1	Between visual and another sense (smell)	Tactile
P 2	Visual	Between visual and tactile
P 3	Another sense (sonar)	Auditory
P 4	Another sense (sonar)	Auditory
P 5	Visual	Auditory
P 6	Visual	Visual

Subjective character: the question of emotions

- In spite of all the possibilities allowed by SSDs, it seems that the emotions associated to this new perceptual modality are missing.

- The shapes perceived in one sensory modality are not directly associated to pleasures or pain felt while perceiving the same shape in another sensory modality (Lenay et al., 2003).

- Is it due to the device itself?

- Similar reports of absence of emotion and meaning felt by persons blind from birth who recover sight by removal of cataract. There are no affective qualities associated to colors and seeing faces is not associated to any emotional content (Gregory, 2003).

Subjective character: the question of emotions

❑ Emotions and learning

- Hypothesis: Emotions could be developped with a longer or early use of the device. The use of the device from childhood might allow the acquired information to be included in an affective context. Attemps of equiping babies with TVSS suggested positive results (e.g., smiles when seeing their mother, Bach-y-Rita et al., 2003).

❑ Emotions and intersubjectivity

- The literature always reports observations on purely individual use of SSDs. The user is surrounded by sighted persons, but is isolated in his particular mode of perception.

- Affective qualities are not contained in the stimuli, that we would pick up as if it was just information processing, but they are constructed by a community of users who share the same means of perception.

- The existence of a community of users might favour the constitution of common values associated to perceptions (Auvray, Lenay, & Stewart, 2009).

Dedication

- This criterion takes into account the evolutionary history of a species in order to determine to what sensory modality a sense organ is evolutionary dedicated to.

- We ought not attribute an electrical modality to an individual unless electrical properties of the world are part of the normal environment of that individual and to which the organism is attuned (Keeley, 2002).

Dedication

- Users of visual-to-tactile substitution devices are capable of visual detection but not of visual reception: They do not carry out visual discriminations in virtue of an anatomical system that has evolved because it allows such discrimination.

→ SSDs build on an existing function in humans: seeing.

→ How can this criterion allow for novelty, i.e., the possibility for any man-made bodily extension to acquire a genuine function?

Criteria for a taxonomy of our senses

Dedication

Behaviour

Stimuli

Neurobiology

Properties

Qualitative experience

(Morgan, 1977)

(Keeley, 2002)

(Grice, 1962)

3. Hasn’t the dilemma been forced on us?

SSDs beyond the perceptual assumption

Problems with the perceptual assumption

1) The data do not not fit with only one of the 2 views

- **EX1: Neurobiology.** Increased activation of V1 after practice with visual-to-auditory (De Volder et al., 1999; Renier et al., 2005) and visual-to-tactile substitution devices (Ptito & Kuppers, 2005; Ptito et al., 2005).

But one brain area can sustain different functions in blind and sighted. Kupers et al., 2006: the subjective experience associated with an activity in the visual cortex after sensory remapping can be tactile and not visual

- **EX2: Qualitative experience**. The participants' phenomenal experience is not necessarily associated with a visual experience nor with an auditory experience (Auvray et al., 2007).

Problems with the perceptual assumption

2) The perceptual assumption overlooks important features of SSD-use and integration

- Limited integration, cognitively demanding activity
- Training built on pre-existing cognitive skills
- Activation beyond primary sensory areas (Amedi et al., 2007)

3) The perceptual assumption might explain the limited success of SSDs among blind persons

- Important discrepancies between hopes and messages from the scientific community (i.e., seeing with the skin or brain cf. Bach-y-Rita et al., 2003; White et al., 1970) and reception by potential users.

4) An alternative model includes

- Transformative aspects of SSDs. Beyond pre-existing capacities.
- A half cognitive, half perceptual skill (e.g. analogous to reading, Deroy & Auvray, 2012)

