

Multisensory perception

Malika Auvray

Institut des Systèmes intelligents et

Robotique

Sorbonne Université

CNRS UMR 7222

Paris, France

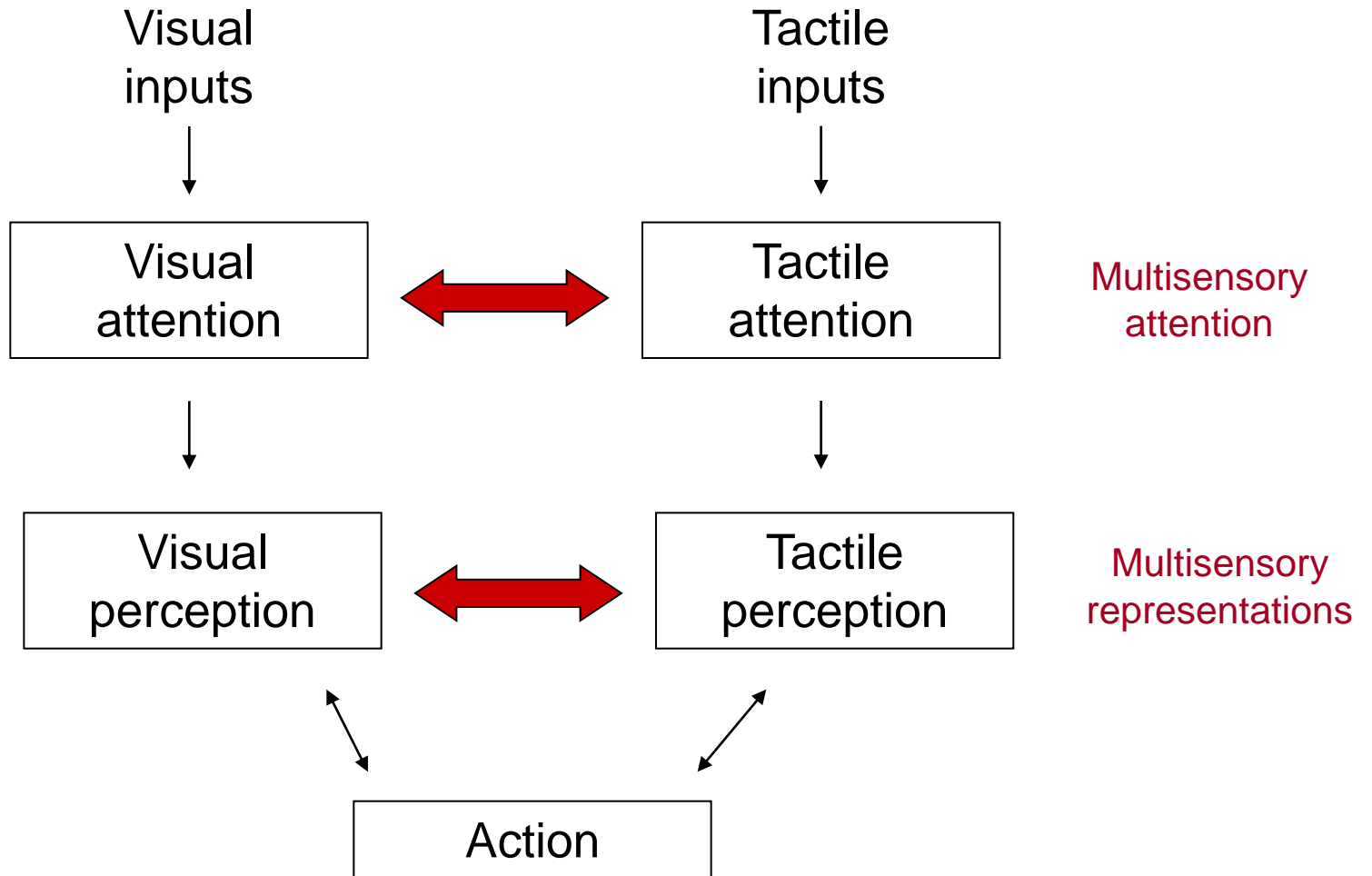


Outline

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

1. Intermodality
2. Crossmodal correspondences
3. Synesthesia
4. Multisensory attentional interactions
5. Intermodal compensation and plasticity

Modal and multisensory approaches



Visuo-auditory interactions

The ventriloquist effect / cinema

The influence of vision on the localisation of an auditory source

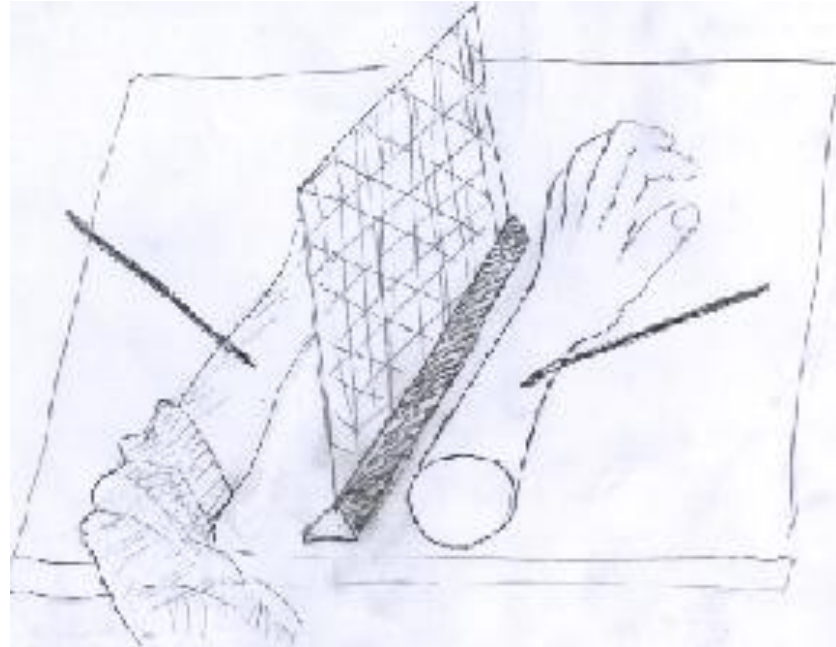


The Mc Gurk effect (McGurk & MacDonald, 1976)



The rubber hand illusion

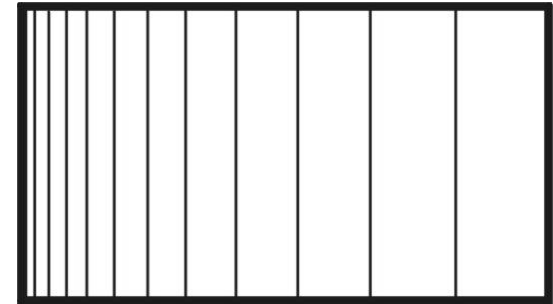
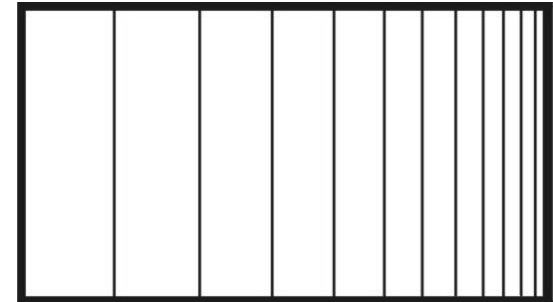
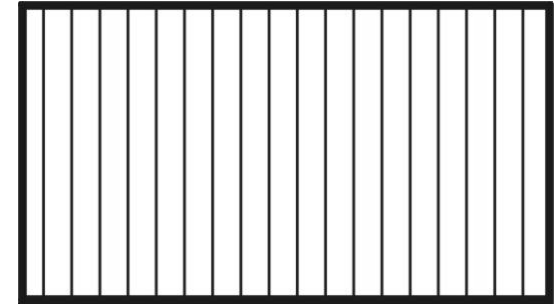
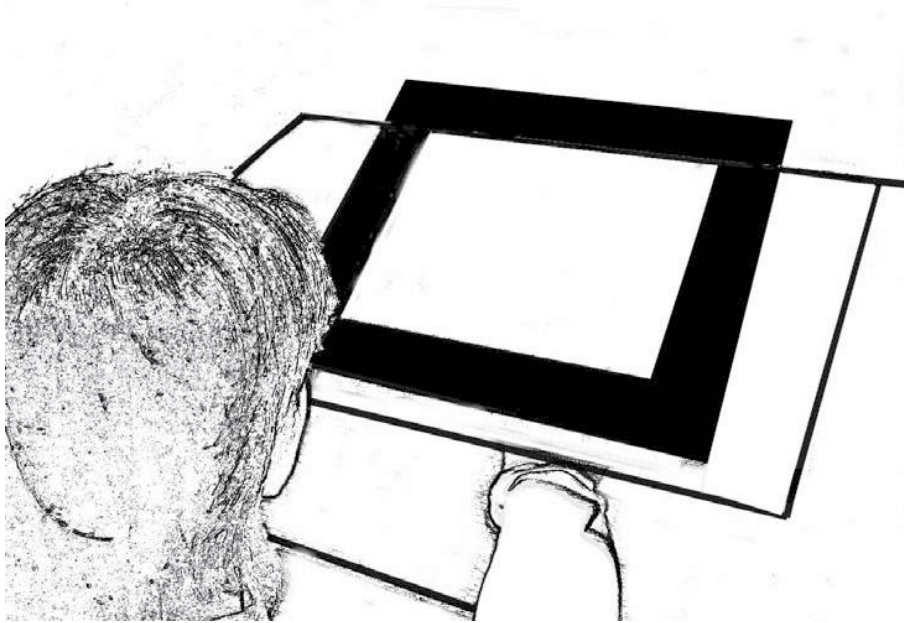
- Extension of the body to a fake limb (Botvinik & Cohen, 1998)



- The impression that the felt sensation comes from the rubber hand comes from an interaction between vision, proprioception, and touch.
- The representation of our bodily space can be modified.



