Multisensory perception

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Outline

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

Road map

1. Spatial cognition
   - Definitions
   - Brain bases

2. Spatial cognition and brain plasticity
   - Brain plasticity and learning pathways
   - Brain plasticity after lesions
   - Flexibility in spatial perspectives

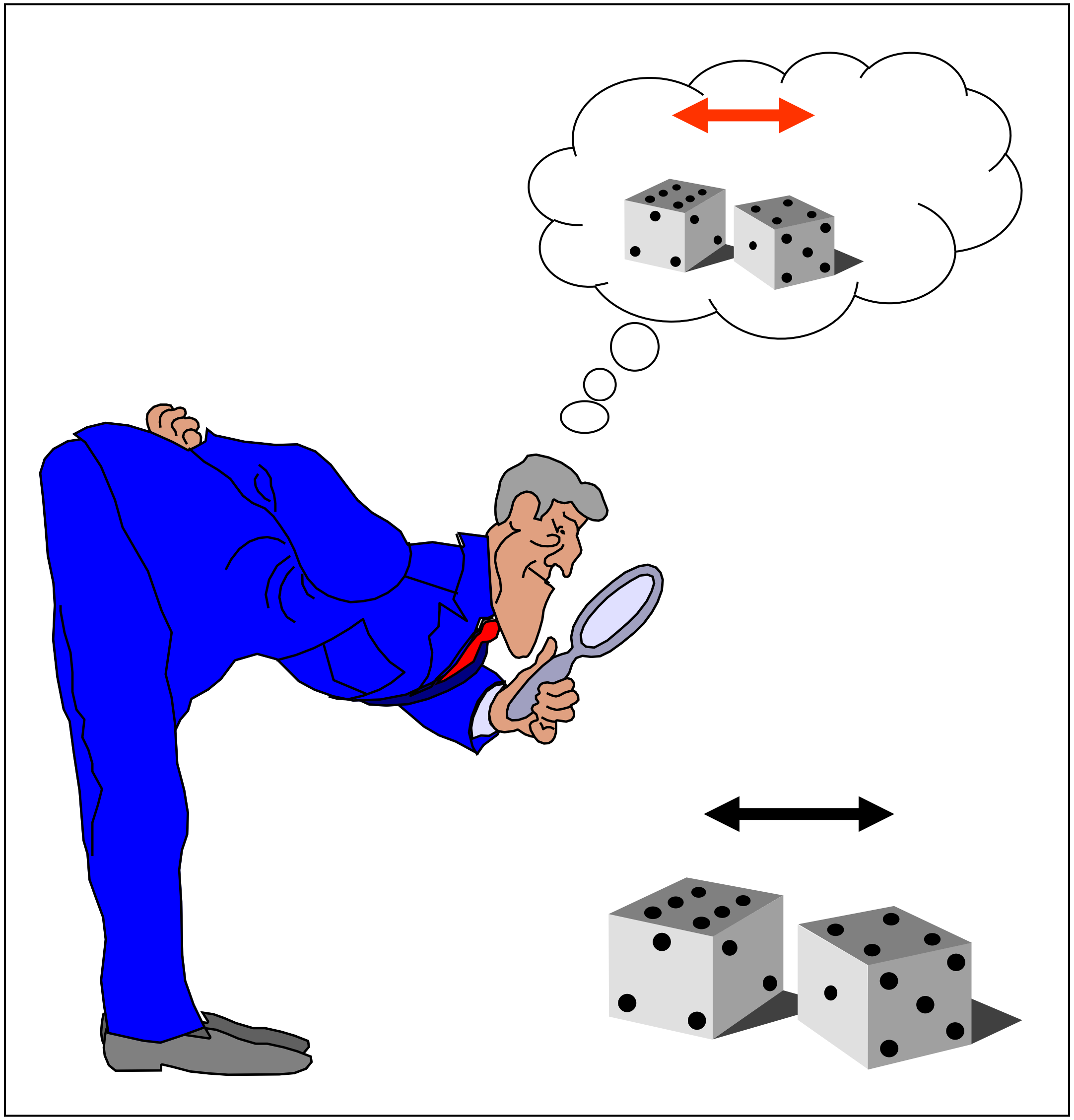
1. Spatial cognition
Definitions
Brain bases

Definition: Spatial cognition

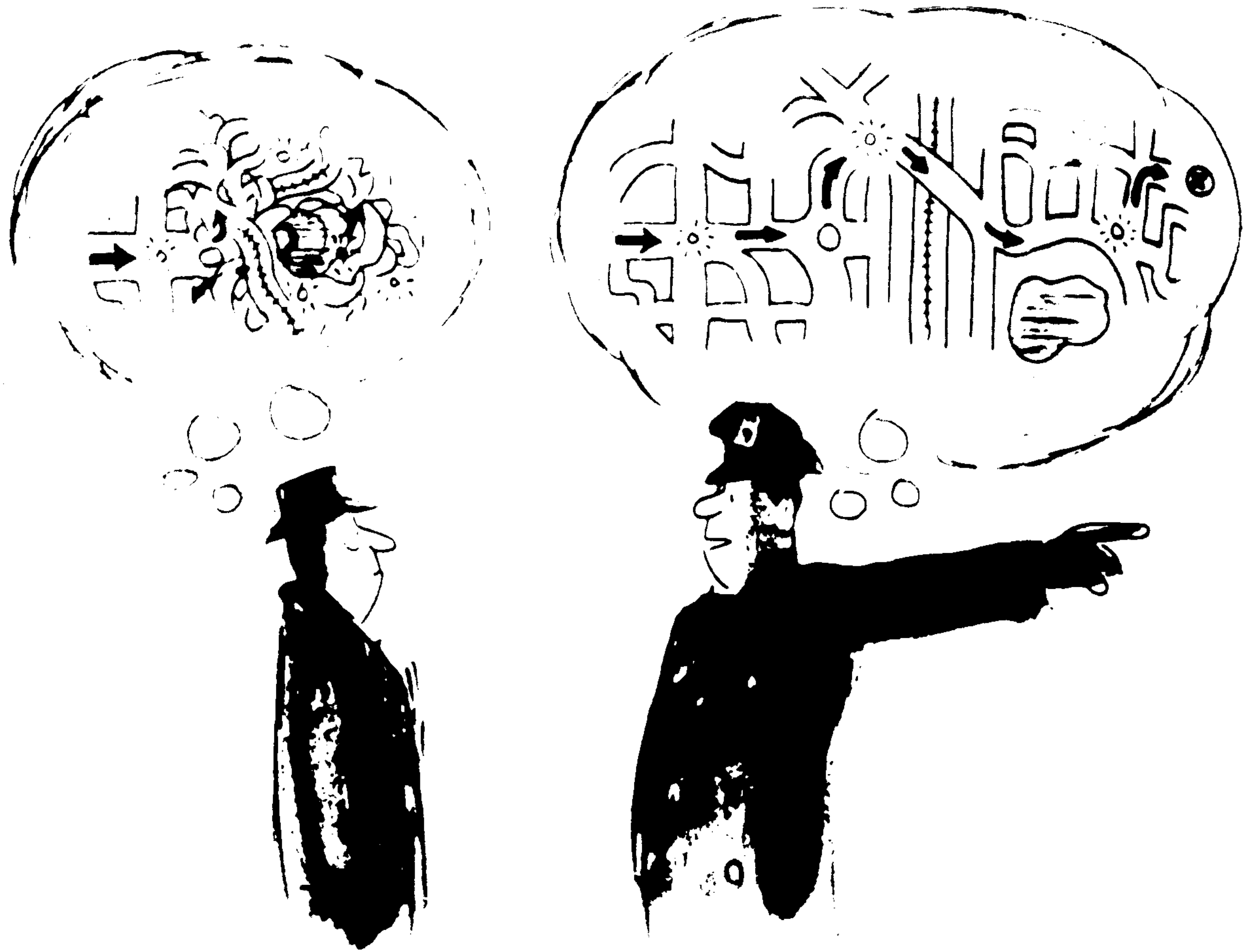
Spatial cognition involves the acquisition, the organisation, the use, and the update of knowledge regarding spatial environments.

These abilities allow humans to perform basic and high level cognitive tasks in everyday life.

How does our brain represent space?

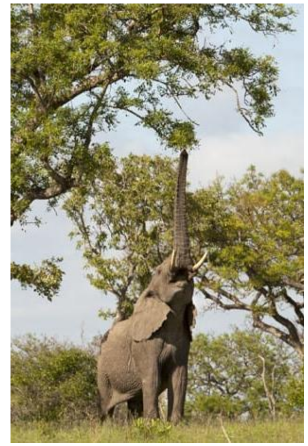


How does our brain represent space?

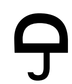


Example of tasks involving mental spatial processes

- Does the elephant's trunk reach the floor when the elephant is in a normal – horizontal – position?



- Imagine the capital letter 'd', turn it 90° left, place the letter 'j' below, in the center. What do you see?



- How many candles do you see?
How many candles the character sees?
(Director Task, Keysar et al., 2000)

- How do you go from this room to your favourite bakery?

Why studying spatial cognition?