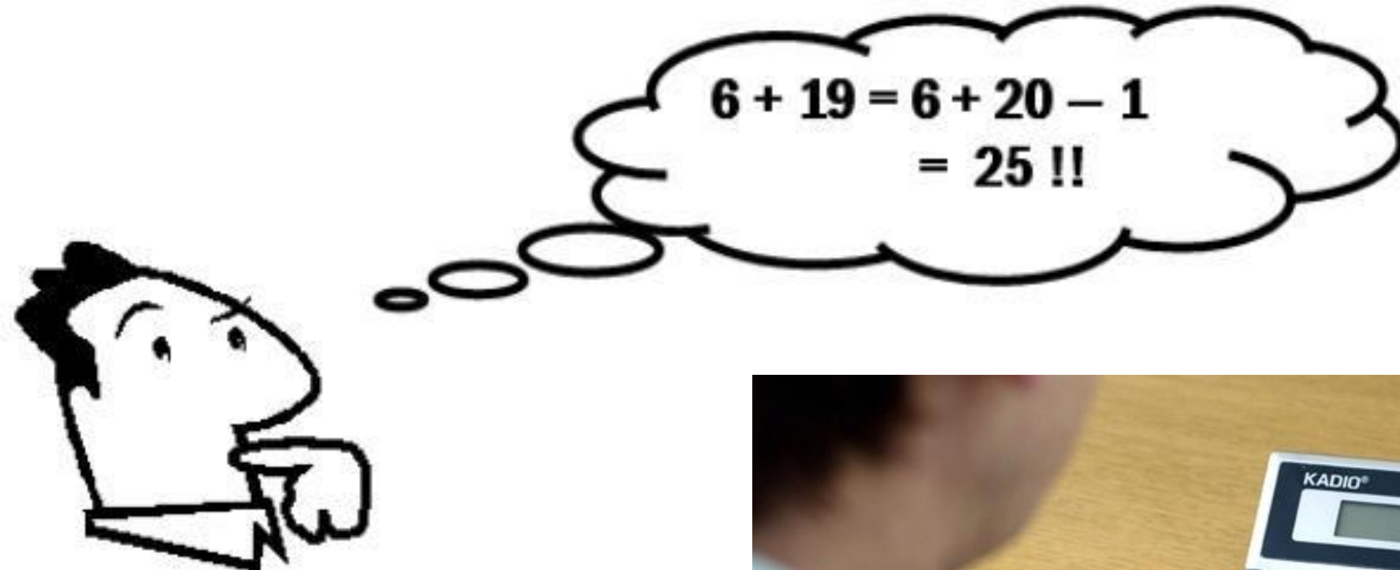
Beyond dominance and deference

• SSD-use is not equivalent to perception in an already existing sensory modality (Auvray & Myin, 2009).

• SSDs transform and extend our perceptual capacities and should be seen as tools giving rise to a novel form of interaction with the environment.

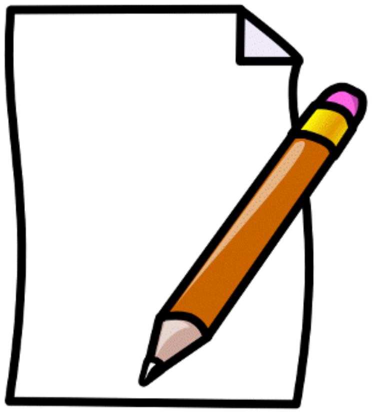
// with 'mind enhancing tools' (Clark, 2003), which provide means of expanding cognition.

Conservative view of METs



- METs as external stand-ins for already existing internal processes

Transformative view of METs



• Novel tools not only facilitate established cognitive processes, they also allow for the appearance of novel cognitive operations, which would have been impossible without them.

• Without the proper means to write down, calculate, or draw diagrams, human cognitive abilities would not have evolved to their current state.

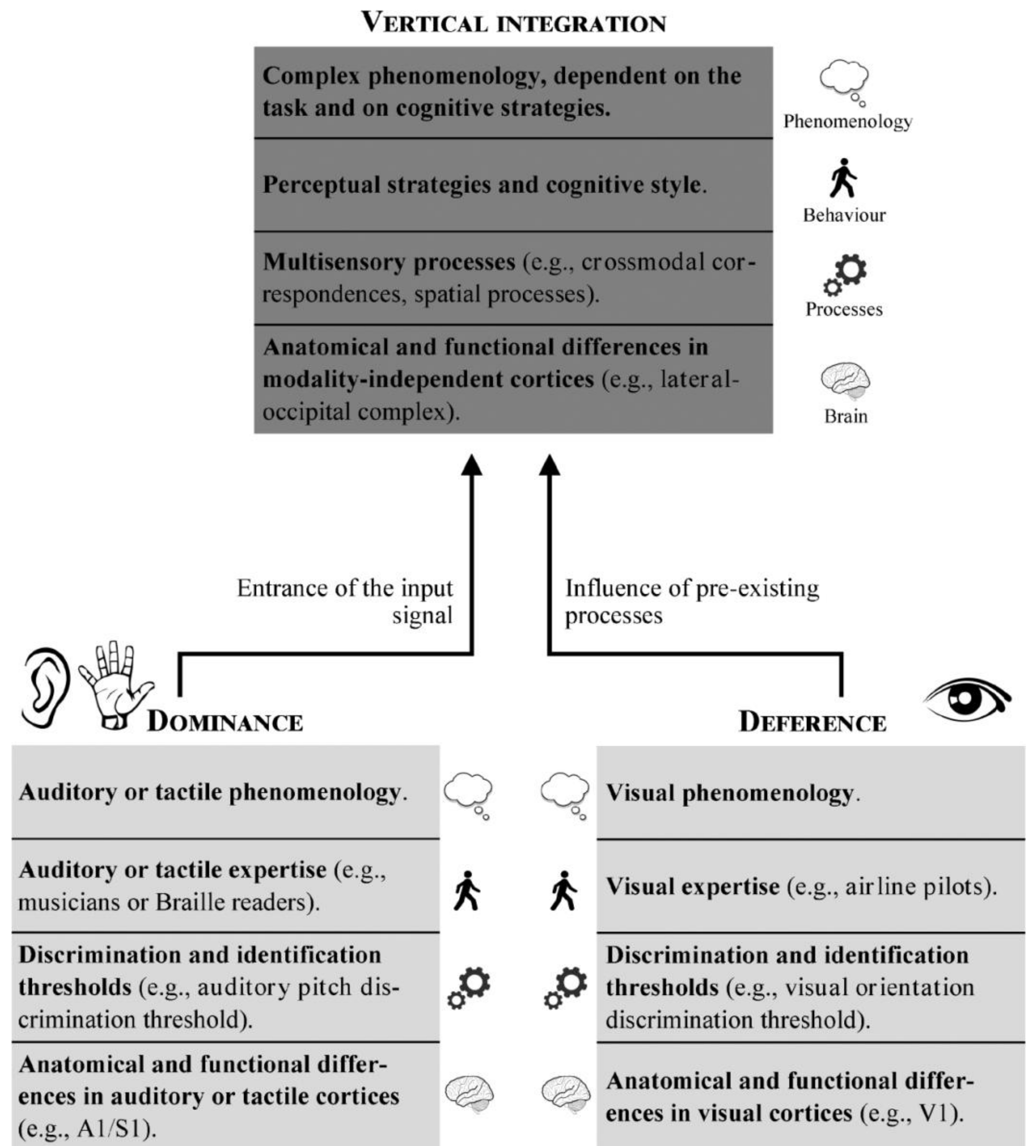
•The same applies to SSDs: They provide novel forms of interaction with the environment, which cannot be reduced to perception in one of the natural senses.