Visuo-haptic interactions - The Oppel-Kundt illusion



➤ Effect of the illusion on line bisection (Gallace et al., 2007)

Cross-modal correspondences

Crossmodal correspondences

- Tendencies for our brain/mind to match sensory features or dimensions across distinct sensory modalities (Spence, 2011; Deroy & Spence, 2013)
- Unexpected
- Arbitrary
- Relative

Crossmodal correspondences

Mil
Mal



Sapir (1929)

Maluma
Takete



Köhler(1929)

bouba
kiki






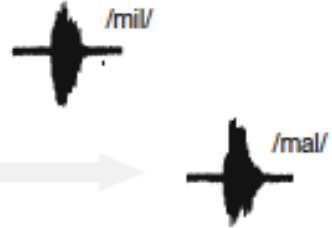

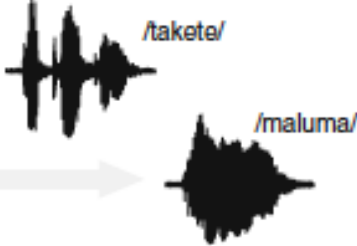

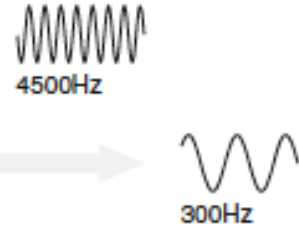

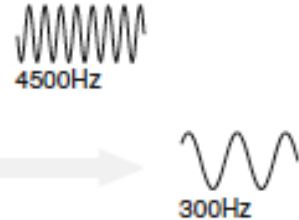
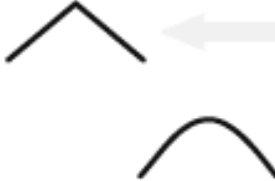
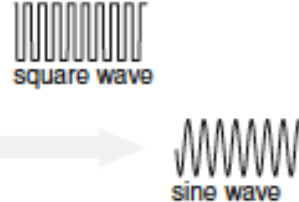
Ramachandran & Hubbard (2001, 2003)

Crossmodal correspondences

Visual dimension	High-pitched sound corresponds to:	Study
Elevation	High elevation	Ben-Artzi & Marks (1995); Bernstein & Edelstein (1971); Evans & Treisman (2010); Melara & O'Brien (1987); Patching & Quinlan (2002); Walker et al. (2010)
Brightness	Brighter stimulus	Marks (1987)
Lightness	Lighter stimulus	Marks (1987); Martino & Marks (1999); Melara (1989)
Shape/Angularity	More angular shape	Marks (1987); Parise & Spence (in press); Walker et al. (2010)
Size	Smaller object	Bien et al. (2012); Evans & Treisman (2010) Gallace & Spence (2006); Parise & Spence (2008, 2009)
Spatial frequency	High spatial frequency	Evans & Treisman (2010)
Direction of movement	Upward movement	Clark & Brownell (1976); Sadaghiani et al. (2009)

(from Spence & Deroy, 2012)

Audiovisual crossmodal
correspondences and
sound symbolism
(Parise & Spence 2012)

Exp	 Visual stimuli	 Auditory stimuli	IAT Results
1			Congruency $F(1,9)=23.84$ $p<.001$ Modality $F(1,9)=33.42$ $p<.001$ Compatibility X Modality $F<1$ n.s.
2			Congruency $F(1,9)=22.08$ $p=.001$ Modality $F(1,9)=38.26$ $p<.001$ Compatibility X Modality $F(1,9)=2.45$ $p=.15$
3			Congruency $F(1,9)=11.07$ $p=.009$ Modality $F(1,9)=12.92$ $p=.006$ Compatibility X Modality $F<1$ n.s.
4			Congruency $F(1,9)=16.54$ $p=.003$ Modality $F(1,9)=13.42$ $p<.006$ Compatibility X Modality $F<1$ n.s.
5			Congruency $F(1,9)=5.71$ $p=.041$ Modality $F(1,9)=21.45$ $p=.001$ Compatibility X Modality $F(1,9)=2.45$ $p=.15$

Audio-tactile crossmodal correspondences

Crossmodal correspondence between pitch & visual elevation both static and dynamic (e.g., Evans & Treisman, 2010; Maeda, Kanai & Shimojo, 2004).

- ☐ Does a similar correspondence between pitch and direction of movement exist in the audio-tactile domain?
- ☐ Does it depend on previous visual experience?
-> Sighted, late and early/congenitally blind

Audio-tactile crossmodal correspondences



Auditory
stimuli



Increasing pitch



Decreasing pitch

Frequency :
700 to 1200 Hz
700 to 200 Hz



Tactile
stimuli

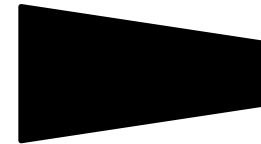
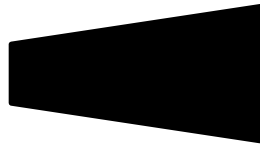
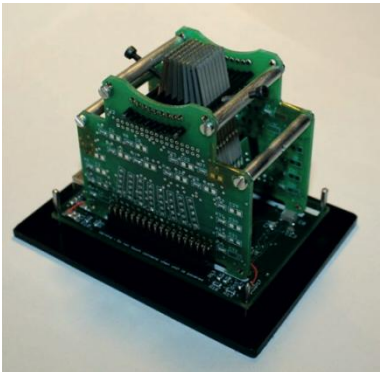


outward



Inward


Speed = 19.2 mm/s
Length = 4.8 mm




Duration = 250 ms

(Deroy et al., 2016)