- Central to many daily activities (ecological importance)

- Space is an attribute common to all of our senses

- **Several interesting neuroscientific findings**

- **High degree of specialisation of neuronal circuits for spatial tasks**

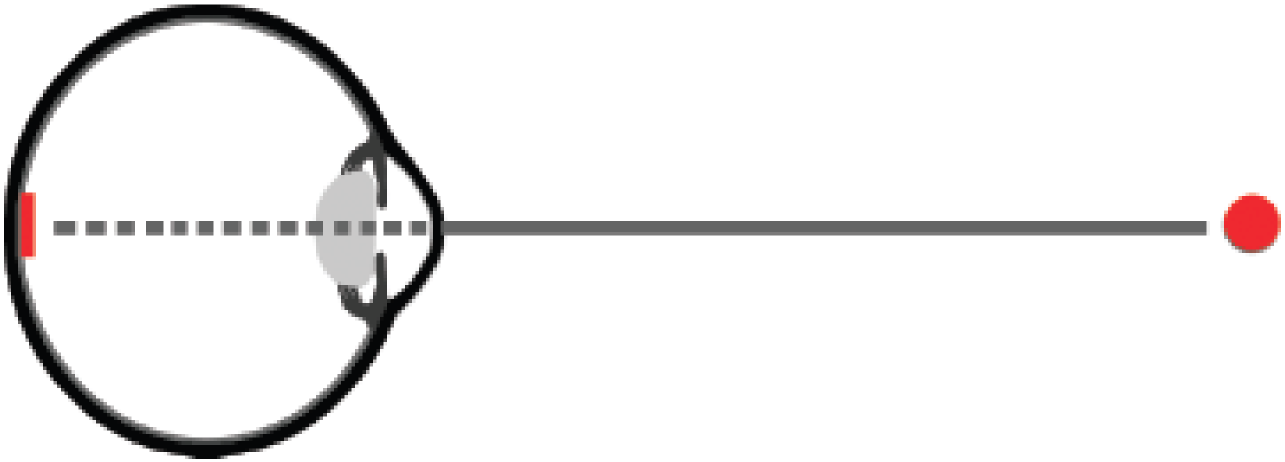
- Other cognitive functions can be mainly motivated by space (e.g., language and communication of spatial information)

- Spatial characteristics involve distance (depth), relative and absolute positions, orientation (direction).

- Difficulty to have access to spatial characteristic « in itself » and incomplete spatial representations

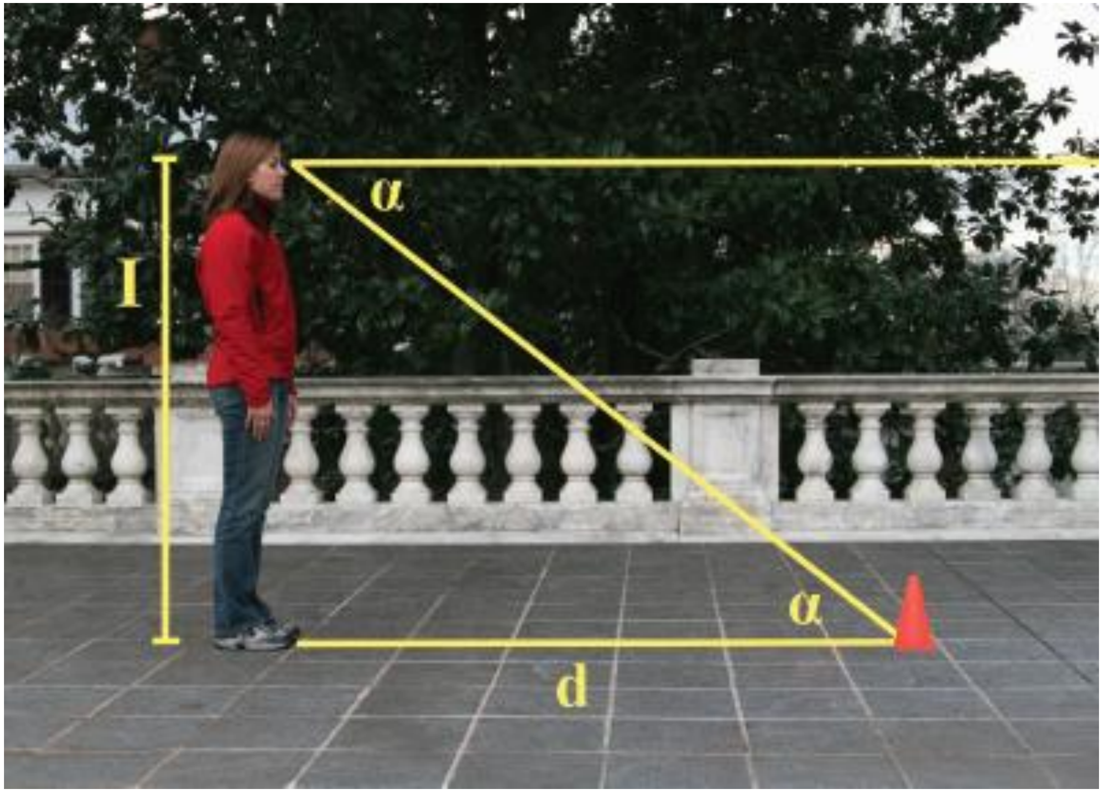
  → visual perception and evaluation of distances

Measuring distances



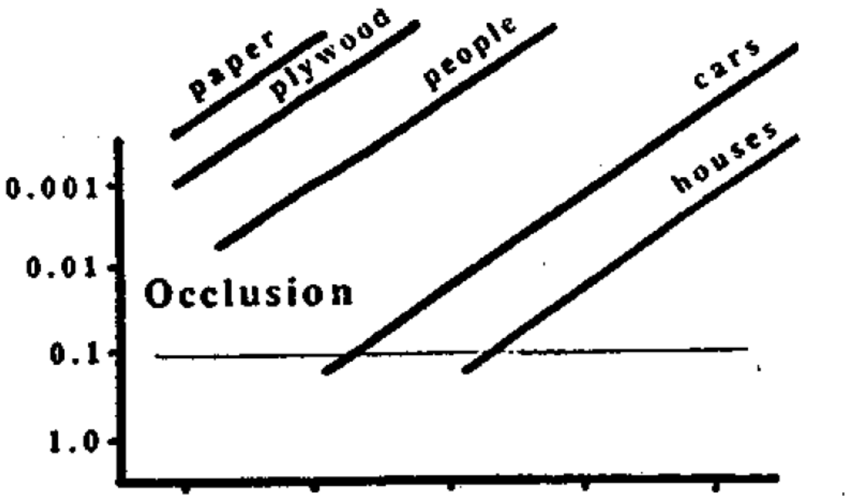
Berkeley observed that information about distances is lost in the retinal projection and thus that the visual landmarks are not sufficient (Proffit 2006).

Measuring distances



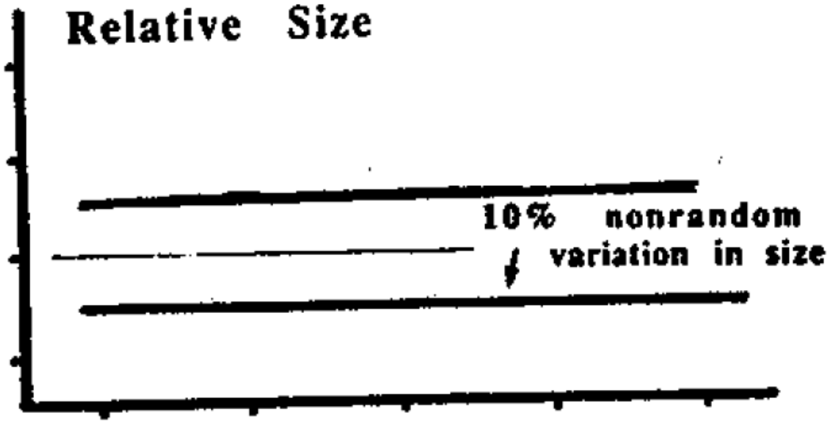
Gibson and Sedgwick then stated that **visual landmarks** can provide information about the **relative** depth (Proffit, 2006).

Measuring distances



Occlusions provide information about the ordinal distance (Cutting & Vishton 1995)

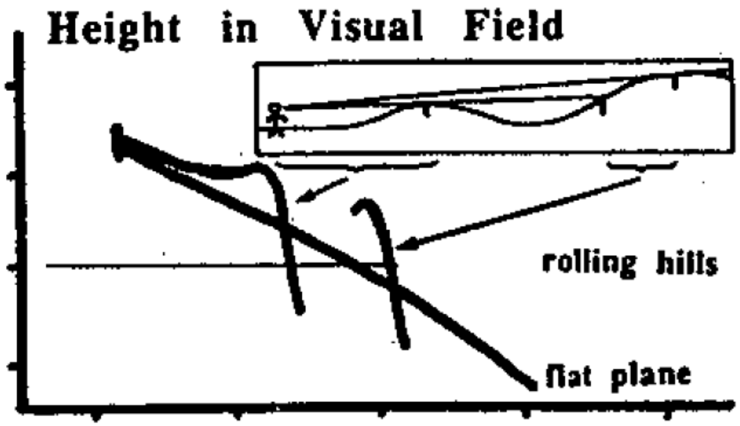
Many cues for depth perception



Relative size provides information about the ordinal distance and the scaling distance. However, the variability in size makes that this cue is moderately informative.

Cutting & Vishton 1995

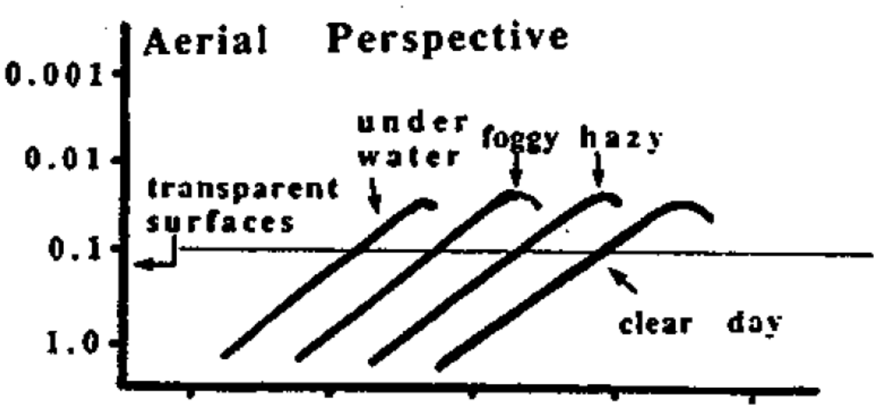
Many cues for depth perception



Kwowing our own **height** can be useful for relative and absolute distances.