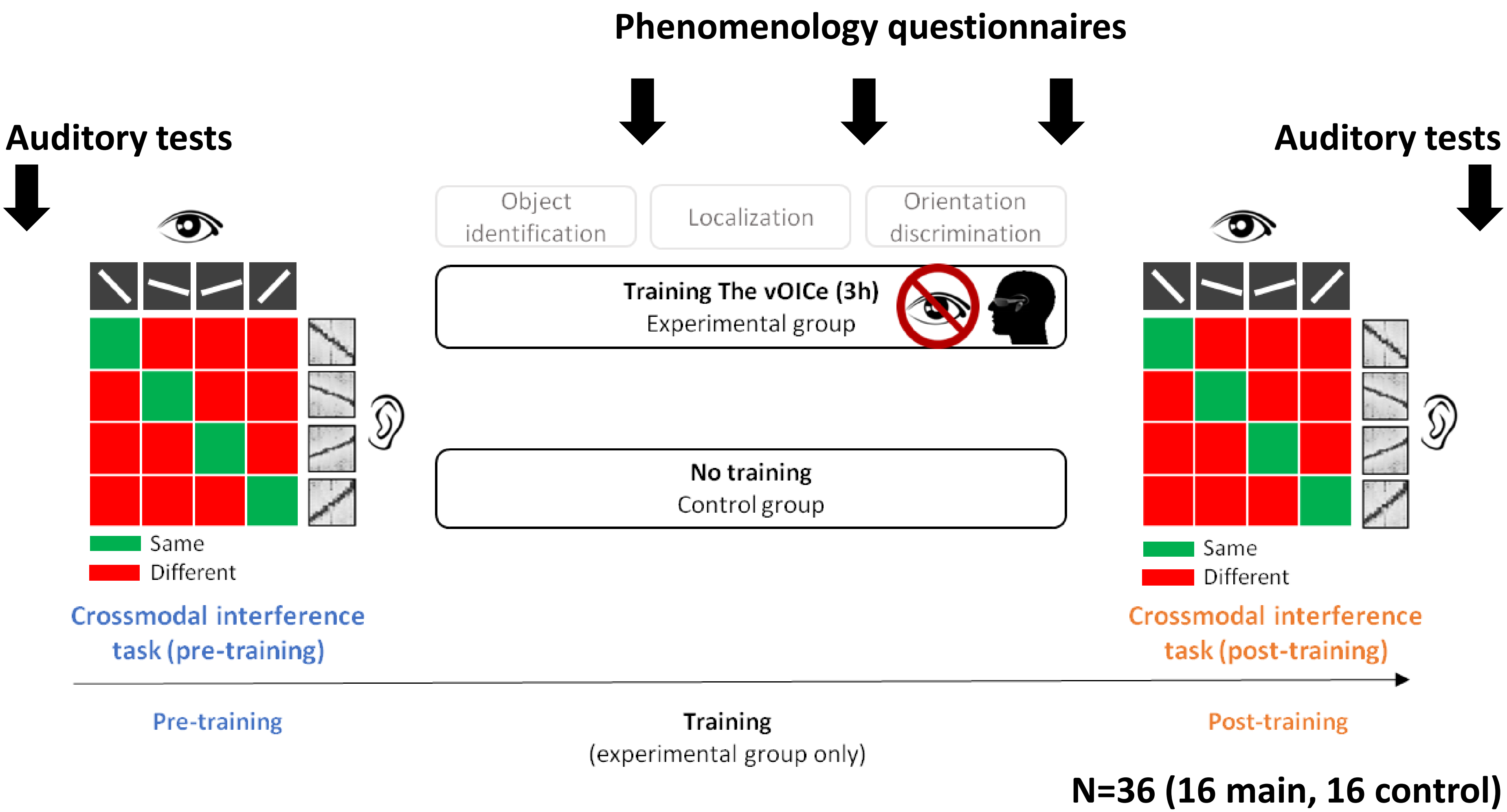
Multisensory and cognitive processings?

Vertical integration hypothesis

- ❑ Perception with a sensory substitution device is vertically integrated and involves both the substituted and the substituting modalities.