Audio-tactile crossmodal correspondences




Increasing pitch




outward tactile movement




CONGRUENT




Decreasing pitch



inward tactile movement




Increasing pitch




inward tactile movement



INCONGRUENT

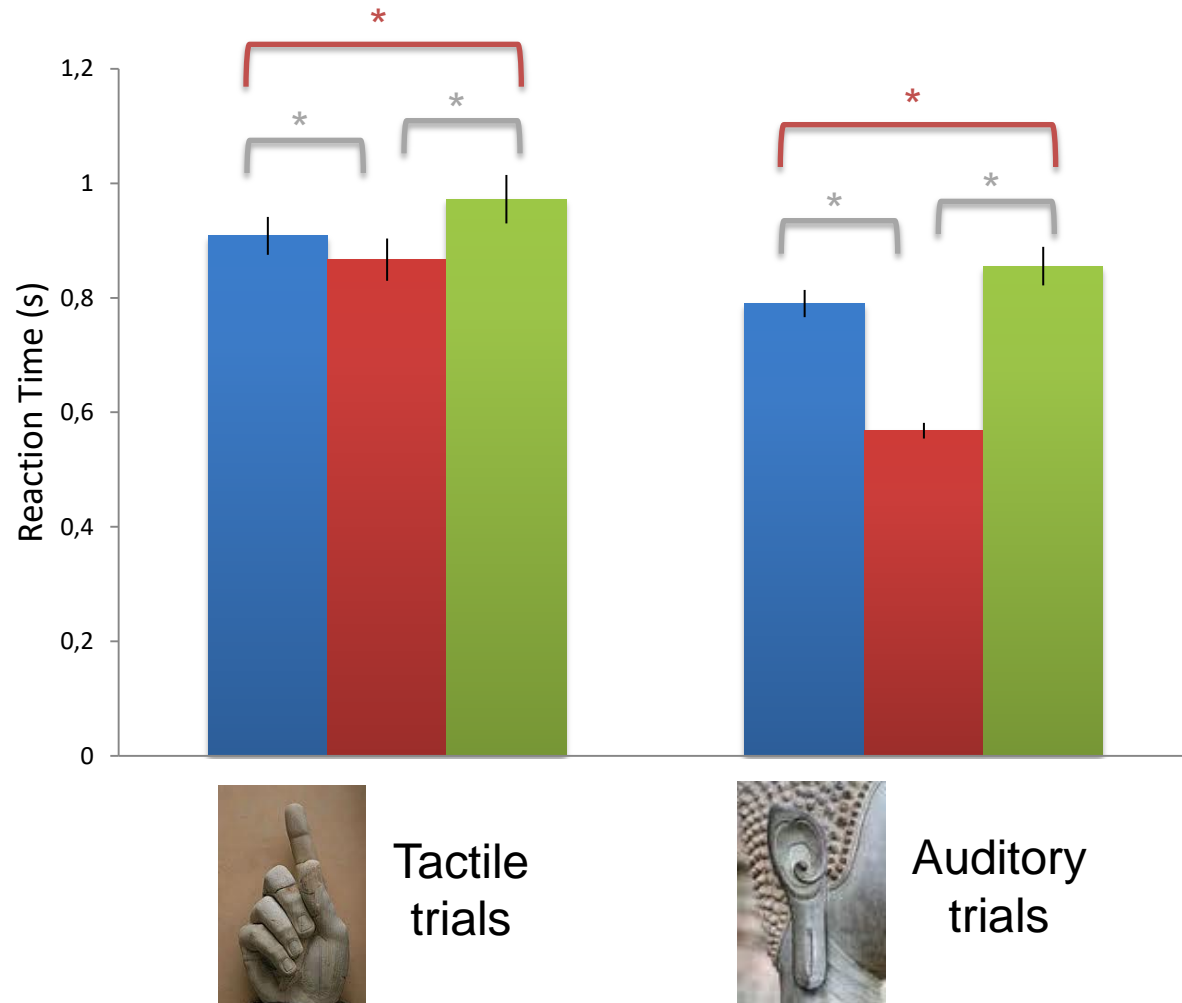


Decreasing pitch



ouward tactile movement

Audio-tactile crossmodal correspondences



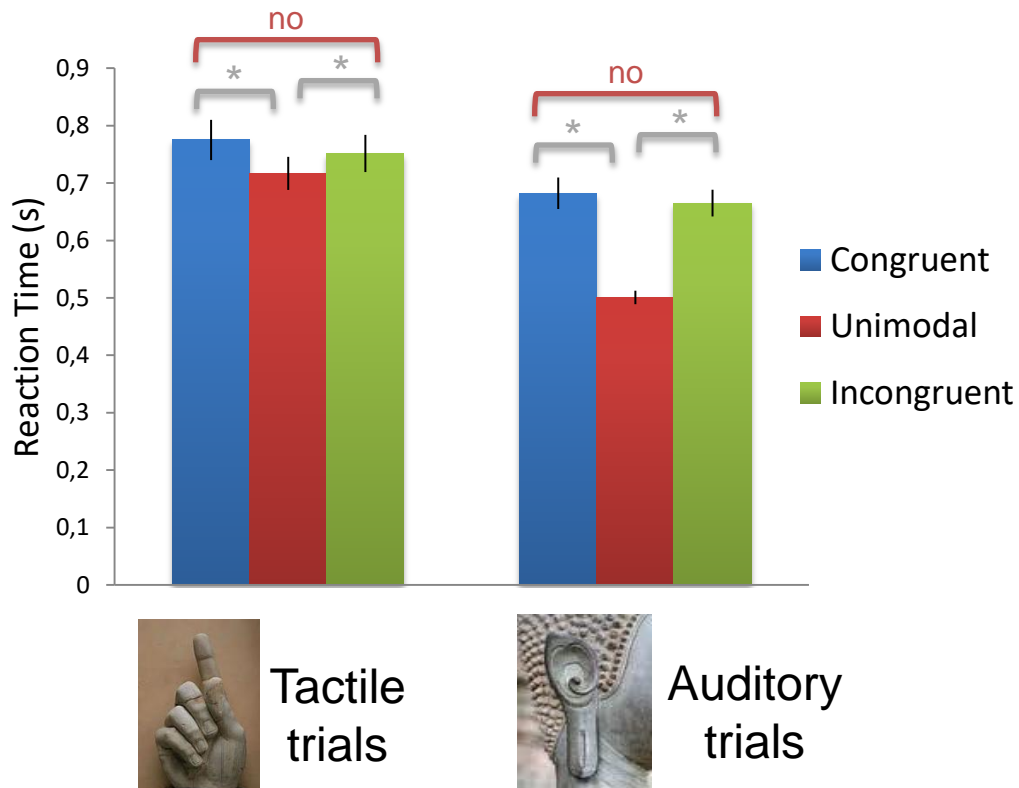
14 sighted participants

Horizontal and vertical arm positions collapsed

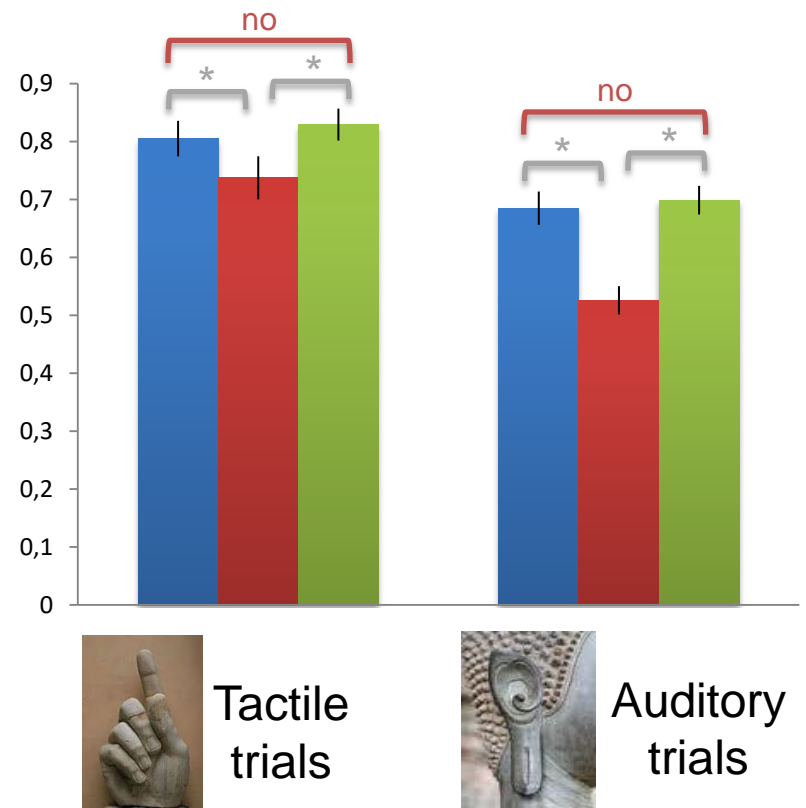
- Congruent
- Unimodal
- Incongruent

Audio-tactile crossmodal correspondences

12 early-blind participants
(8 congenitally blind, 4 blind with 1
to 3 years of visual experience)



12 late-blind participants



Summary

- ❑ Audio-tactile CC, dynamic, in sighted participants.

- ❑ No effect of congruency in early and late blind participants.

→ Visual mediation plays a necessary role in the acquisition and persistence of the pitch-elevation correspondence?

→ Implication. Some mappings in conversion devices are not necessarily intuitive for their blind users.

Crossmodal correspondences



Crossmodal correspondences between

- Low-pitched tones and bitterness
- High-pitched tones and sweetness

(Crisinel & Spence, 2012)

The music of tastes

Table 1 Summary of crossmodal correspondences between basic tastes and sonic elements demonstrated to date

Author(s)	Auditory property	Sweet	Sour	Salty	Bitter
Bronner, 2012	Sharpness/spectral balance	low	high		
	Roughness	low	high		
	Ambitus	small	large		
	Articulation	legato	staccato		
	Rhythm	even	syncopated		
	Melodic intervals	small	large		
	Melodic consonance	consonant	dissonant		
	Tempo	slow	fast		
Crisinel & Spence, 2009	Pitch		high		low
Crisinel & Spence, 2010a	Pitch	high	high	average	low
	Instrument type	piano	brass	brass	brass
Crisinel & Spence, 2010b	Pitch	high	high	ns	ns
Crisinel & Spence, 2012	Pitch	higher			lower
	Instrument type	piano			ns
Knöferle & Spence, 2012	Pitch	high	average	average	low
	Roughness	low	high	average	high
	Sharpness/spectral balance	ns	high	ns	low
	Discontinuity	low	high	high	high
	Attack	ns	ns	ns	ns
	Speed	ns	fast	ns	slow
Mesz et al., 2011	Pitch	average	high	low	low
	Articulation	legato	average	staccato	legato
	Loudness	soft	average	average	average
	Chord consonance	consonant	dissonant	average	average
	Melody consonance	consonant	dissonant	average	average
Ngo et al., 2011 ²	Consonants	soft			hard
	Vowel backness	back			front
Simner et al., 2010	Vowel height	higher	lower	lower	lower
	Vowel backness ³	back	front	front	front
	Discontinuity	lower	higher	ns	higher
	Spectral balance	lower	higher	ns	ns

Crossmodal
correspondences
(most documented
cases)

Crossmodal
mapping or
matching

Surprising

Consistent

From rare to frequent

From idiosyncratic
to universal

Moderately
automatic (control)

Not necessarily
conscious

Relative

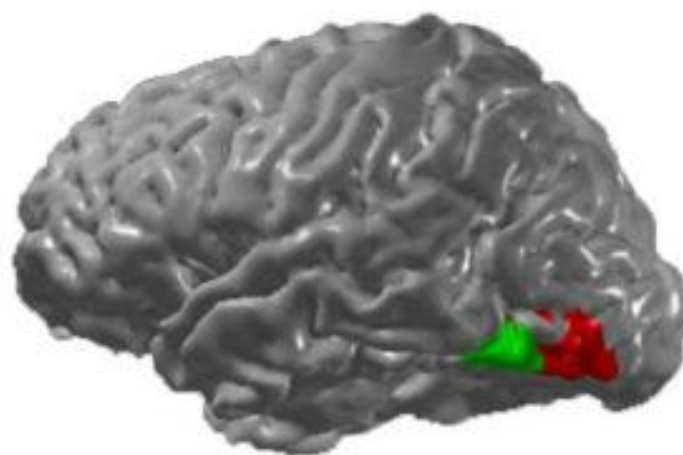
Bidirectional

Transitive

Malleable

Explainable by
exposure

Synesthesia



*It would be truly surprising
if sound were not capable of suggesting color,
if colors could not give the idea of the melody,
if sound and color were not adequate to express ideas.
-- Claude Debussy*

Definition of synesthesia

Comes from the greek syn (together) and aiesthesis (perception).

Synaesthesia is a condition in which “stimulation in one sensory or cognitive stream leads to associated experiences in a second, unstimulated stream”. Synaesthesia is thus normally described as a “startling sensory blending” “not experienced by most people under comparable conditions”

In synaesthesia, sensory experiences (such as tastes) or concepts (such as numbers) automatically evoke additional percepts, such as colors



Simner (2012). Defining Synaesthesia. *British Journal of Psychology*, 103, 1-15

Hubbard, E.M., & Ramachandran, V.S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron*, 48, 509-520

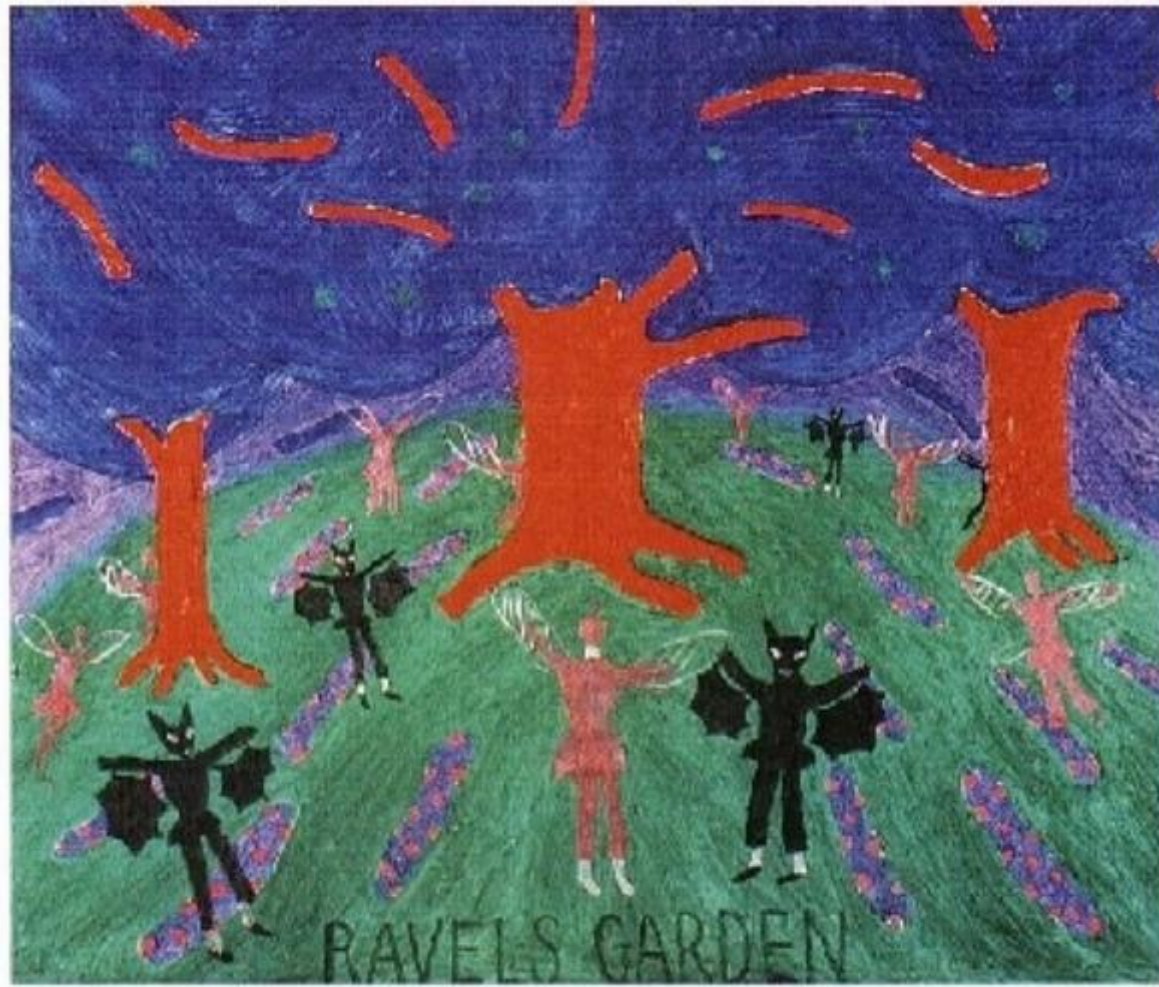
For example, a grapheme-color synaesthete can experience colors when reading a digit or a letter (Cohen-Kadosh & Walsh, 2006)



A lexical-gustatory synaesthete can experience tastes when she hears or reads certain words (Dixon et al., 2000)