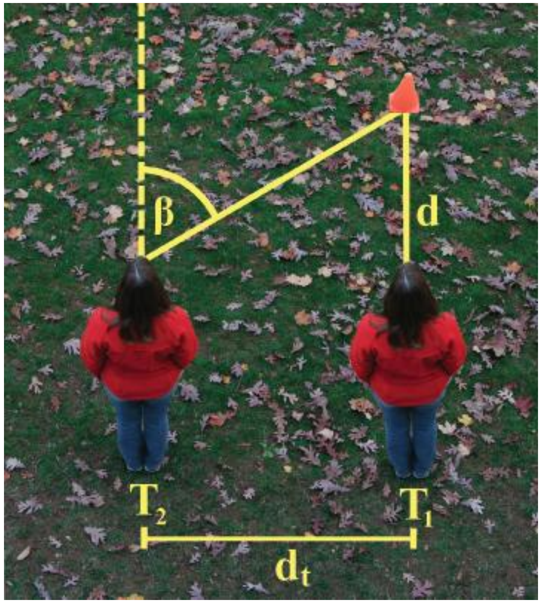
Cutting & Vishton 1995

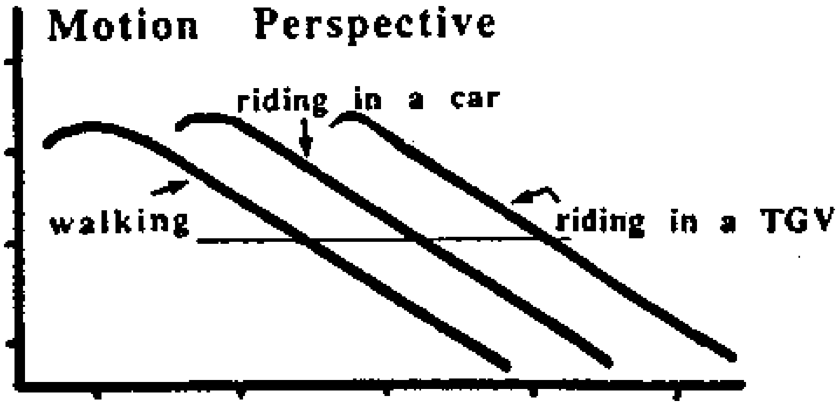
Many cues for depth perception



A**tmospheric effects** can provide information about depth (for instance, objects further away seem more blue and have less contrasts.

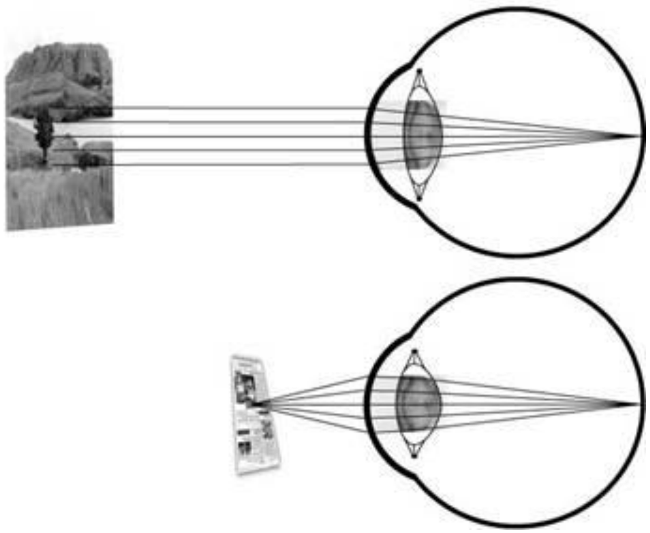
Many cues for depth perception

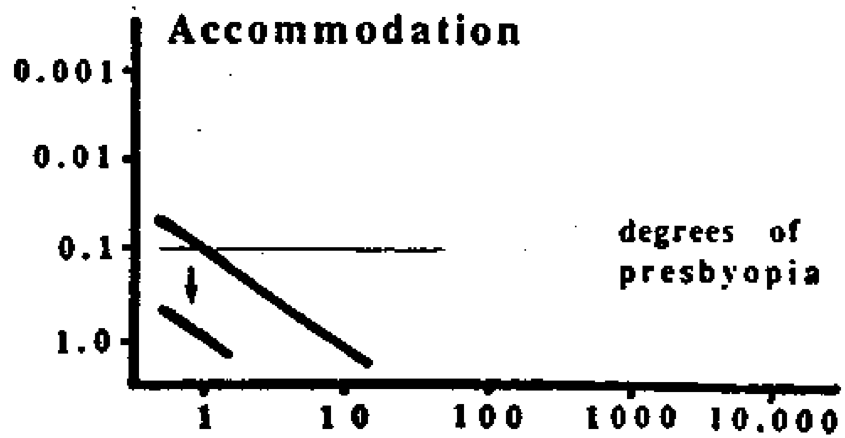




Observer's motion in a rigid space provides information about depth.

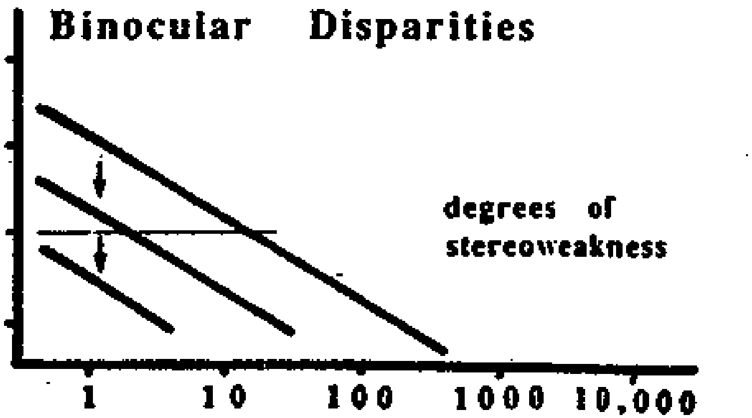
Many cues for depth perception





To focus on different distances, our eyes have to adapt by modifying the **focal distance** of our lenses.

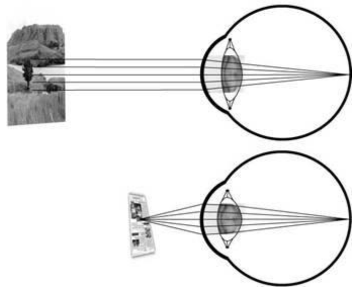
Many cues for depth perception



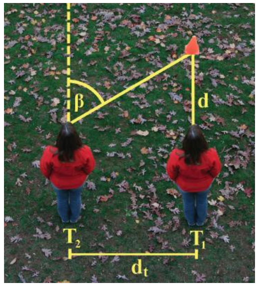
Light entering our 2 eyes provide **stereo** information, hence depth information