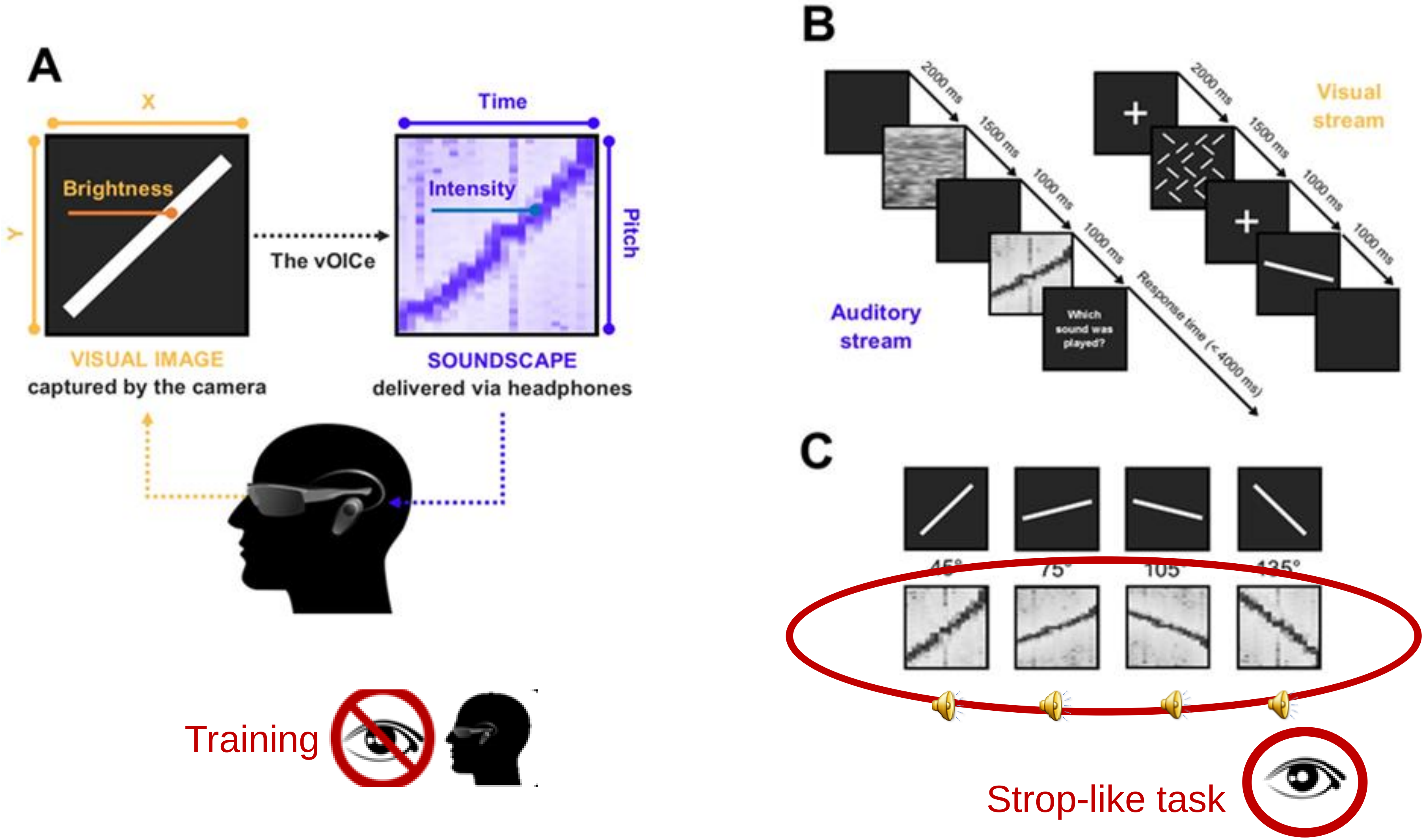
- ❑ Multisensory experience
Based on pre-existing capacities
Perceptual strategies
Individual differences
(Arnold, Pesnot-Lerousseau, & Auvray, 2017; Deroy & Auvray, 2012)





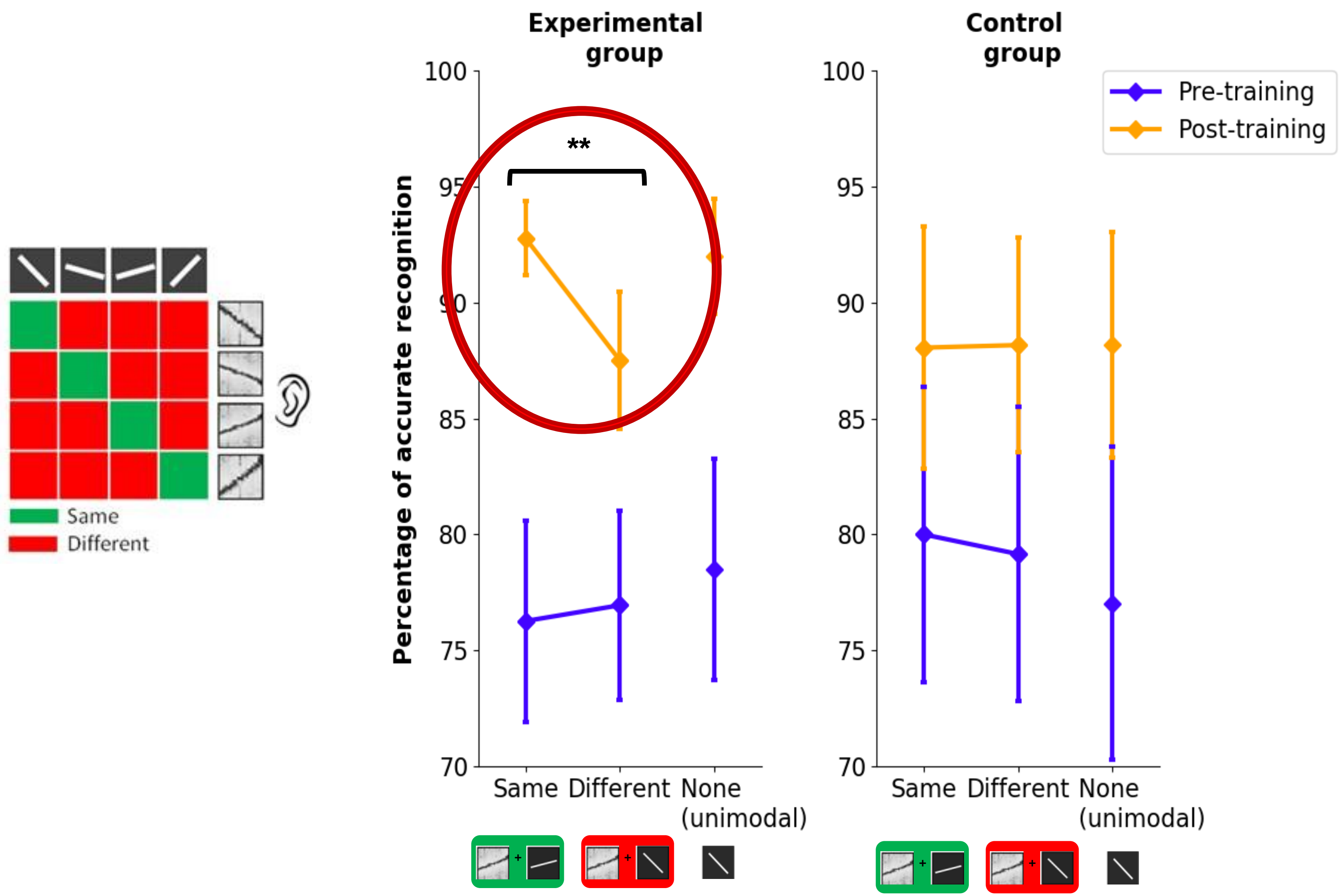
- Auditory tests before and after the main experiment: Hint (hearing in noise test) + pitch, duration, intensity discrimination tasks
- Phenomenology questionnaires after each training task with the vOICe