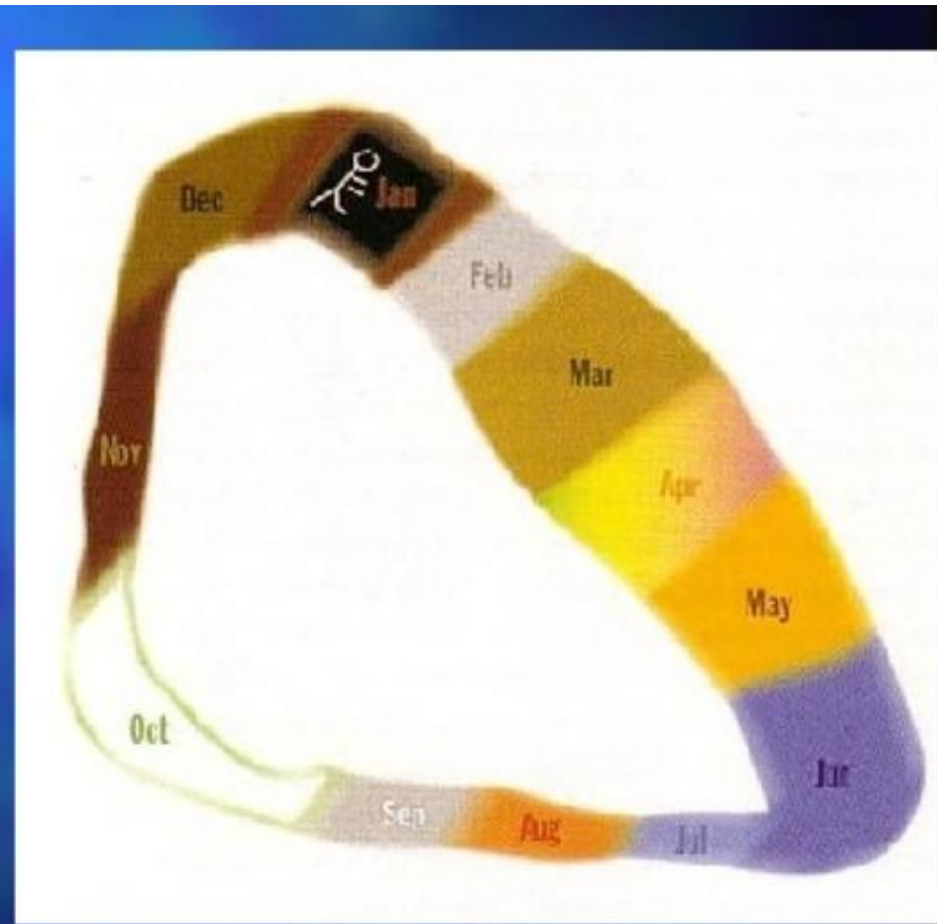
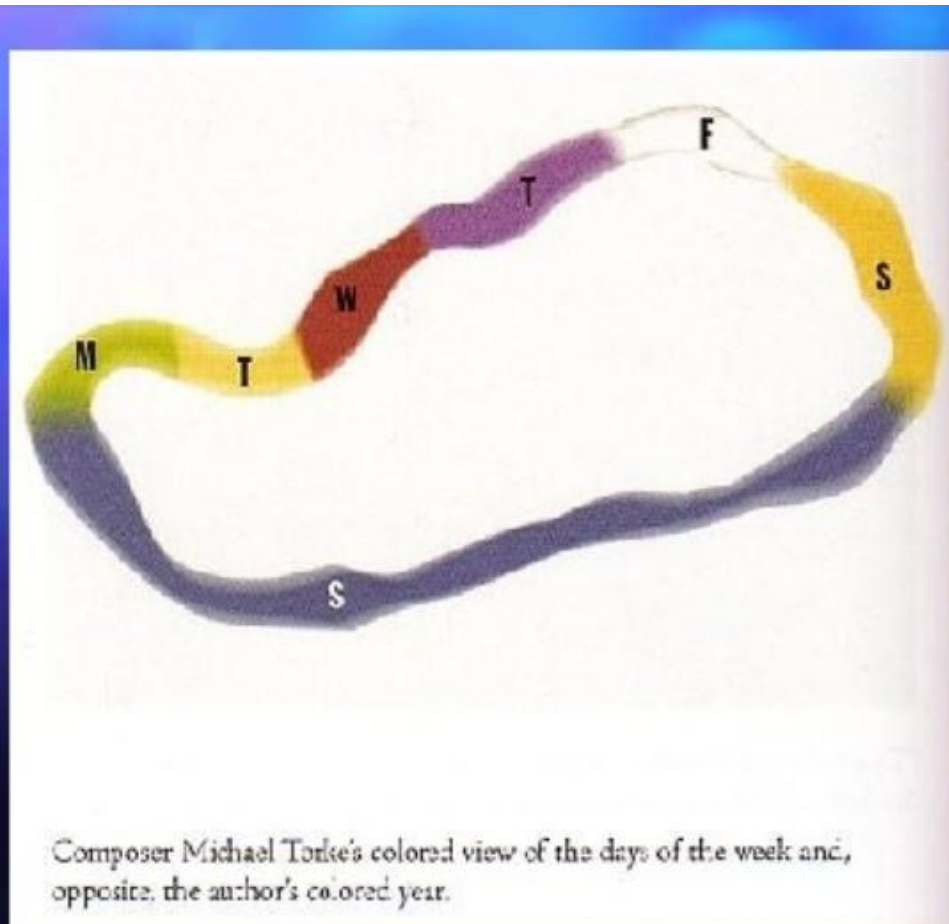
Analogously, a hearing-color synaesthete can see colors when she hears particular sounds (Rich et al., 2005)

Colored music (Duffy, 2001)



"Ravel's Garden with Night Glow," by David Hockney. Hockney painted with the colors he heard while listening to Ravel.

Colored time (Duffy, 2001)



Colored letters in music (Duffy, 2001)

The image shows the Schrödinger wave equation with various letters colored to represent musical notes. Arrows point from these letters to their corresponding musical concepts:

- $\hbar/2\pi$: \hbar is colored blue, with an arrow pointing to the note B.
- i : i is colored red, with an arrow pointing to the note C.
- $\sqrt{-1}$: An arrow points to the note C.
- $2m$: m is colored red, with an arrow pointing to the note C. The word "Mass" is written below with an arrow pointing to the m .
- $\psi(x,t)$: ψ is colored blue, with an arrow pointing to the note B. The words "Wave Function" are written above with an arrow pointing to the ψ .
- $\alpha^2 \psi(x,t)$: α is colored blue, with an arrow pointing to the note B.
- αx^2 : α is colored blue, with an arrow pointing to the note B.
- $V(x,t)$: V is colored red, with an arrow pointing to the note C. The words "Potential Energy" are written below with an arrow pointing to the V .
- $\psi(x,t)$: ψ is colored blue, with an arrow pointing to the note B.

The equation is written as:

$$\frac{\hbar}{i} \frac{\alpha \psi(x,t)}{\alpha t} = - \frac{\hbar^2}{2m} \frac{\alpha^2 \psi(x,t)}{\alpha x^2} + V(x,t) \psi(x,t)$$

Schroedinger's wave equation as seen by physicist and synesthete professor Geoffrey Chester.

Some facts about synesthesia

- Synesthesia is not associated to any other neurological particularity nor any deficit.
- Many synesthetes do not realize that their perception of the world is unusual until they try and speak about it to someone else.
- Co-occurrence of synesthesia. Having one type of synesthesia makes 50% more likely to have another type.
- Synesthesia tends to be more frequent in children (sometimes it disappears with age, in particular puberty) and in women (72% but they might be more prone to report about it).
- Higher prevalence within a family.
- Prevalence difficult to assess. Recent studies :
> 4% & > 1% grapheme-color

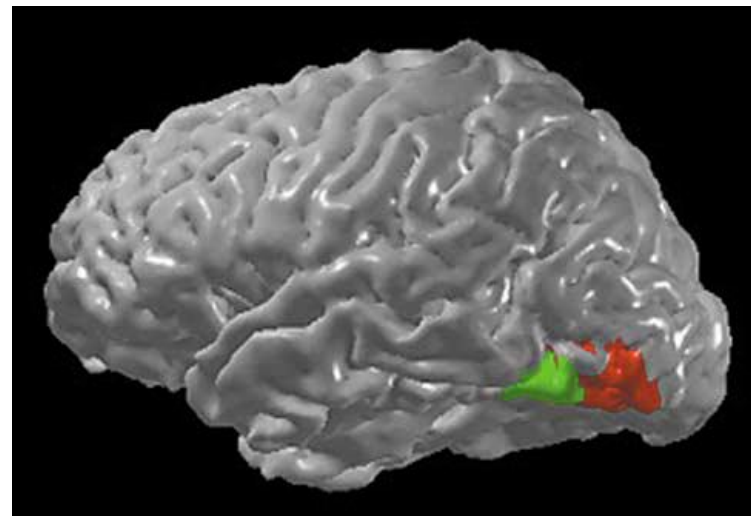
Famous syneshetes

- Vasily Kandinsky (painter, 1866-1944)
- Olivier Messiaen (composer, 1908-1992)
- Charles Baudelaire (poet, 1821-1867)
- Franz Liszt (composer, 1811-1886)
- Arthur Rimbaud (poet, 1854-1891)
- Richard Phillips Feynman (physicist, 1918-1988)



The neural bases of synesthesia

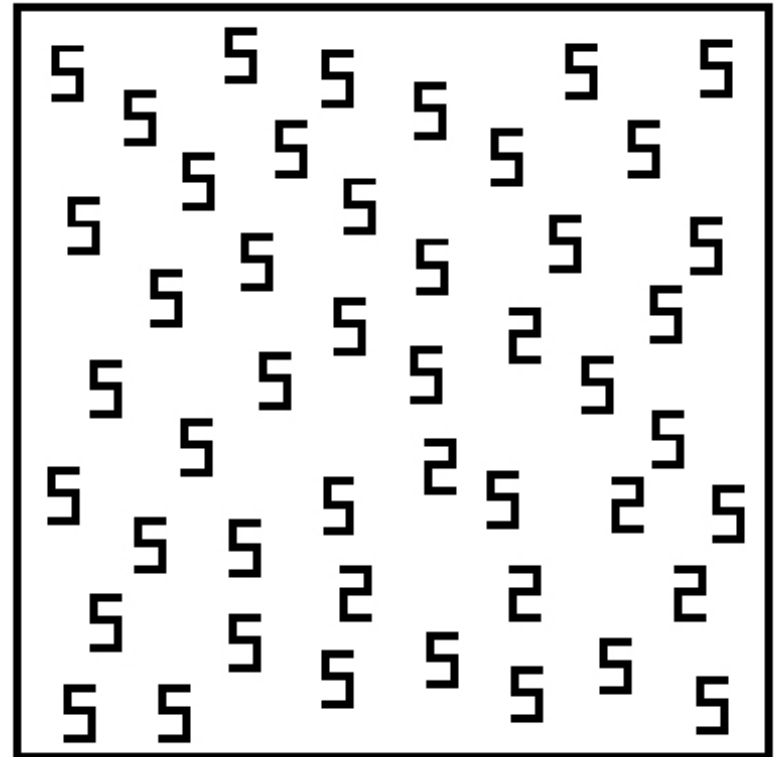
- Synesthesia might be due to important cerebral connectivity.
- This cross-activation may arise due to a failure of the normal developmental process of pruning, which is one of the key mechanisms of synaptic plasticity, in which connections between brain regions are partially eliminated with development.
- In grapheme-color synesthetes, since regions involved in the identification of letters and numbers lie adjacent to a region involved in color-processing (V4), the additional experience of seeing colors when looking at graphemes might be due to "cross-activation" of V4 (Ramachandran & Hubbard 2001).