Many cues for depth perception

Binocular disparity



Accommodation



Motion perspective

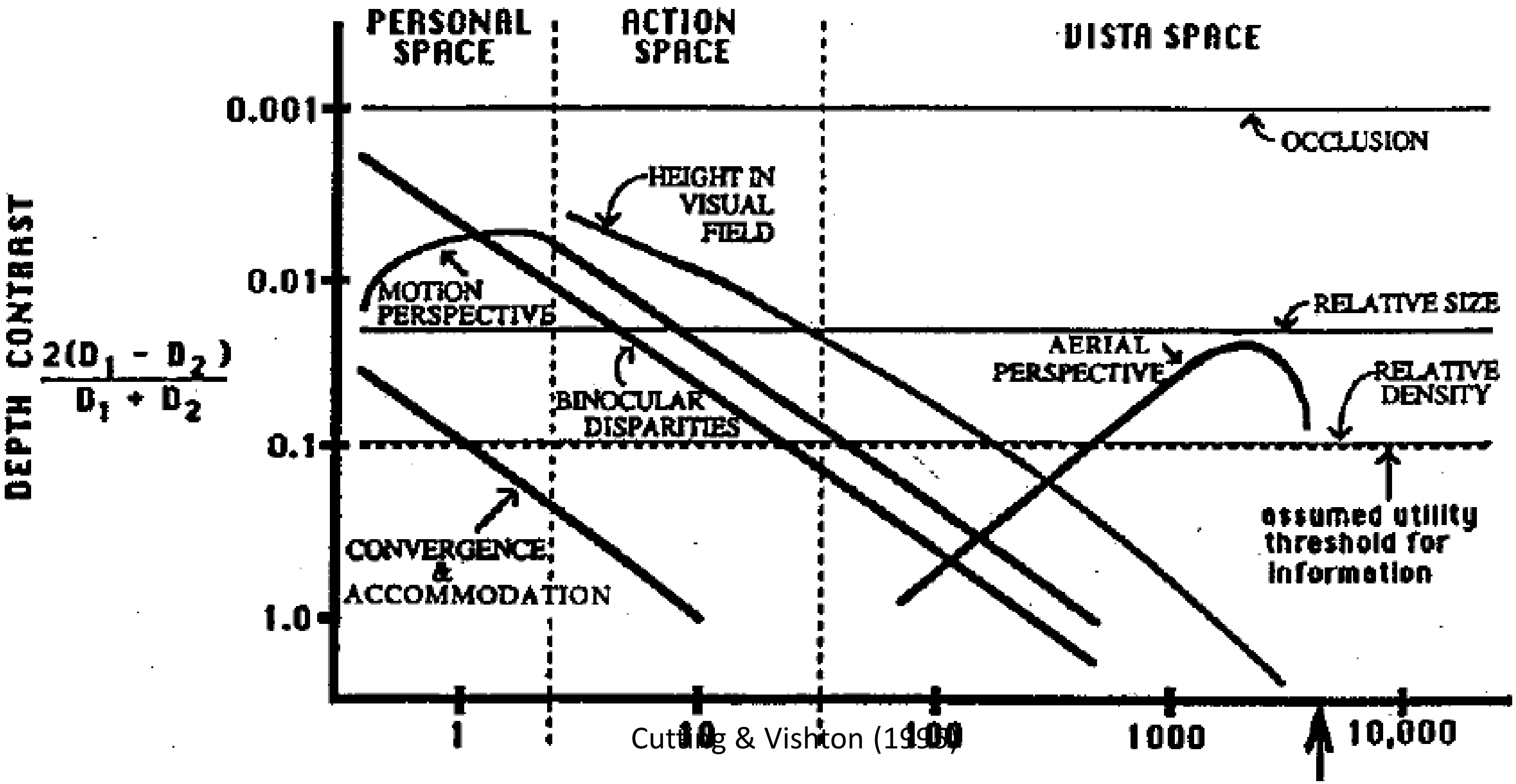
Relative size

Occlusion

Atmospheric perspective

Height in the visual field

Why are there so many cues? How do they interact?



Cutting & Vishton (1995)

Redundancy is useful.

Different cues are useful at different distances

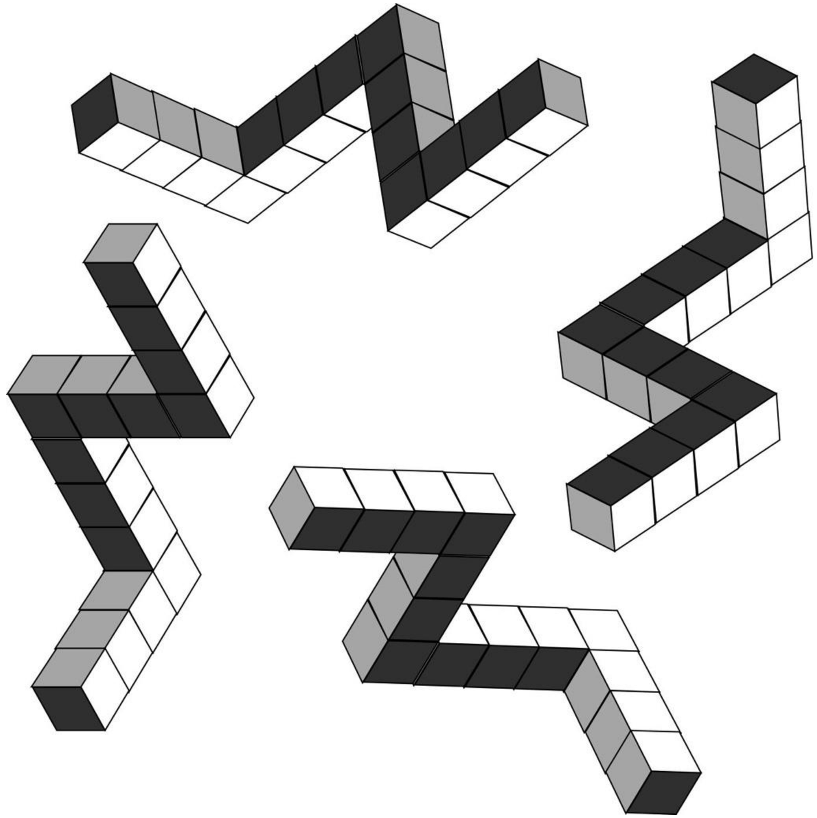
The context influences the perception of distances

- Being tired gives the impression that distances are bigger.
  (Proffit et al. 2003, Witt et al. 2004)

- The goal of the task is important.
  (Witt et al. 2004)

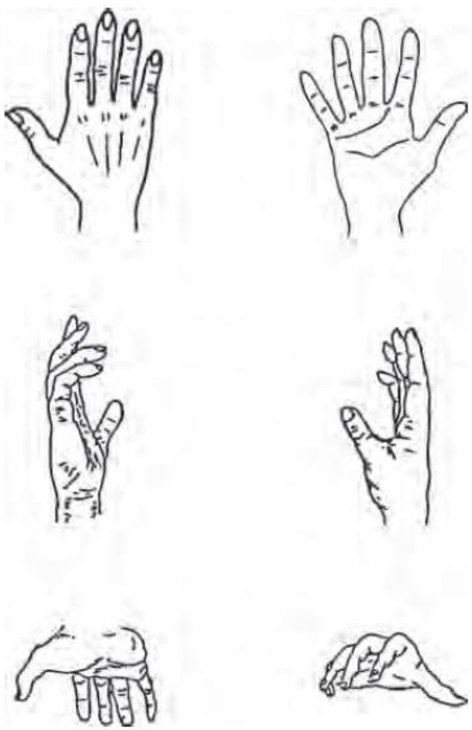
- Fear gives the impression of bigger distances.
  (Schnall et al. 2005, Proffit 2006, Stefanucci 2006)

Beyond the perception of distances: Mental imagery



Linear increase in RTs with increase in rotation

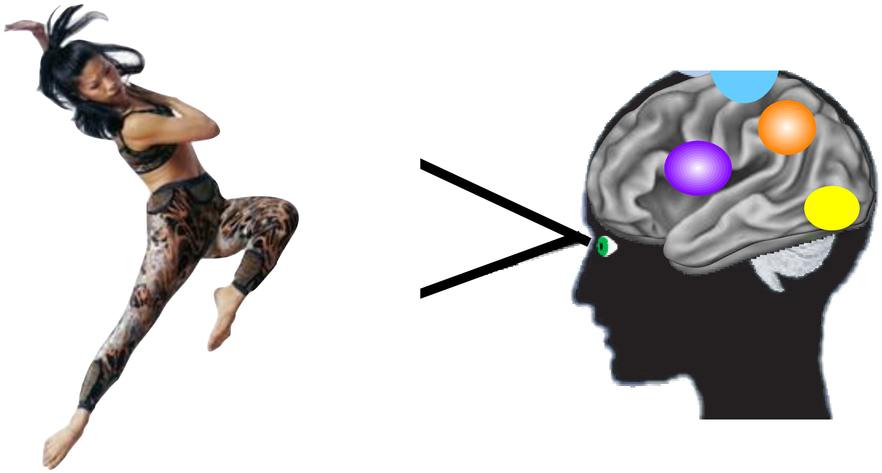
Body schema and mental imagery



Parsons (1994)

RTs correlate with the time necessary to reach the position

What happens after our brain receives visual informations?



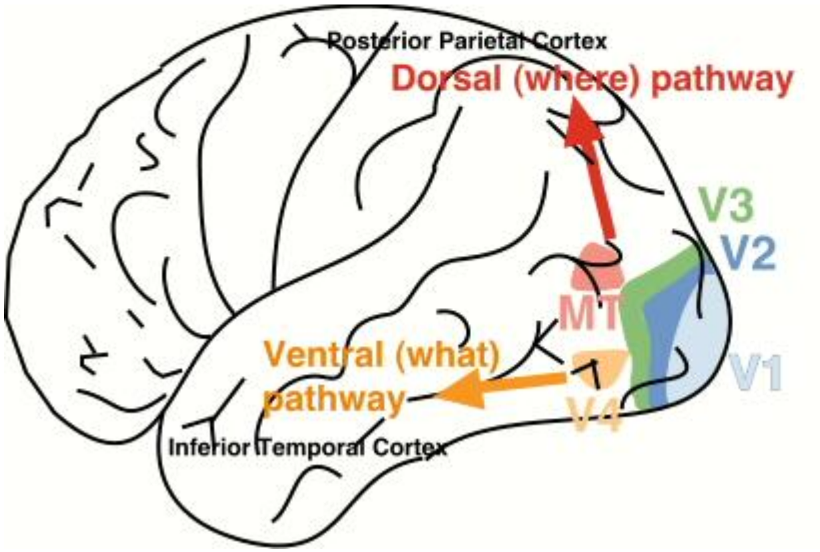
Neuroanatomy of spatial cognition

After ou brain receives visual information:

(1). Ventral visual pathway, leading to the inferior temporal cortex.

(2). Dorsal visual pathway leading to the posterior parietal cortex.

Ventral and dorsal pathways: parallel systems with important **inter-connectivity**.



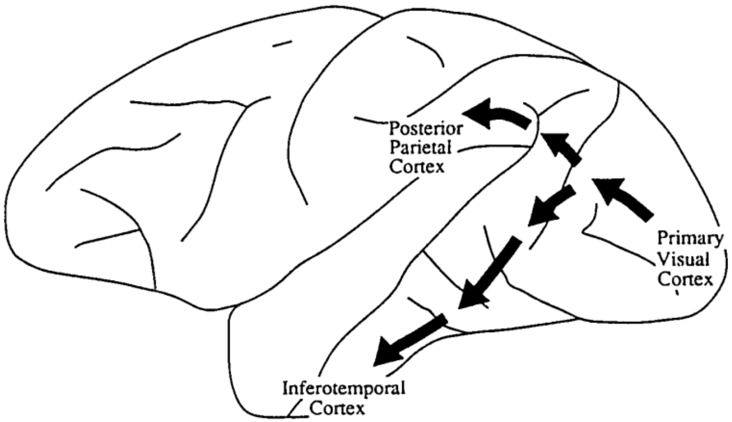
Ventral vs. dorsal pathways

This anatomical separation of the processing of visual information through the dorsal and ventral pathways is now well established.