The crossmodal interference task

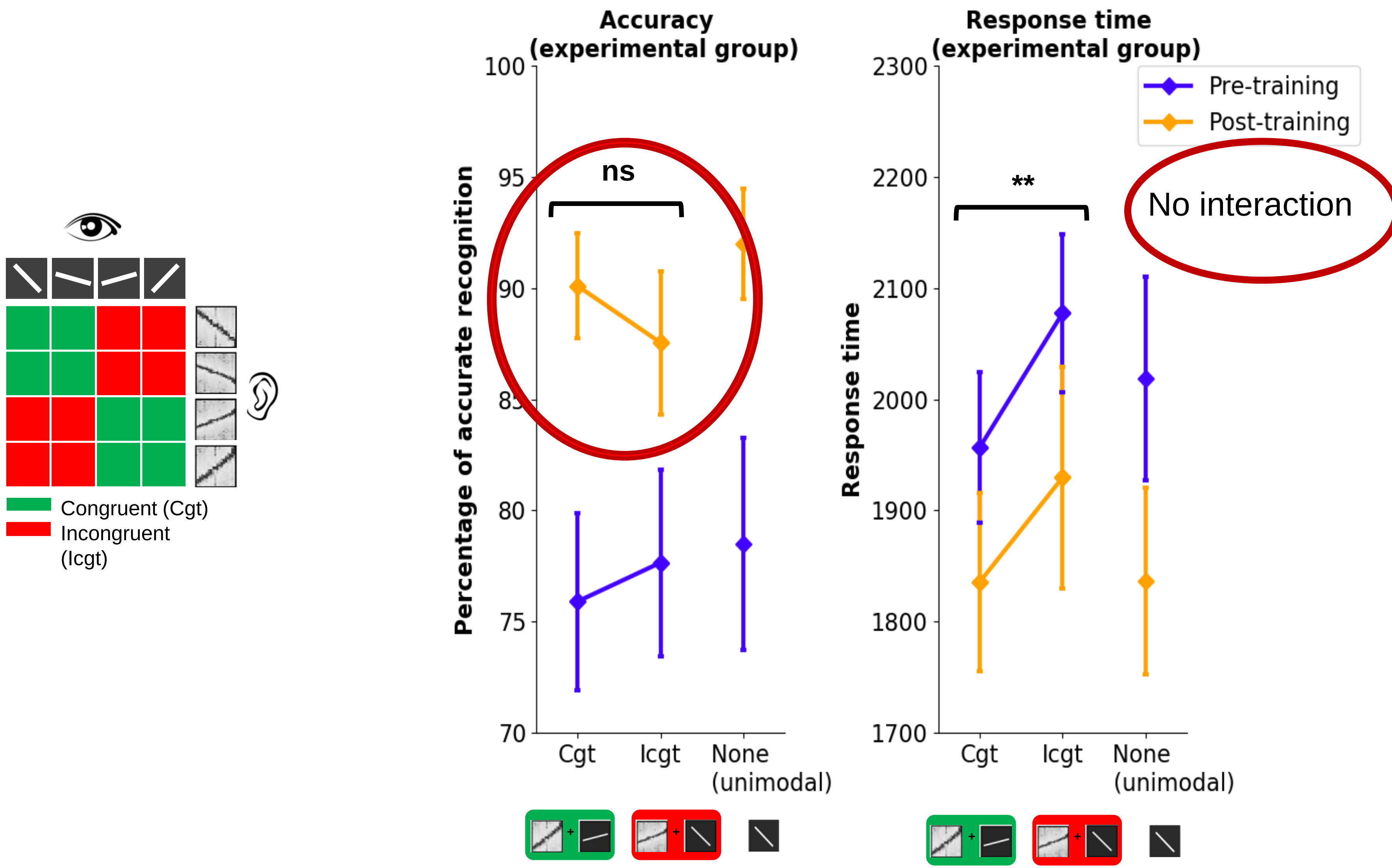


If VA sensory substitution involves visual processes, concurrent visual stimuli should interfere with the processing of the sounds.