Perceptual synesthesia (\neq semantic association)

The “Pop Out” effect

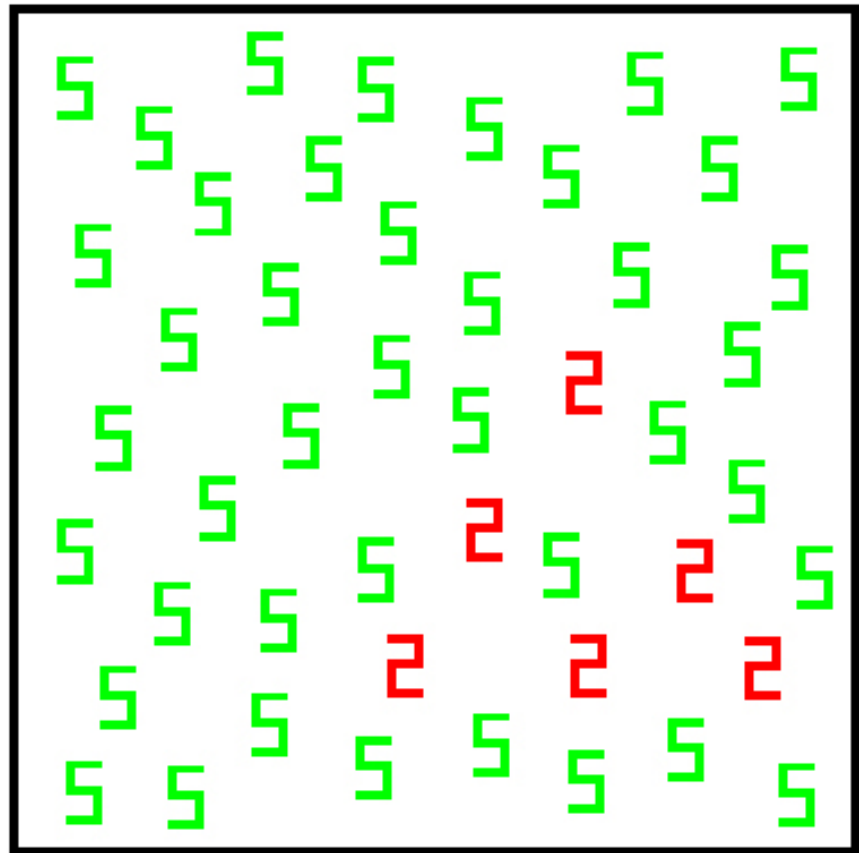
Perception in control
participants



Perceptual synesthesia (\neq semantic association)

The “Pop Out” effect

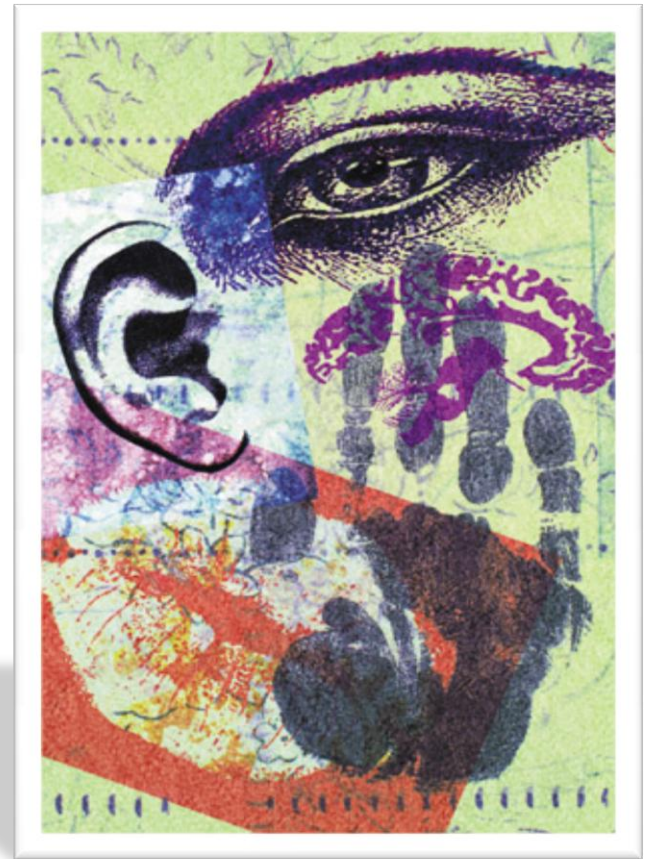
Perception in
grapheme-colors
synesthetes



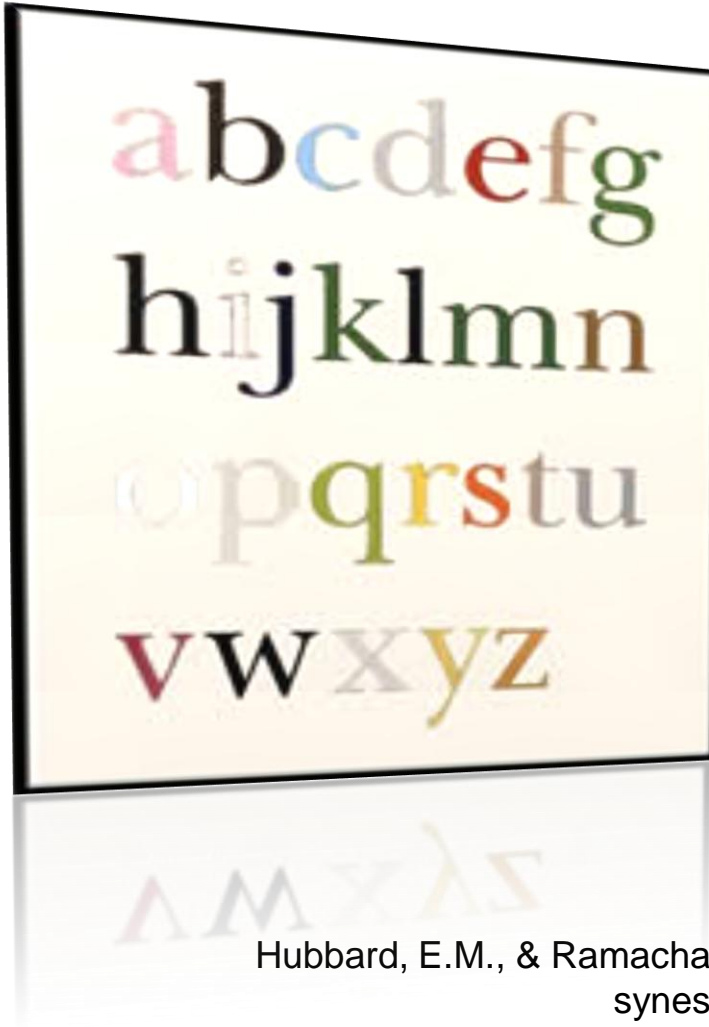
4 characteristics of synesthesia

1) Synaesthesia is characterized by the existence of an inducer-concurrent pairing (Grossenbacher & Lovelace, 2001)

Inducer refers to the experience of the triggering stimulus that causes the correlated synaesthetic experience to emerge. Concurrent denotes the associations being experienced by the synaesthete. The inducer must be always consciously experienced.



4 characteristics of synesthesia



2) Synaesthesia is relatively idiosyncratic. In synaesthesia, the induced sensory attributes '*are not experienced*' by most people under comparable conditions' (Simner, 2005)

Hubbard, E.M., & Ramachandran, V.S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron*, 48, 509-520.

Colored alphabet of two synesthetes

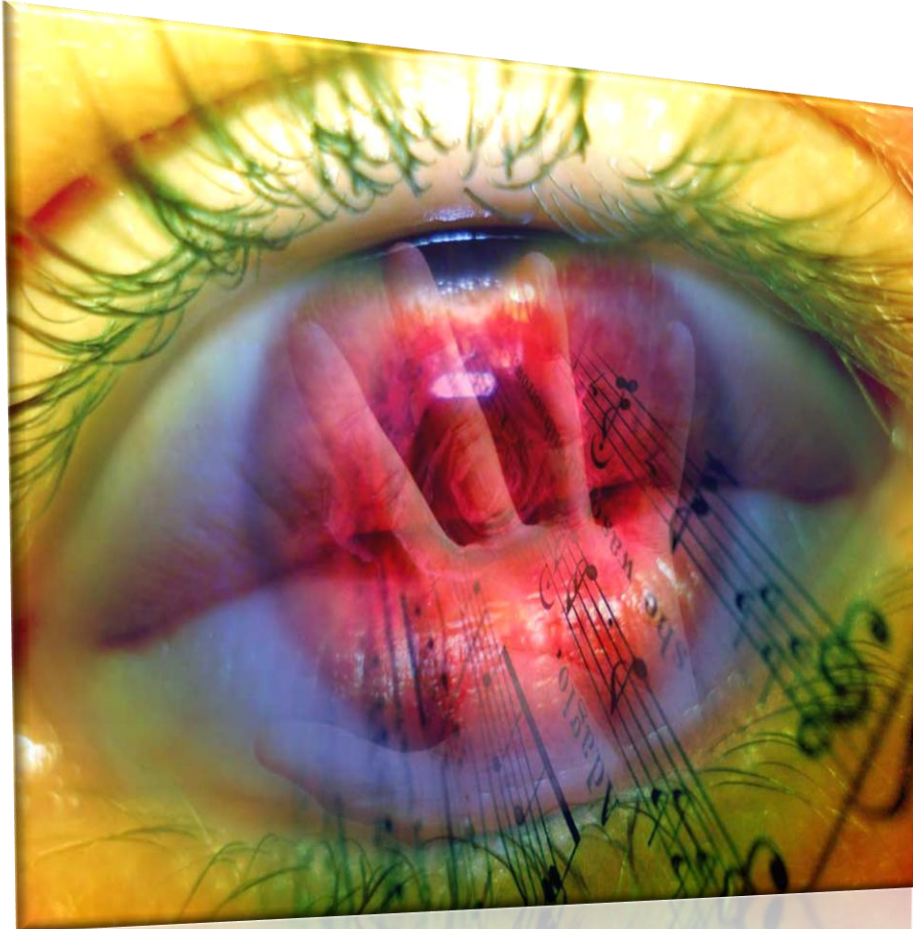
abcdefghijklmnopqrstuvwxyz

Two synesthetic colored alphabets: on the left, the author's; on the right, artist Carol Steen's.