What about the functions corresponding to these two pathways?

Ungeleider & Mishkin (1982)
Ground their distinction on stimulus attributes

<u>Classical view:</u>
Dorsal pathway: Where is the stimulus?
Ventral pathway: What is the stimulus?



Ventral vs. dorsal pathways

Ungeleider & Mishkin (1982)

Experimental evidence to back up this functionnal distinction:

Studies of lesions in monkeys:

Two tasks: object discrimination and spatial discrimination.

Ventral vs. dorsal pathways

Ungeleider & Mishkin (1982)

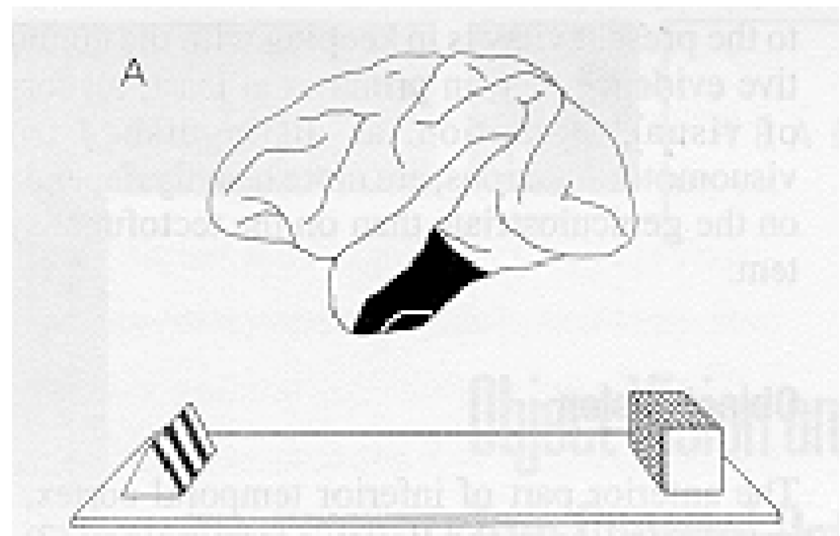
<u>Lesion studies in monkeys:</u>

Lesion in the ventral pathway

Object discrimination

- Pairing task

→Monkeys with a bilateral lesion in the sub-temporal lobe are impaired in this task.



Ventral vs. dorsal pathways

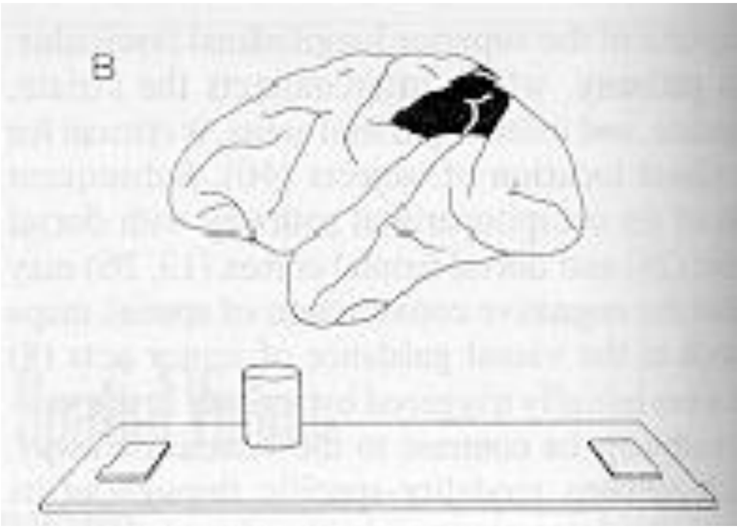
Ungeleider & Mishkin (1982)

<u>Lesion studies in monkeys:</u>

Lesion in the dorsal pathway

Spatial discrimination

• Choose the biscuit the closer to the landmark (landmark discrimination)



Monkeys with bilateral **posterior parietal lesions** are impaired in this task.

→ **Role of the parietal cortex in spatial discrimination tasks**

Ventral vs. dorsal pathways

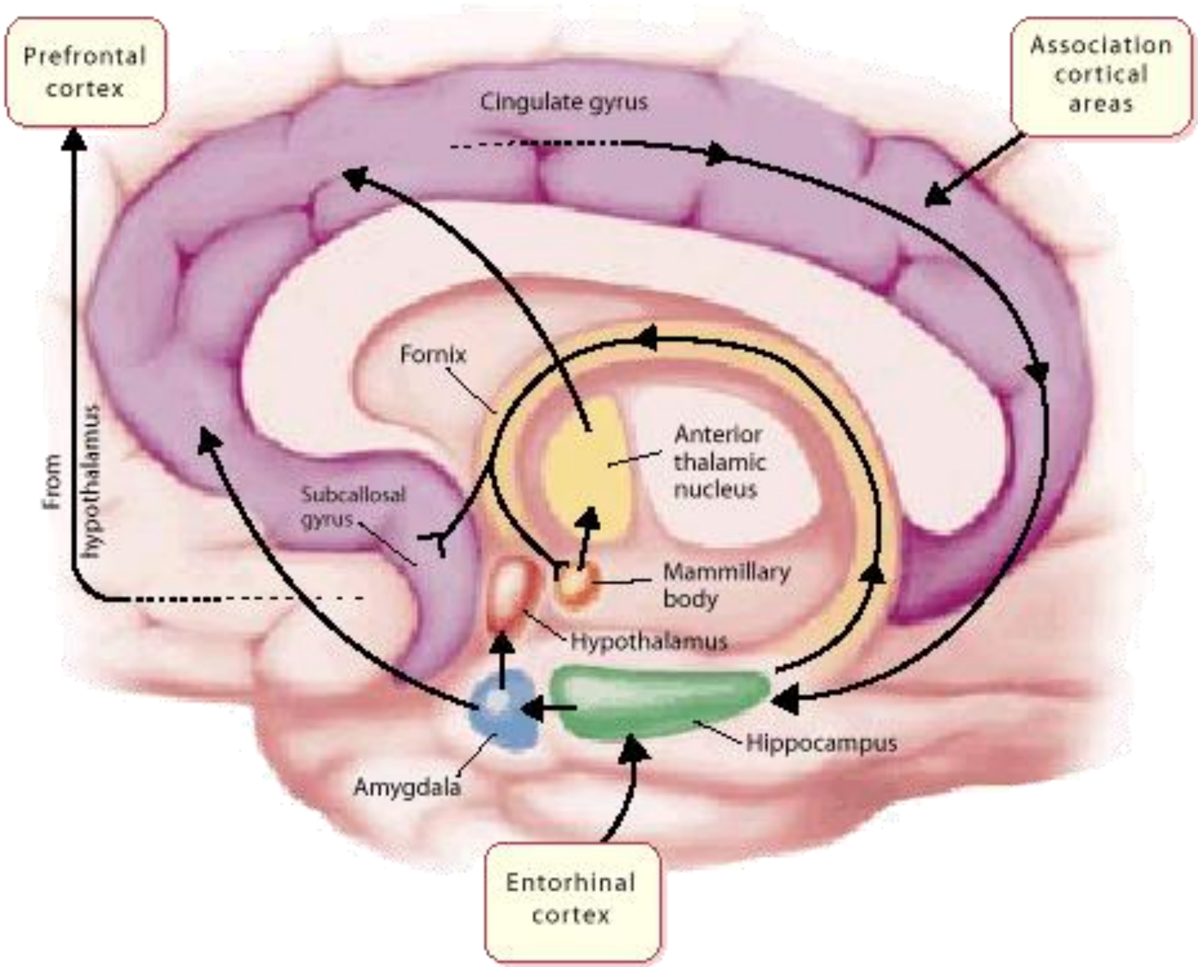
Milner & Goodale (1995) have criticized Ungeleider & Mishkin's conclusion.

Instead, they proposed a division of work based on the use of visual information rather than on the characteristics of the stimulus.

Ventral: Visual perception

Dorsal: Visual guiding of action toward a goal

Hippocampus: a central role in spatial navigation and memory



The hippocampus gathers multimodal information highly processed and consolidates them in memory.