Visual interference effect



Control for crossmodal correspondences effects



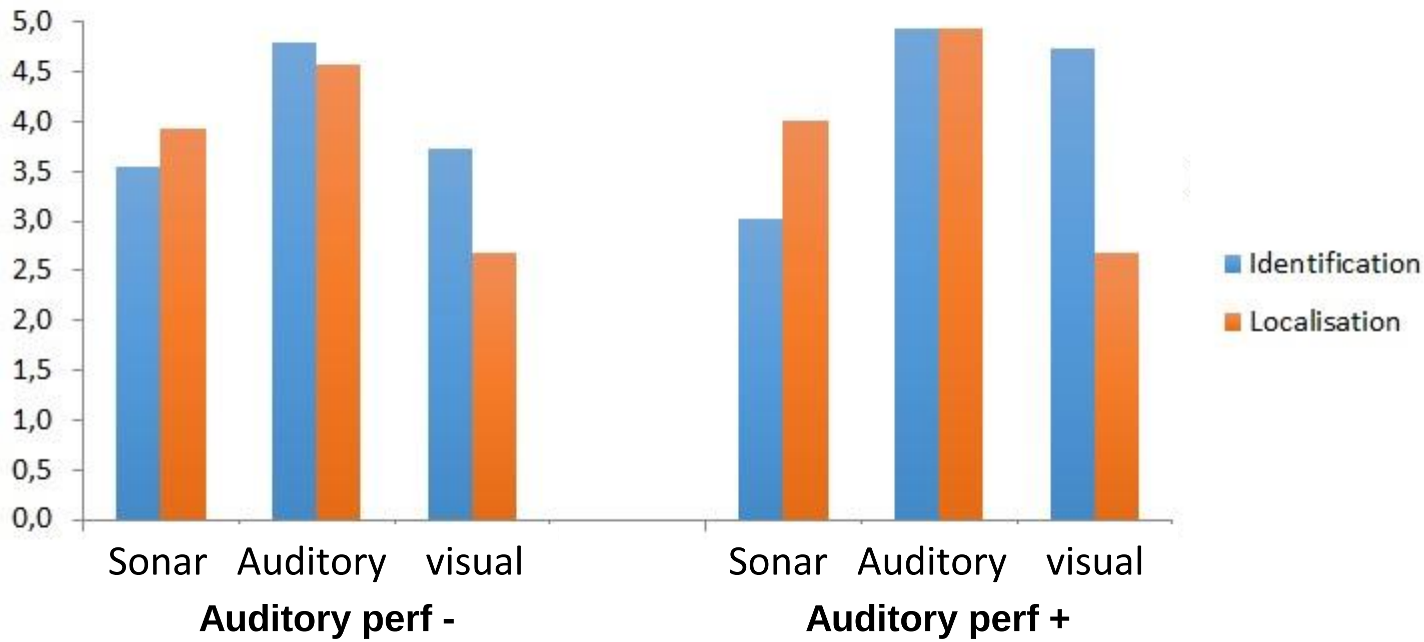
Individual differences with the Voice

• Performance with the device during the training phase is influenced by auditory abilities: the better the auditory abilities, the better the performance with the device (r = .70; p < .01).

• Individual phenomenology is not unisensory.

• It varies with auditory abilities.

For participants with high auditory abilities, task dependent: visual for the identification task; sonar-like for the localization task.



Summary

❑ Training with a SSD induces functional plasticity.

❑ The visual interference effect obtained during the auditory task suggests that trained people spontaneously evoke visual images when processing sounds from the device.

❑ Both performance during training with the device and individual phenomenology depend on low-level auditory capacities.

❑ In favor of the vertical integration hypothesis: Processes with a VA SSD find roots both in the visual and auditory sensory modalities.

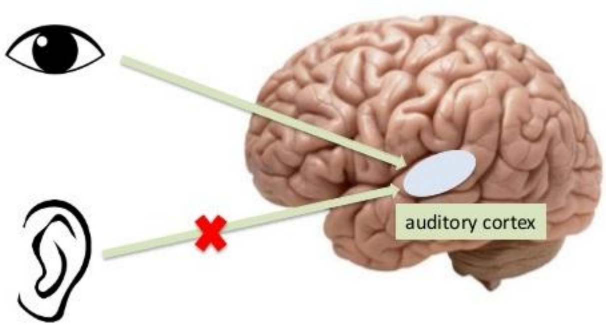
❑ In James' words, brain plasticity with SSDs allows people to see the thunder while still hearing it.

Reminder of Jame's hypothesis

- William James (1890) made the hypothesis that, if our eyes were connected to the auditory brain areas and our ears to the visual brain areas, we would “hear the lightning and see the thunder”.

- Research conducted by Mriganka Sur on neonatally rewired ferrets’ brains: visually responsive cells in auditory cortex. + in response to visual stimuli, ferrets exhibited visual rather than auditory behaviour.

- Even though visual stimuli can be processed by the auditory cortex, they remain perceived as visual rather than auditory - the lightning is still seen, not heard.



4. Optimisation of sensory substitution device: a balance between learning and intuitive coding.

Sensory substitution devices: issues

Many studies are conducted

- ❑ Important outcomes for fundamental research; e.g. cerebral & functional plasticity, multisensory perception, perceptual learning, spatial cognition

However, SSDs are barely used by blind people

- ❑ Amount of learning they require before they can be properly used
- ❑ High cognitive and attentional load they continue to demand afterwards

Multisensory and spatial processes in sensory substitution

(1) Are the codings similarly intuitive for all users?

-> Intuitive coding and crossmodal correspondences

(2) How to adapt at best learning protocols to different perceptual conditions?