abcdefghijklmnopqrstuvwxyz

(Duffy, 2001)

4 characteristics of synesthesia



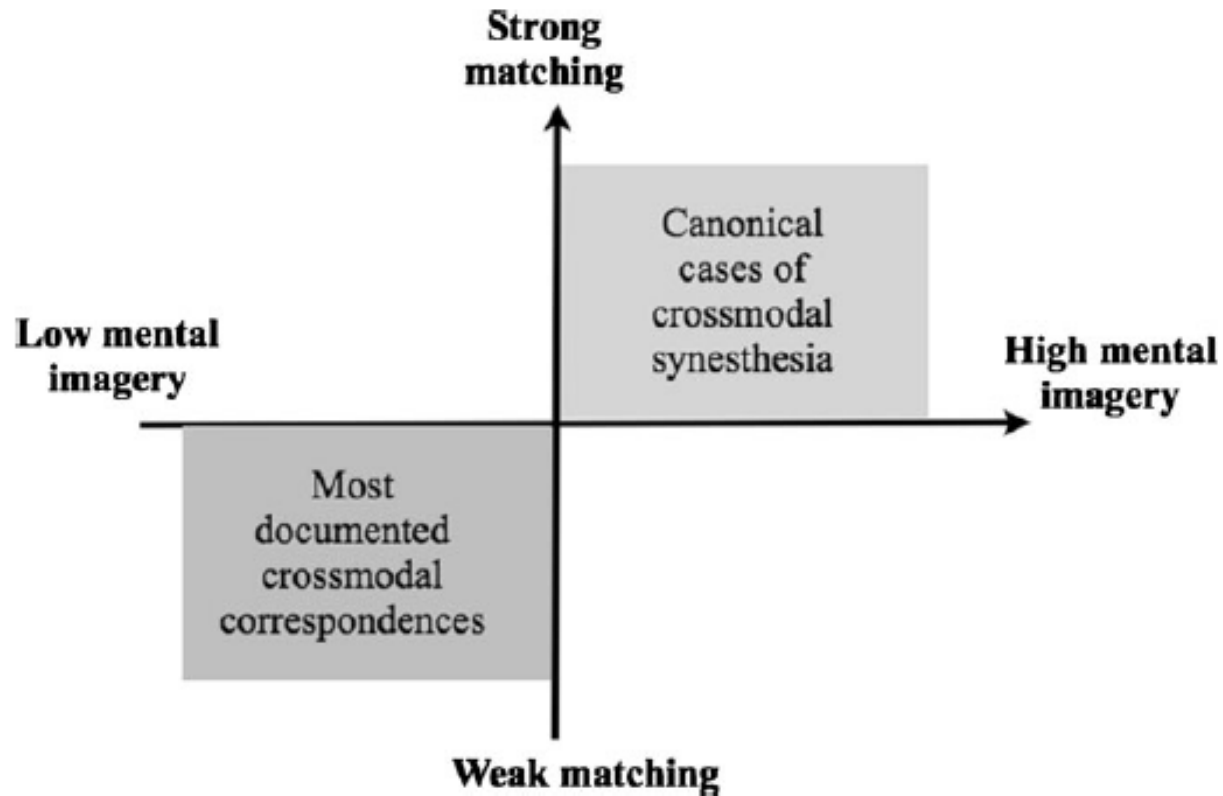
3) Synaesthesia is automatic. The concurrent is experienced as an inevitable and involuntary consequence of the synaesthete coming across a specific inducer (Sagiv et al., 2006)

4) Synaesthesia is consistent. The same inducer always triggers the same concurrent (Ward et al., 2010)

	Synesthesia (canonical cases)	Crossmodal correspondences (most documented cases)
Overt similarities	Crossmodal inducing relation	Crossmodal mapping or matching
	Surprising	Surprising
	Consistent	Consistent
Differences (still compatible, with a difference in degree)	Rare	From rare to frequent
	Idiosyncratic	From idiosyncratic to universal
	Automatic	Moderately automatic (control)
	Necessarily conscious	Not necessarily conscious
Key differences	Absolute	Relative
	Unidirectional	Bidirectional
	Intransitive	Transitive
	Rigid	Malleable
	Not explainable by regular exposure	Explainable by exposure

(Deroy & Spence, 2013)

Differences between synesthesia and crossmodal correspondences



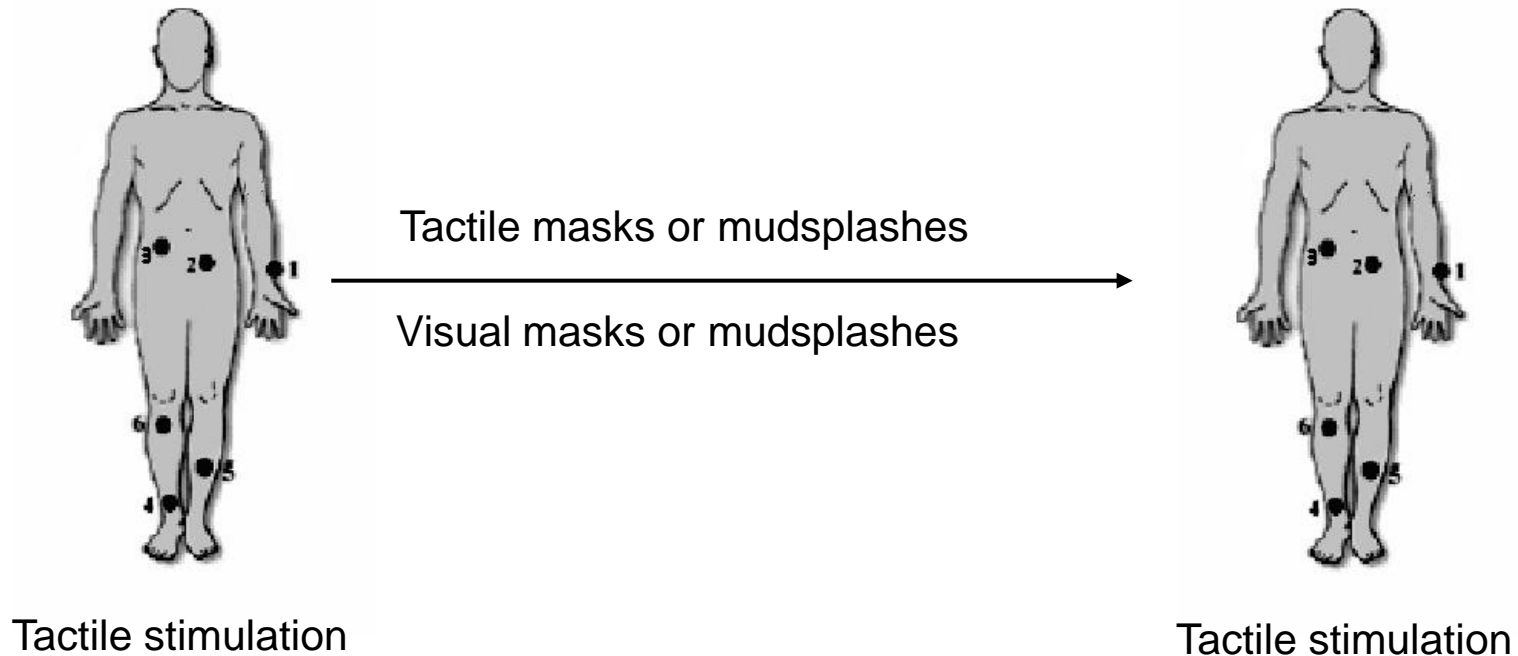
Cross-modal change blindness

Visual change detection

- ✓ **The change blindness paradigm:** Difficulties to detect changes when motion transients no longer attract attention to the location of the change.
- ✓ Only a small part of the information available in a scene is maintained from one view to the next of the same scene

Change blindness in audition and touch

- Change deafness (Vitevitch, 2003)
- Tactile change blindness (Gallace et al., 2006)

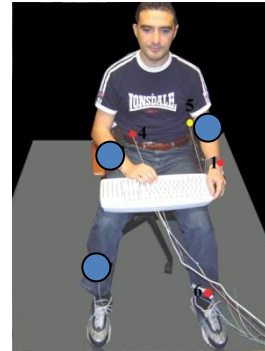


- **Multisensory change blindness?**

Tactile change blindness with visual distractors



Continuous



Interval (110ms)



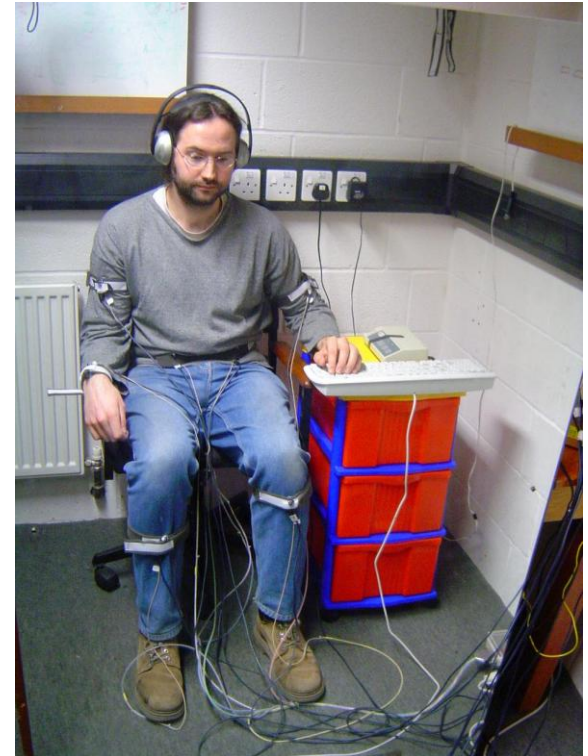
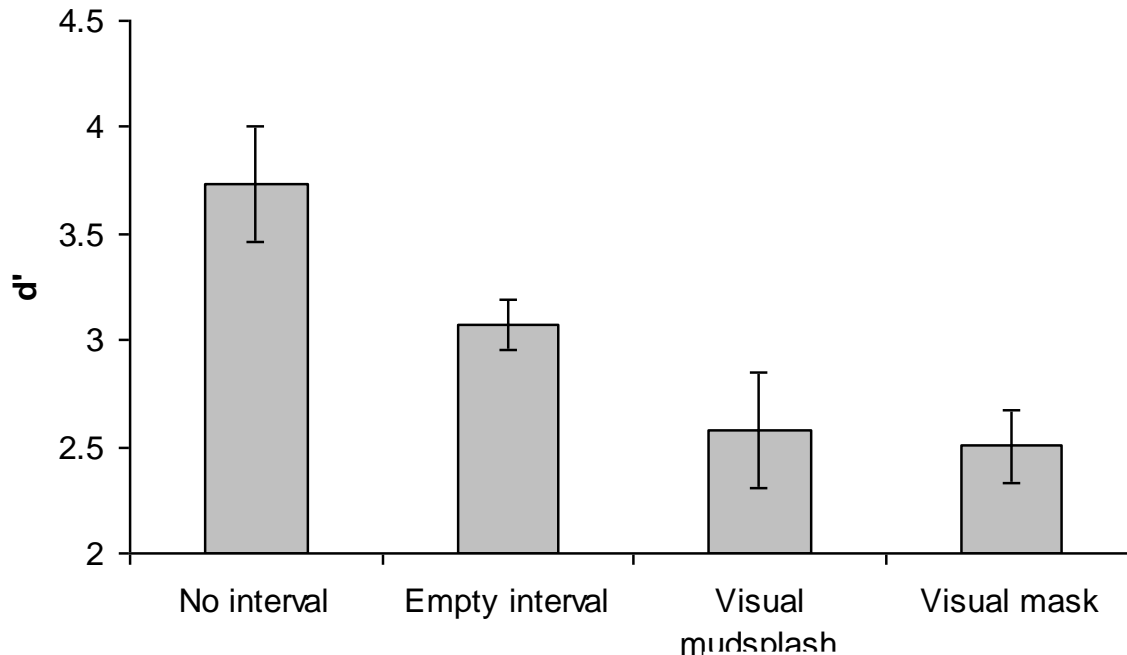
Visual 'mud splash'