Connections toward and from the hippocampus

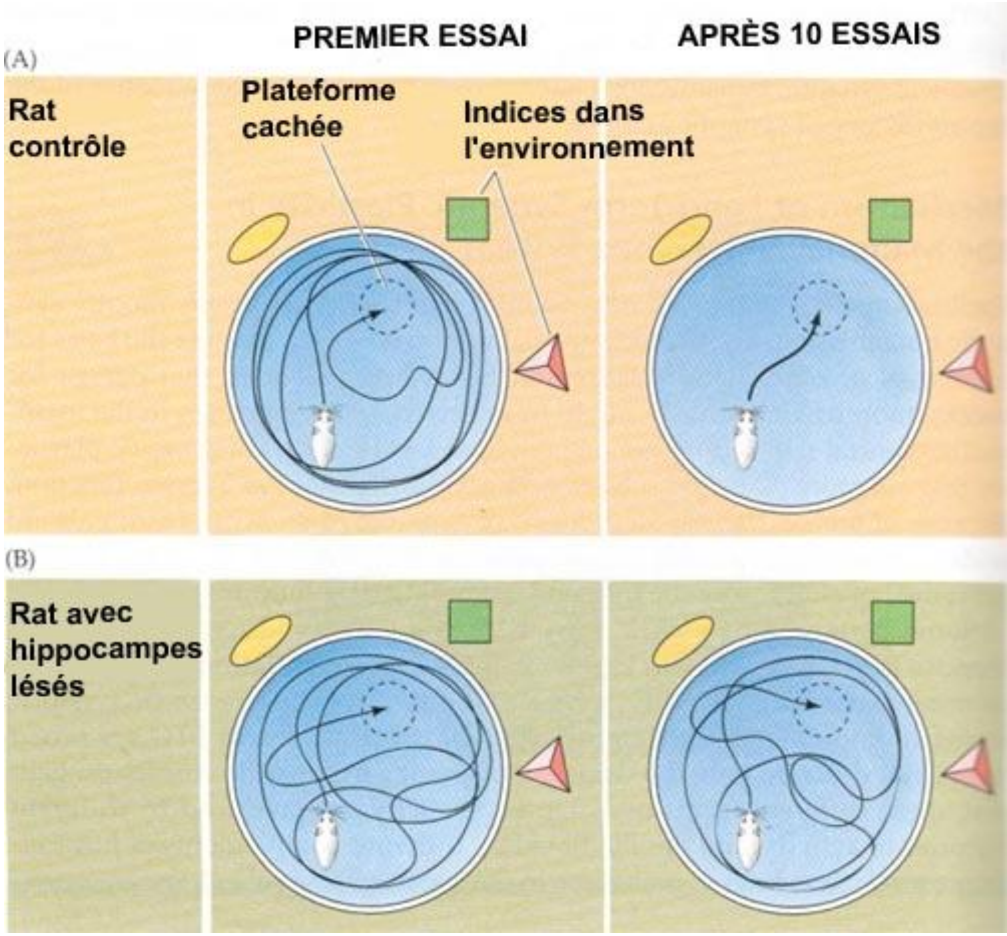
Example: spatial learning in rats

Morris' maze

(A) Rats are placed in a circular swimming pool (child size) filled with opaque water. In the environment around the swimming pool there are cues such as doors, curtains, windows.
A little platform is placed inside the swimming pool, just under the surface, such that it remains invisible.

→**After few trials, normal rats swim directly toward the platform at each trial.**

(B) On the other hand, the trajectory of rats with a lesion to the hippocampus shows an **inability to remember where** is the platform, and this, even after several trials.



The role of hippocampus in spatial cognition

In the hippocampus, there are place and direction cells that code location, distance, direction and speed.

These functionnal properties form the basis of cognitive maps that underlie:

a) Orientation
b) Identification of goals and computation of trajectories
c) Planning of interactions between agents and objects
d) Other cognitive abilities (e.g., temporal, linguistic).

Brain plasticity

If the macroscopic organisation of the cortex is fixed, there are processes of plasticity at the levels of the molecules, neurons, dendrites and synapses, and neural networks.

2. Spatial cognition and brain plasticity

Brain plasticity and learning pathways
Brain plasticity after lesions
Flexibility in spatial perspectives

Brain plasticity

- Neural plasticity is widely acknowledged in the scientific community:
- The brain is always changing
- Learning modifies the brain
- Experience and context modifie the brain

Example of brain plasticity – hippocampus of taxi drivers

The hippocampus is known to be involved in spatial navigation and cognition in animals.

↑ in the relative volume of the hippocampus in small mammals and birds who have habits requiring spatial memory (e.g., storing foods).

↑ in the volume of the hippocampus during the seasons during which the necessity to use spatial abilities is the highest; depends on the species.

→Tendency of the hippocampus to undergo structural changes as a result of behaviours requiring spatial memory.

Maguire et al., 2000, PNAS

Example of brain plasticity – hippocampus of taxi drivers

The hippocampus plays a similar role in humans.

- Structural difference in the brain as a function of groups of persons (e.g., musicians vs. non musicians.
- Research on lesions and functionnal neuroimagery confirmed in humans the involvement of the hippocampus on spatial memory and navigation but not its specific role.

→ Pre-determined differences in brain morphology or plastic changes in response to environmental stimuli?

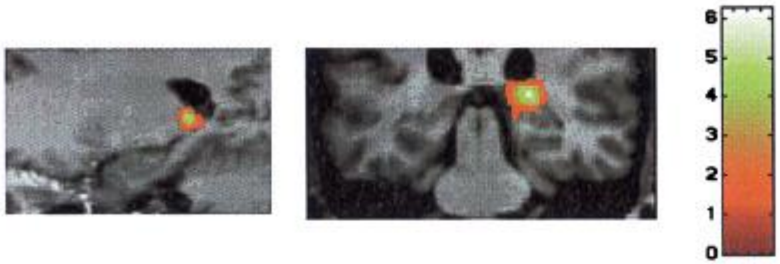
Hypothesis of the study: In healthy humans, the hippocampus would be the brain region the most likely to display physical changes associated to an intensive navigation.

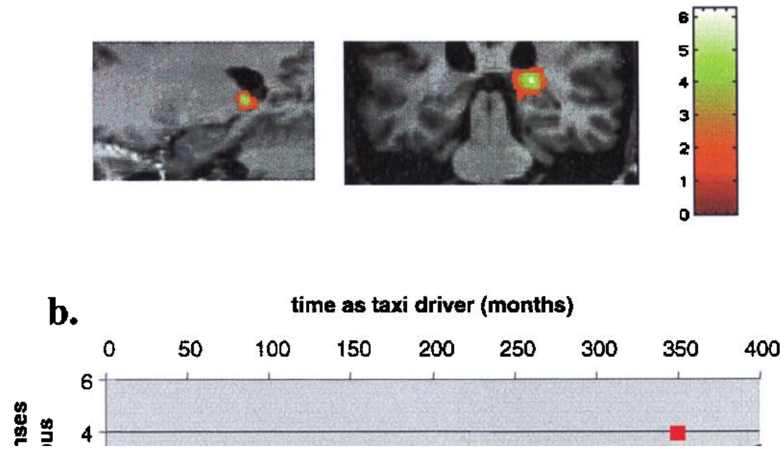
→ Comparison of the structure of the hippocampus in taxi drivers (acquired experience).

Maguire et al., 2000, PNAS

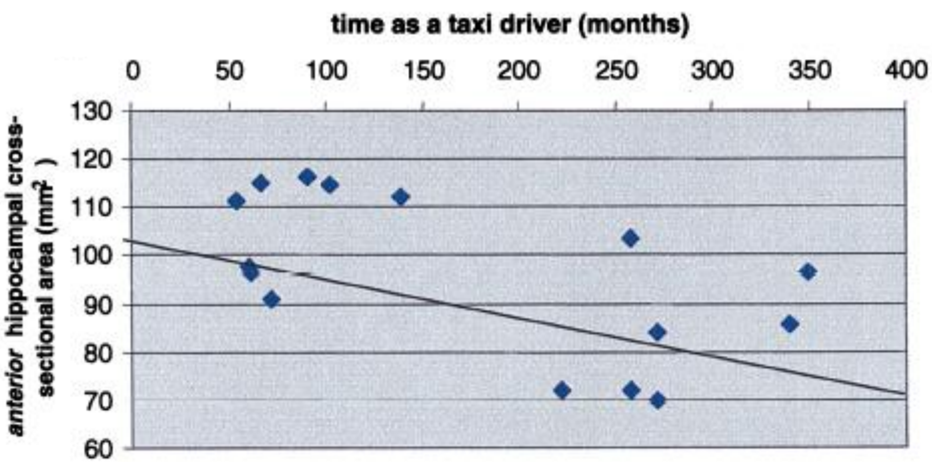
Example of brain plasticity – hippocampus of taxi drivers

- The longer the time spent as a taxi driver the bigger the size of the right posterior hippocampus.





- The longer the time spent as a taxi driver, the smaller the size of the anterior hippocampus.



Maguire et al., 2000, PNAS

Example of brain plasticity – hippocampus of taxi drivers

Implications

- Hippocampus plasticity results from spatial experience.
- An important spatial experience induces a growth in posterior hippocampus.
- Trade-off between the sizes of the posterior and anterior hippocampus
  - Posterior hippocampus: Storage of previously learned spatial information.
  - Anterior hippocampus: Coding of novel spatial environment.

→ Brain plasticity to improve reaction times and spatial memory.

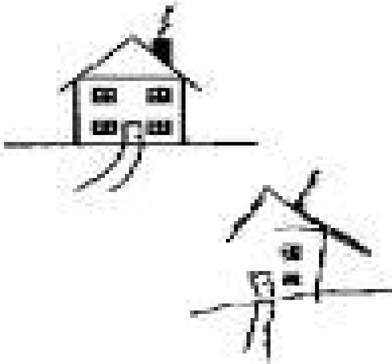
Example of brain plasticity – Hemineglect

→ After a lesion of the right hemisphere, many hemineglect patients have impairments in their perception of space, external world, and position of their own body.