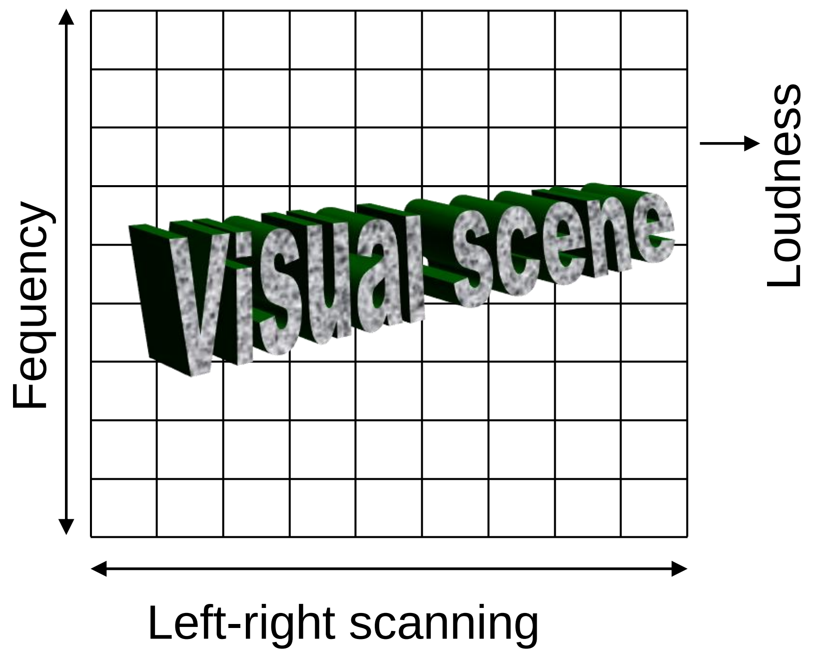
-> Perceptual learning: specific vs. generalized

(1) Are the codings similarly intuitive for all users ?

-> Intuitive coding and crossmodal correspondences

Intuitive codings of SSDs

How to code at best visual dimensions into auditory dimensions?



The Voice (Meijer, 1992)
Similar coding for Cronly-Dillon et al. (1999, 2000) + musical notes
Coding visual brightness -> auditory loudness;
visual elevation -> auditory frequency, also used for The PSVA (Capelle et al., 1998) and The Vibe (Hanneton , Durette & Auvray, 2010)

Intuitive codings of SSDs

As seen in part one, CC frequency elevation in sighted but not in blind persons.

→ Implication. Mappings used in SSDs are not necessarily intuitive for their blind users.

> **Future research:** Investigating more systematically the possible CCs in audition, vision, and touch to find the most intuitive codings for SSDs for the different categories of users.

(2) How to adapt at best learning protocols to different perceptual conditions?

-> Perceptual learning: specific vs. generalized

Specific vs. generalized perceptual learning

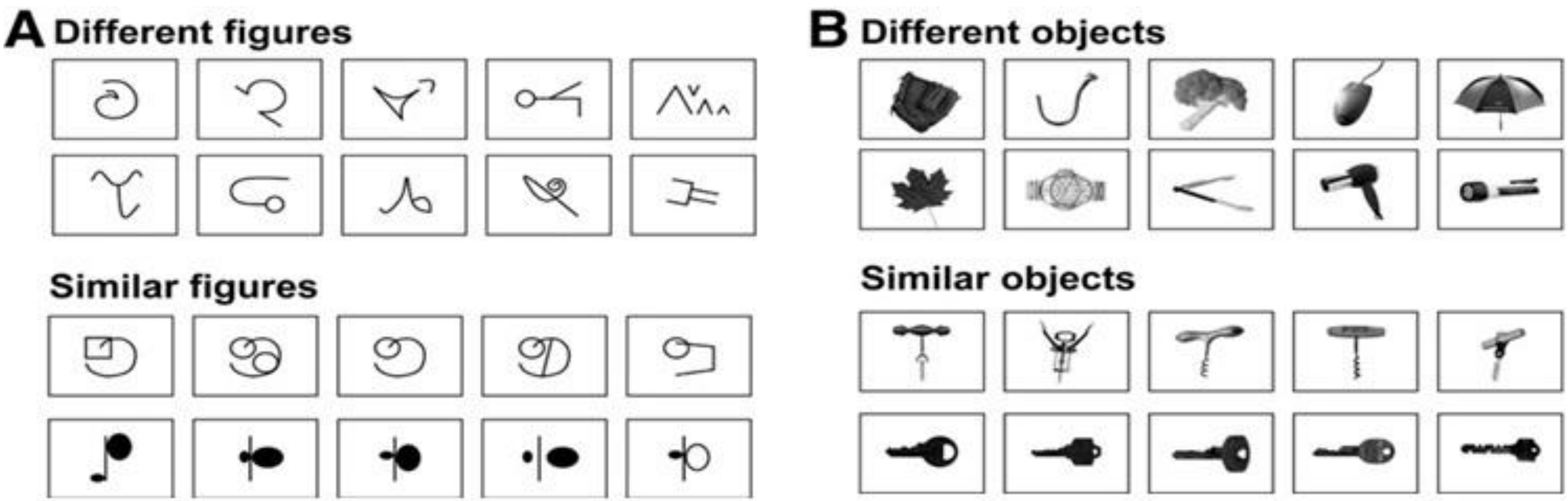
Perceptual learning: increase in perceptual performance after training.

Specific learning: increase in performance only to the learned stimuli in the same perceptual conditions (distance, position, orientation)

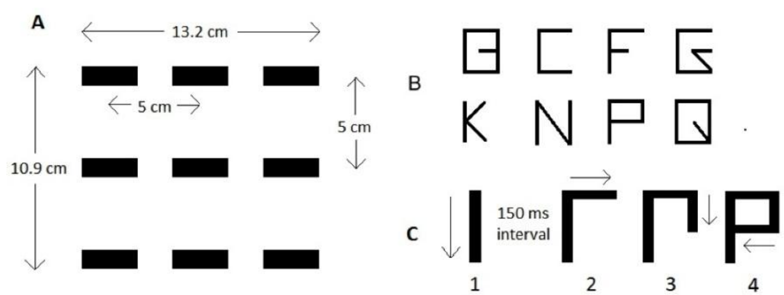
Generalized learning: extraction of perceptual rules allowing to recognize novel stimuli in novel perceptual conditions.