Or visual mask

(Gallace et al., 2006)

Tactile change blindness with visual distractors

Experiment 1 (direct viewing)



➤ **Tactile** change blindness with **visual** distractors

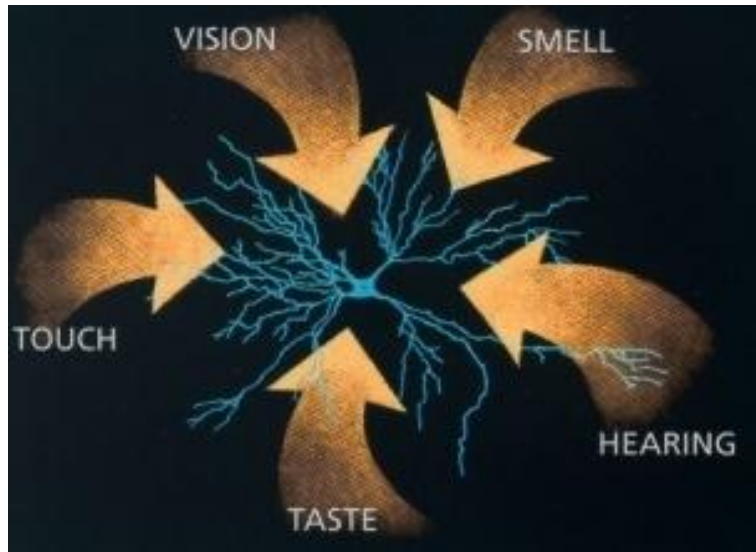
➤ Similar effects when the distractors are viewed directly (Experiment 1, N=13) or via a mirror reflection (Experiment 2, N=12).

Crossmodal change blindness



- ✓ Changes in position between two patterns of stimuli presented:
 - to the same sensory modality (visual or tactile)
 - to different sensory modalities (one visual and the other tactile)
- ✓ 2 ou 3 stimuli
- ✓ Presented either consecutively, separated by a 250 ms empty interval, or else by a 250 ms masked interval (either visual or tactile)

The multisensory nature of spatial attention



➤ Change blindness is not a strictly unimodal phenomenon.

➤ Possibility to compare positions across different sensory modalities: some of the information required to compare spatial locations are encoded in an amodal / multisensory format.

➤ Asymmetries: some of the information are encoded in a modality specific frame of reference.

Intermodal compensations and plasticity

Brain plasticity and development of the senses

How comes that when we lose a sense we can develop performance in another sensory modality?

Are these new performance enough to compensate for the sensory loss?

After losing sight, is it possible to develop touch enough to compensate for sight?

Developing the sense of touch:

When we're born we already possess **basic sensory abilities**, i.e. vision, touch, audition, smell and taste, which will develop all along our childhood. In the human fetus, touch is the first sensory modality to develop.



Brain plasticity and development of the senses

How can we develop a sense?

When we use a sense, the brain uses more neurons. We develop acuity.

Whether we are blind or sighted, when we use our sense of touch, we develop it.

Blind persons that use more their sense of touch will develop it more and thus will have a more efficient sense of touch.

→ People that are blind from birth and use since they are child their sense of touch to perceive objects and their surrounding will master more this sense; on the other hand, late blind persons will have more difficulties to use touch to perceive their surrounding.

Ex: late blind will use only one finger to read Braille

Whereas congenitally blind will use the two hands at the same time

On the other hand, the less we use one of our senses or one of our members, the more we will lose acuity.

For instance, a plastered arm for several weeks will be less sensitive. Given that the mechanoreceptors located on this area were not stimulated, limb performance decreases.

Brain plasticity in blind persons

With the increase in brain imaging techniques in neurosciences, it now becomes possible to explore the neural substrate of behaviors, for instance in blind persons.

When blind persons perform non-visual tasks, areas in their visual cortex are activated. This occurs during:

- Braille reading (Sadato et al.,1996)
- Verbal memory (Amedi et al.,2003)
- Auditory localization (Weeks et al.,2000)
- Language processing (Röder et al.,2002)

→ **Functional reorganization of visual areas**

Activation of the visual cortex in blind



Le braille est un système de lecture et d'écriture tactile utilisé par des personnes aveugles ou malvoyantes.

L'image de droite présente, en **IRM**, une « coupe virtuelle » du cerveau de deux volontaires au niveau du cortex visuel.

- L'image **a** correspond à une personne voyante qui effectue, les yeux bandés, une reconnaissance de caractères tactiles en braille.
- L'image **b** correspond à la même tâche effectuée cette fois-ci par une personne non-voyante (ayant perdu la vue à l'âge de trois ans et habituée à la lecture en braille).



When a blindfolded sighted person reads Braille there is no activation of the visual cortex.

However, the same task performed by a person blind from 3 years of age and trained in Braille reading will activate visual areas.

Activation of the visual cortex in blindfolded

Sighted persons wore a mask on their eyes during 5 days (thereby being deprived of any visual stimulation).

+ Learning of Braille (4-6h each day)

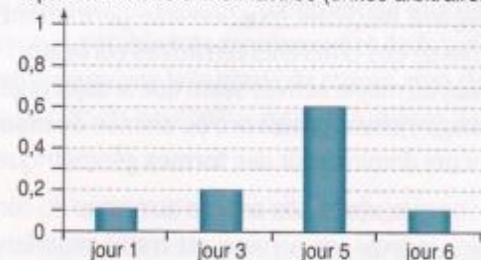
- Faster learning with blindfold
- Increased activation in the visual cortex with experience
- Deactivation when the blindfold is removed (day 6)

Réponse des neurones du cortex visuel à des stimuli tactiles



a IRM.

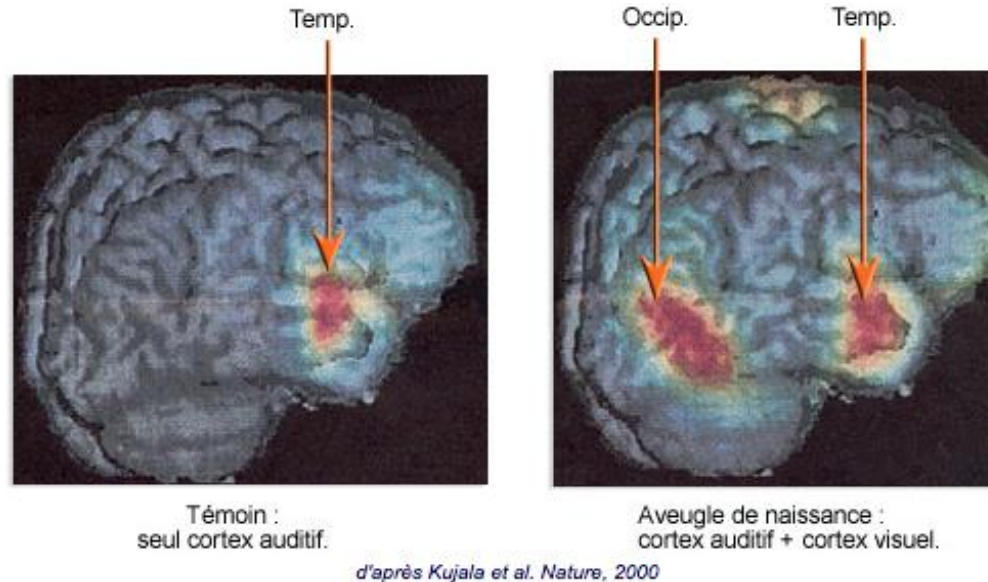
neurones du cortex visuel
répondant à des stimuli tactiles (unités arbitraires)



b Activité des neurones du cortex visuel chez les sujets ayant les yeux bandés.

- The mechanisms of this plasticity are not yet all resolved. However this **fast and reversible adaptation** does not rely on novel structures but rather on the activation of pre-existing neural circuits.
- It has also been shown that the visual cortex is recruited for language processing in blind persons. This can account for the difference found during Braille reading, not necessarily due to the tactile stimulation.

Auditory task: activation of the visual cortex in the blind



- Sighted persons use their visual cortex to look at an object or a place.
- In blind persons, the primary function of the visual cortex will be diverted to improve olfactory, tactile, or auditory abilities.

The increase in these abilities will allow blind persons to better recognize objects or to better navigate in an environment they discover.

Example of the influence of the innate (genes) and the acquired (experience) on the functional organization of the brain. The genes code for the modular organization (which zone in the brain perform a given processing or analysis of the sensory information) whereas experience (blindness) allows changing the sensory types of some brain areas. In this case allowing tactile and auditory processing in the visual cortex.

Is it possible that a period of post-natal blindness is enough to trigger an intermodal reorganization that will last years after the recovery of sight?

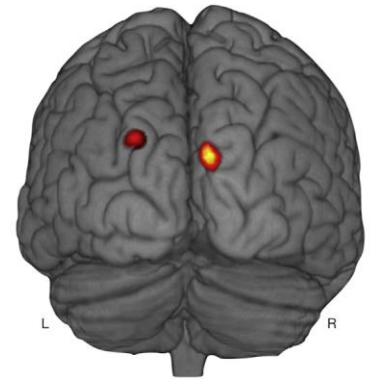
Study of brain responses to auditory stimuli in 11 adults that had congenital cataract in the two eyes, and then had a recovery of sight after surgery. Time without vision: 9 days to 8 months. (*Collignon et al., 2015*)

- Blindness at birth, the most crucial period for brain development.
- Tested when they are adults, after years of vision

→ Observation of an auditory activity in visual regions

→ A **short and temporary loss of sight** early in life leads to a **permanent intermodal reorganization** of the circuits usually devoted to vision.

→ **Role of the early post-natal experience in the functional organization of the brain.**



Intermodal plasticity in the case of blindness = vital mechanism of compensation of the brain in the case of lack of visual information.