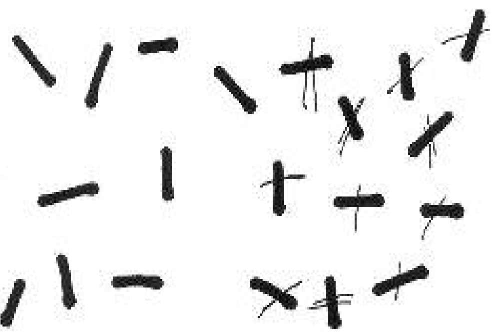
Example of brain plasticity – Hemineglect

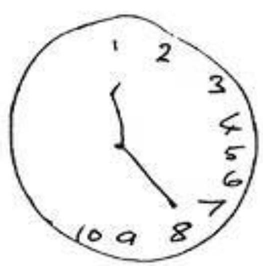
Examples of tests conducted in hemineglect patients
(here after lesion of the right hemishere)
Deficit in visuo-spatial perception

Drawings from a model or from memory



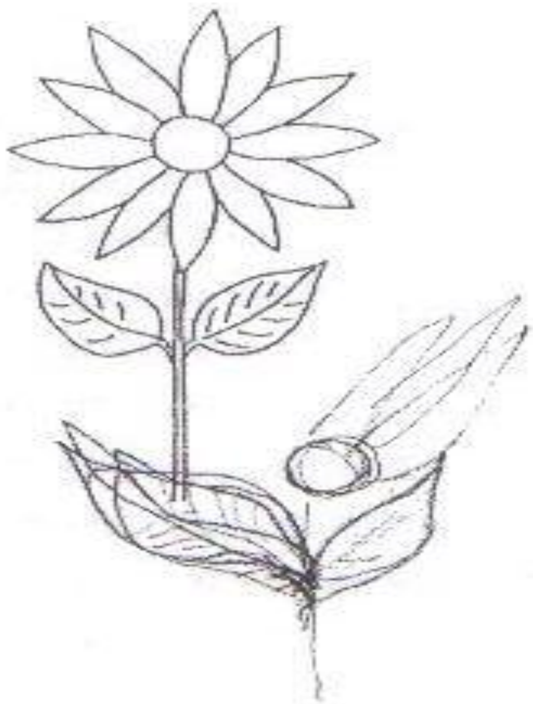
Cross out lines



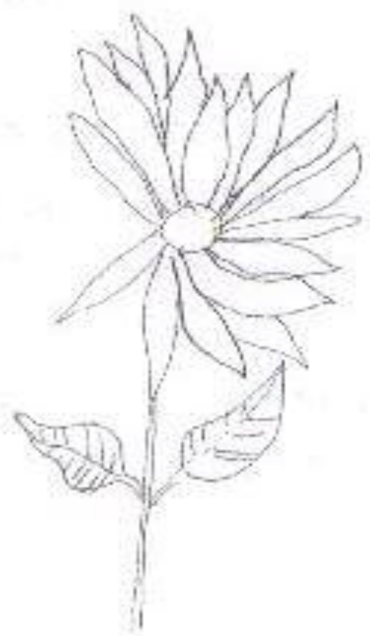


Example of brain plasticity – Hemineglect

Functional recovery



Model + drawing 1 month after stroke



Drawing 4 months after stroke

Example of brain plasticity – Somatoparaphrenia

Multiples bodily models in the brain

Determined as a function of:

- **Sensory channels** from which the information is extracted and combined
- **Reference frames and perspective** in which information about the body is encoded.
- **Body (own versus another person)** from which the information comes from.

- **Somatoparaphrenia**: The patients no longer recognize their own limbs, sometimes they have the impression that they are erased or that they belong to someone else.

> "But my eyes and my feelings don't agree, and I must believe my feelings. I know they [left arm and leg] look like mine, but ***I can feel they are not***, and I can't believe my eyes."'

- C.W.Olsen, 1937

Example of brain plasticity – Somatoparaphrenia

Somatoparaphrenia: example of deficit in ‘egocentric’ perception.

- **Functional recovery:**

Training by means of mirrors -> they re-connect their 1st and 3rd person perception. Recovery of the feeling that their limbs belong to them.

Spatial perspective taking

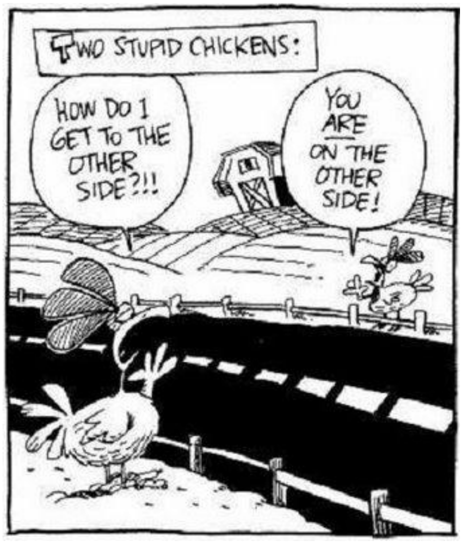
There are several ways to define the spatial coordinates (bottom, up, right, left) of a tactile stimulation.

Spatial coordinate assignment depends on the perspective adopted to perceive the stimulation.

(i) perspective centred on the observer.

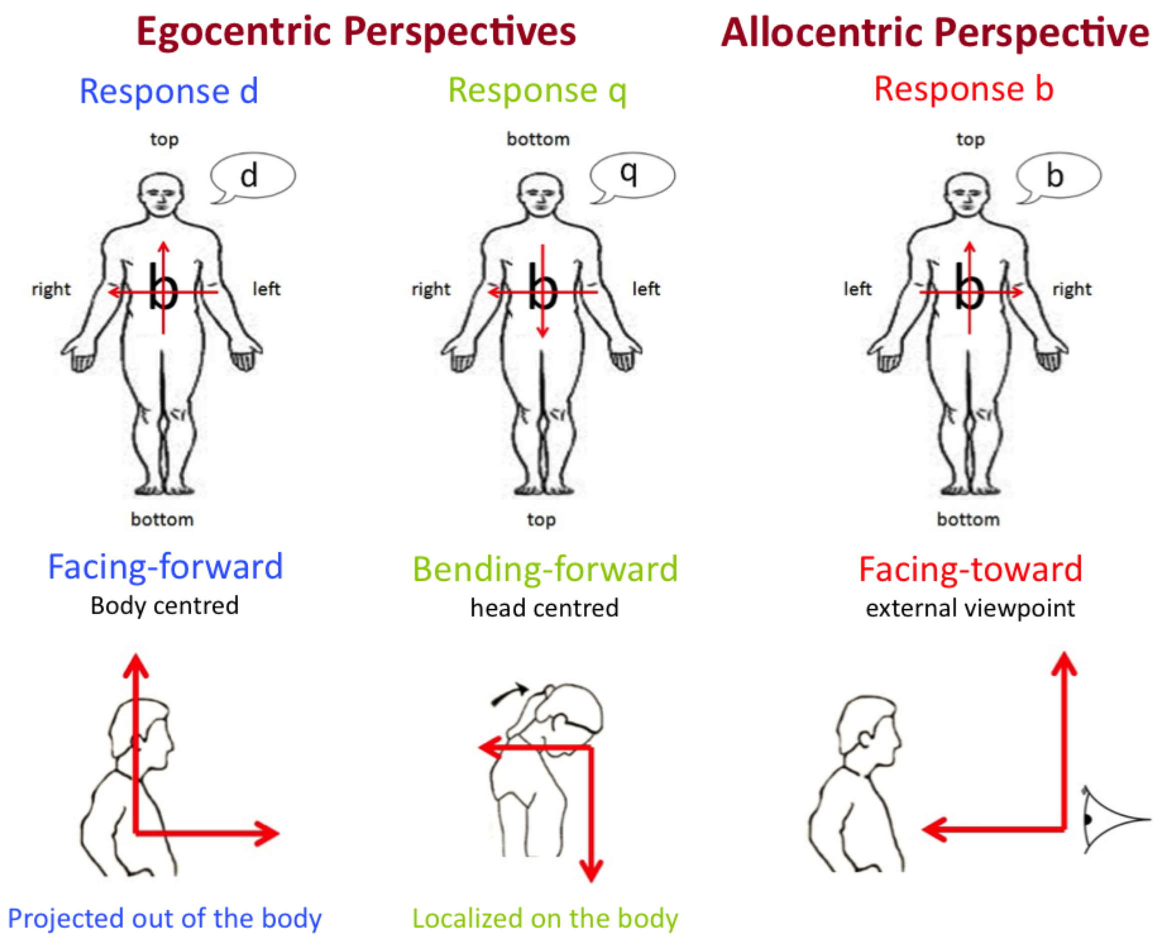
(ii) decentred perspective (external point of view)

→ Task. Recognition of ambiguous tactile symbols drawn on the body surface.



Spatial perspectives

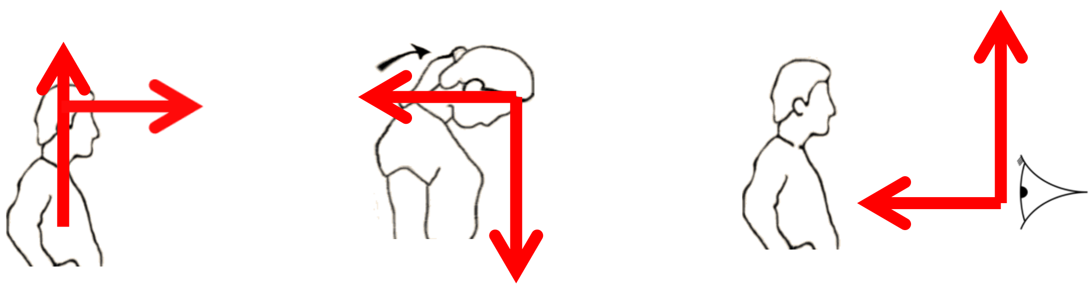
Recognition task of letters (bdpq) traced on the stomach by means of a 3*3 tactile matrix (Arnold et al., 2016).