Specific vs. generalized perceptual learning

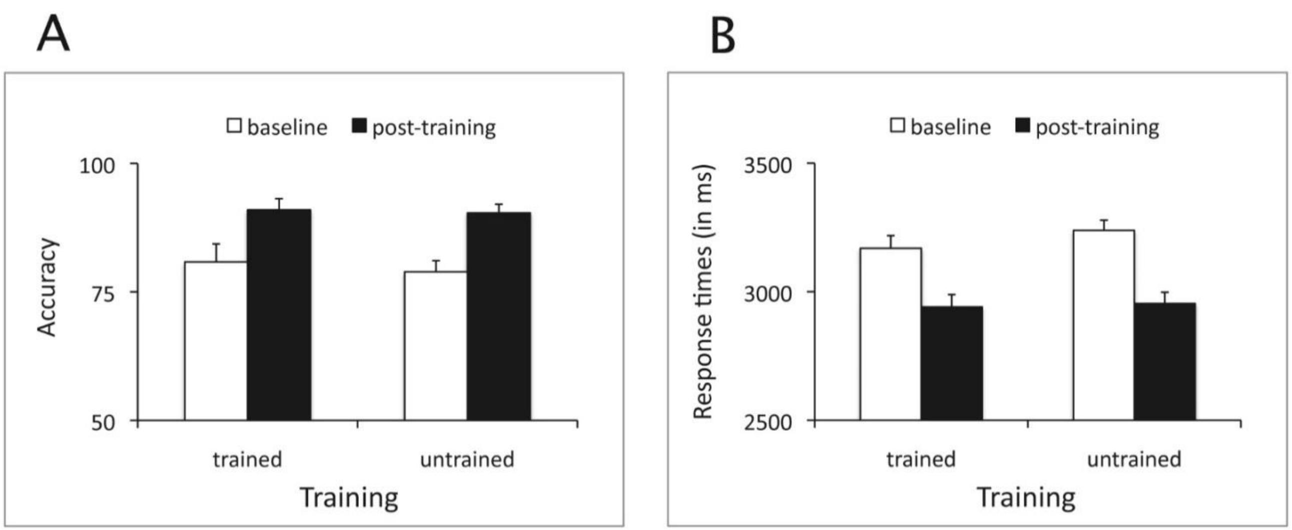
Different patterns of generalisation to novel objects: faster for object belonging to the same category as those learned during training (Kim & Zattore, 2008)



Specific vs. generalized perceptual learning



3 sessions
Baseline: belly, thigh, shin
Training on only one surface
Post training on all



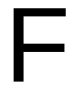
Symbol recognition is faster after training: For both trained and untrained surfaces (transfer); For both adjacent and non-adjacent surfaces.

Arnold, G., & Auvray, M. (2014).

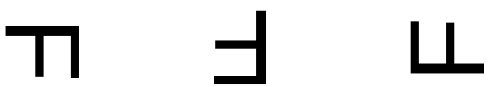
Specific vs. generalized perceptual learning

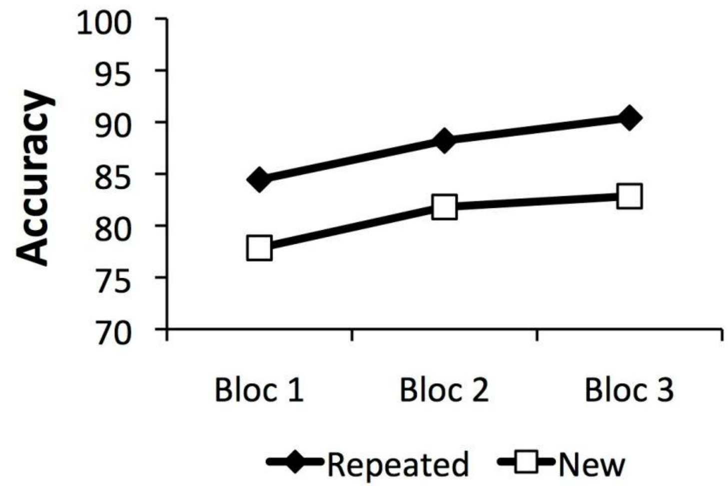
Protocols based on the alternation of repeated and novel lists of symbols (Arnold & Auvray, 2018)

Repeated orientation



New orientations





- ❑ Generalizes to novel orientations

The spatio-temporal characteristics of each symbols can be learned independently of the orientation of the stimuli on the body.

Specific vs. generalized perceptual learning

Protocols based on the alternation of repeated and novel lists of symbols

The learning of high level tactile stimuli:

- ❑ Generalizes to new stimuli
- ❑ & Generalizes to new perceptual conditions

Learning strategies differ as a function of the number of information presented during learning and on the type of features the learned stimuli have.

Optimisation: summary of the principal results

Performance & qualitative experience differ as a function of participants' perceptual abilities.
→ Learning protocols based on auditory, tactile, or visual strategies

Crossmodal correspondences differ between sighted and blind
→ Choices of intuitive codings in sensory substitution

Tactile learning transfers from one body site to another
→ Flexibility in the location of the matrix of stimuli

The generalisation of tactile learning depends on the number and type of learned informations
→ Implications for learning protocols

Studies on perception and sensory substitution devices: reciprocal contributions

Studies in the field of sensory substitution allows a better understanding of some perceptual aspects, such as:

- Multisensory interactions
- Cerebral plasticity
- Perceptual learning (of a new mode of interaction with the environment)
- Spatial cognition (and distal attribution)

In turn, studies in the fields of multisensory perception and spatial cognition allow improving the design and use of sensory substitution devices.