The presence of responses to auditory stimuli in the occipital cortex of patients that had cataracts raises important questions regarding the **coexistence of visual and auditory data and their possible interference.**

Brain plasticity in the blind

- Importance of tactile experience in the development of increased tactile experience in blind persons (Goldreich & Kanics, 2003).
 - Blind persons have smaller thresholds at their fingertips than sighted of the same age.
 - On the other hand, no difference was observed between groups regarding tactile acuity on the lips.
- Suggests that the lower threshold observed on the blind's fingertips is due to mechanisms relying on experience in touch.
- Impact of a prolonged tactile experience on the spatial tactile resolution of only the trained body parts.
- **Importance of experience in brain plasticity**

Brain plasticity in the sighted

Experience de Facchini et Aglioti (2003)

The effect of short-term deprivation of light on tactile spatial acuity has been measured by asking 28 adults to perform a task of orientation detection (netting).

Results:

The 14 participants that were kept during 90 minutes in total darkness showed, immediately after deprivation, a reversible improvement in tactile spatial acuity. No change in acuity was observed in the 14 participants that were not deprived of vision.

→ These results suggest that even a short-term visual deprivation induces **plastic and dynamic interactions between the visual and tactile systems**.

→ **Short term light deprivation increases tactile spatial acuity in sighted people**

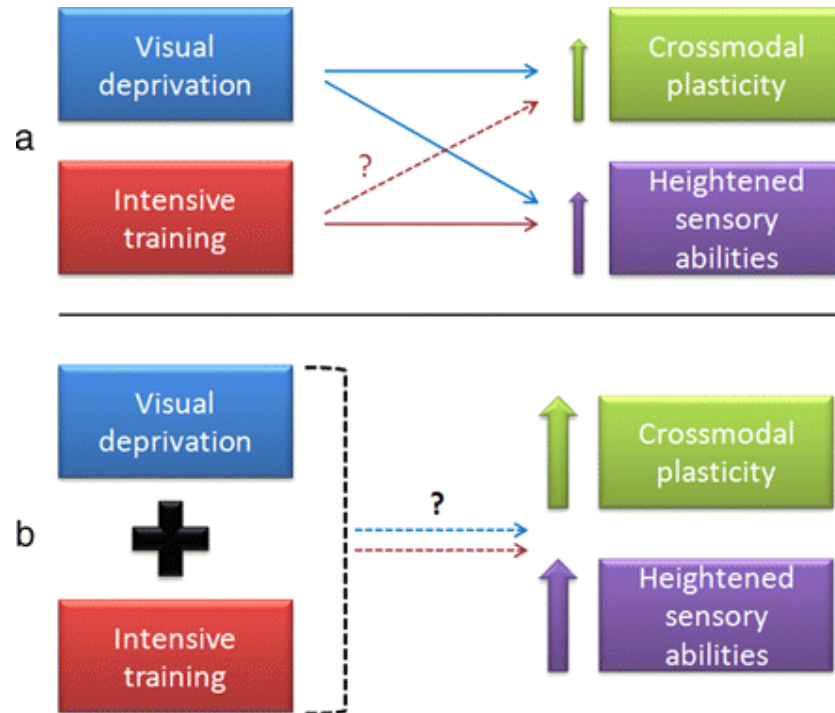
→ **Additional evidence for the importance of experience**

Brain plasticity in the blind

Sensory deprivation and intensive training improve sensory capacities

→ How do they interact?

Does blindness motivate tactile training or does the existence of a multimodal plasticity (i.e. the use of the visual cortex for other tasks) offer a unique occasion to develop increased sensory abilities?

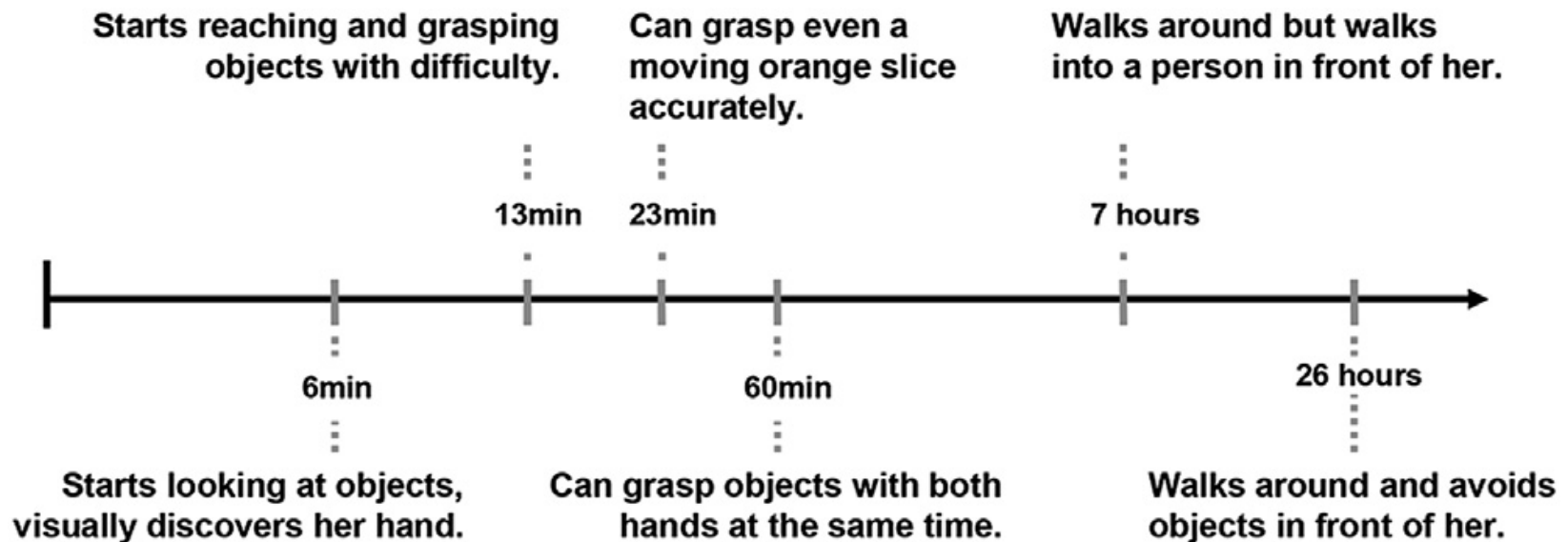


→ The lack of visual inputs in the blind's visual cortex might favor and accelerate the anatomical and functional plasticity resulting from an intensive training.

→ A synergy between training and deprivation might also result in a performance ceiling that would be higher in the blind than in the sighted.

Fast integration of visual and tactile information in a recently sighted child

- After a removal of cataract, a blind child was able to reach and grasp accurately an object after only 23 minutes.
- The day after, the child was able to immediately recognize by sight an object he previously saw and held.
- The third day, the child hold an object without seeing it and then recognized it visually.



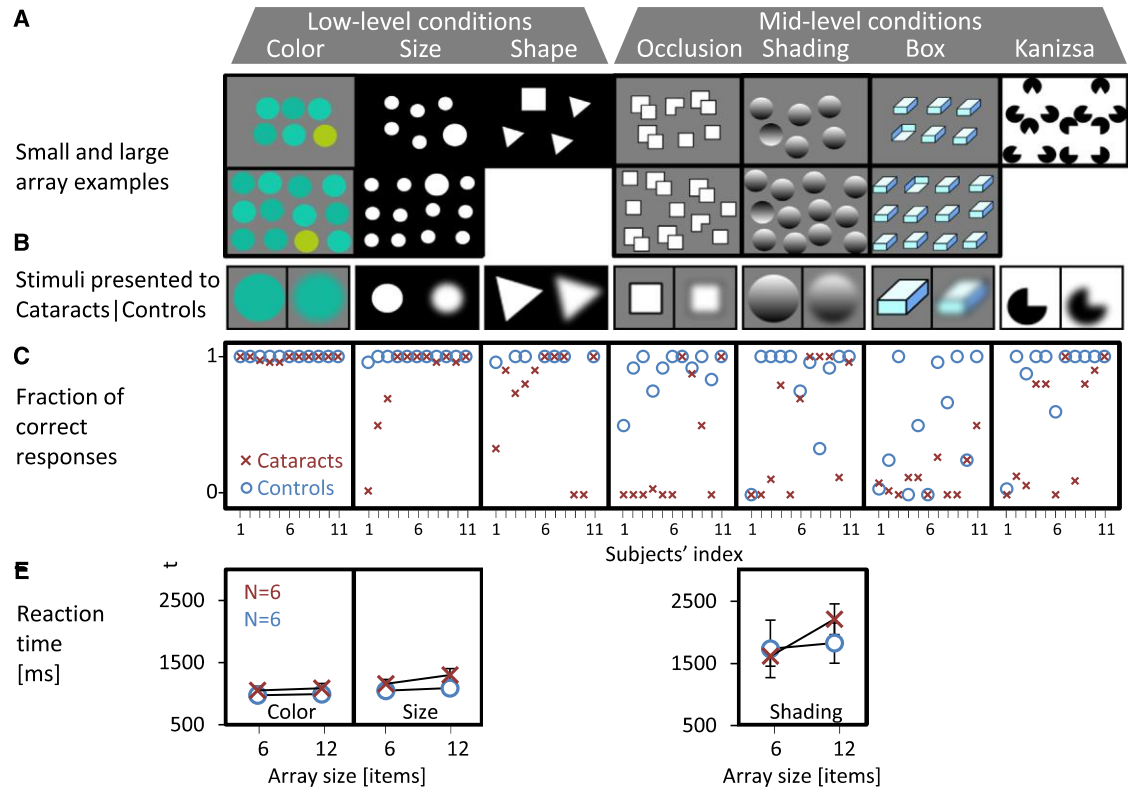
→ Visuo-motor and intersensory transfert developed very rapidly.

Limits of form recognition after a late recovery of sight

Test of congenitally blind children who recovered sight years later on different recognition tasks.

- Children learned to discriminate colors, but they did not use 3D depth rules to recognize the structure of shapes.

→ Vision grounded on inferences (such as depth) is very vulnerable to long term deprivation



→ This suggests that some mid-level visual functions can only be acquired during a critical period of development.

→ Additional incentive to for an early treatment of cataracts in order to restore functional vision.

Conclusions: Brain plasticity in blind persons

- Blind persons seems to be better than the sighted for some tactile tasks, maybe due to their specific tactile experience. However, some of these tasks might involve non-spatial cues and the impact of early or late blindness and that of Braille reading remain uncertain.
 - It now appears obvious that visual brain areas are recruited during tactile spatial perception in blind persons, in addition to a variety of other tasks involving linguistic ones.
 - There is an interaction between sensory experience and the effects of training; with critical periods of development.
- Future research should focus on the delimitation and extent of the functional specialization in the blinds' visual cortex as well as on the relationship between the long-term multimodal plasticity and its temporal evolution, its perceptual consequences, and the influence of modulating factors such as specific sensorimotor experience.