Spatial perspectives

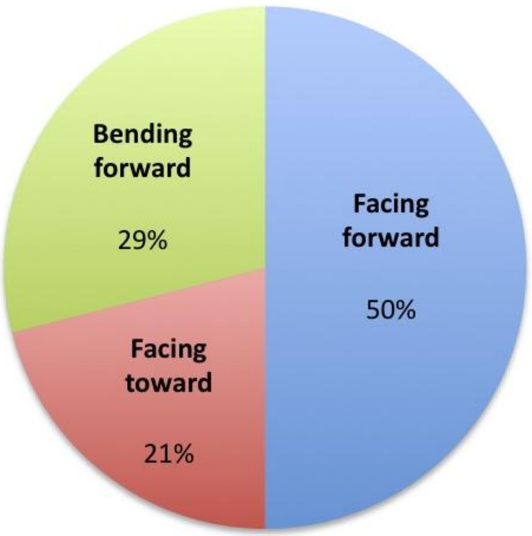
Egocentric RF | Allocentric RF

- Facing forward — Trunk centered
- Bending forward — Head centered
- Facing toward — External viewpoint



From Arnold, Spence, & Auvray (2016)

Proportion of sighted participants adopting each perspective

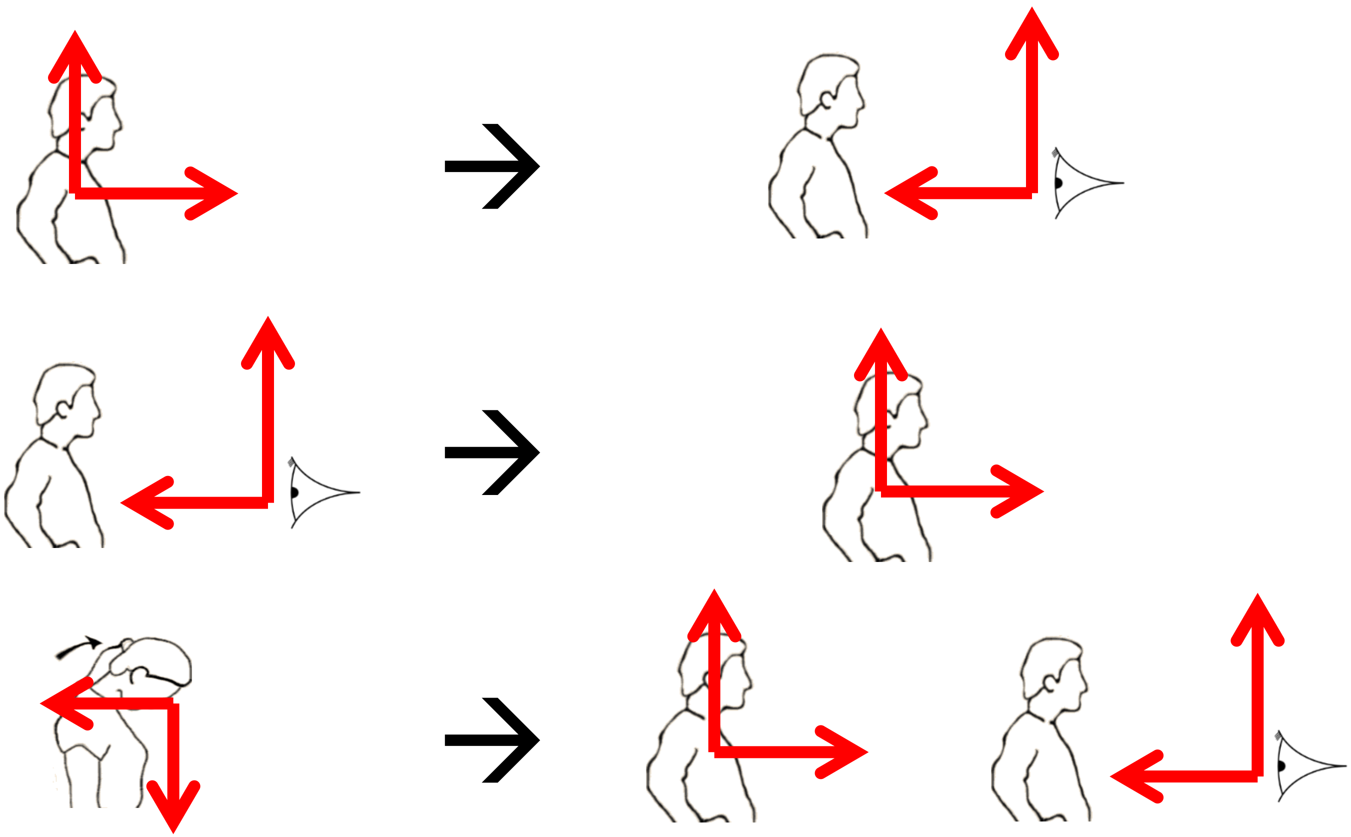


N = 250 (150 F / 100 H)

79% egocentric

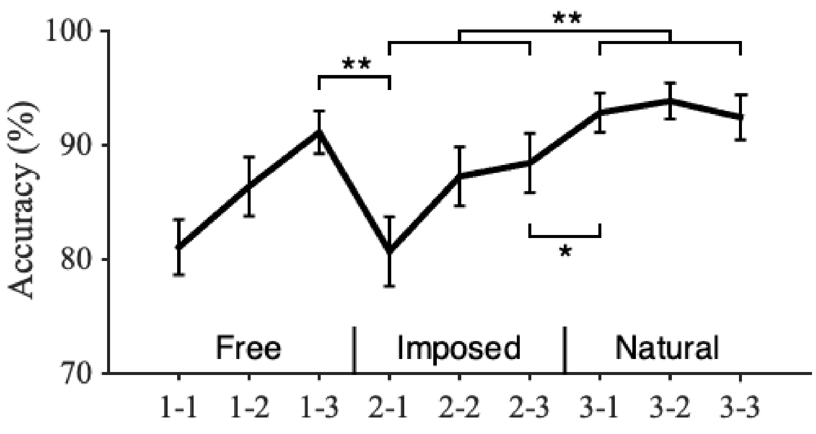
Perspective in session 1

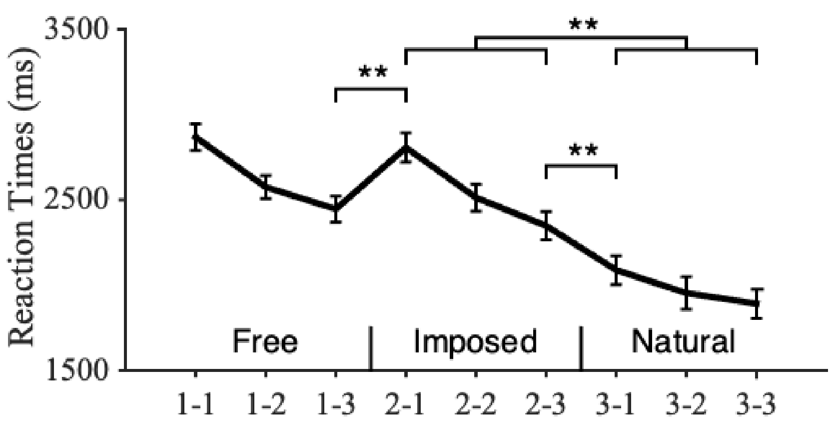
Imposed perspective in session 2 or 3



	Session 1 free	Session 2 imposed	Session 3 imposed
same-different	free	same	different
different-same	free	different	same

Spatial perspective taking





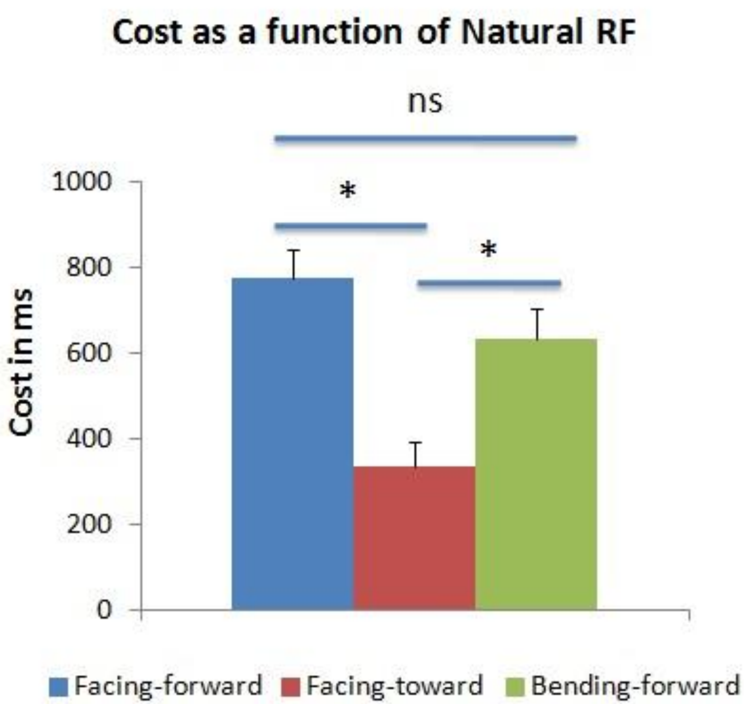
Change in perspective: cost
Lower performance (accuracy and RTs)

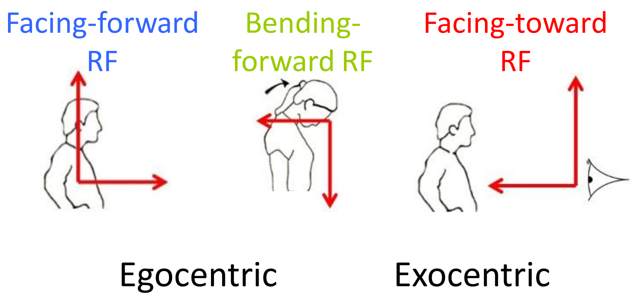
Going back to the first chosen perspective: improvement (accuracy and RTs)

The cost linked to the change is not just due to task switching.

The perspective adopted freely is a natural one not a mere cognitive choice.

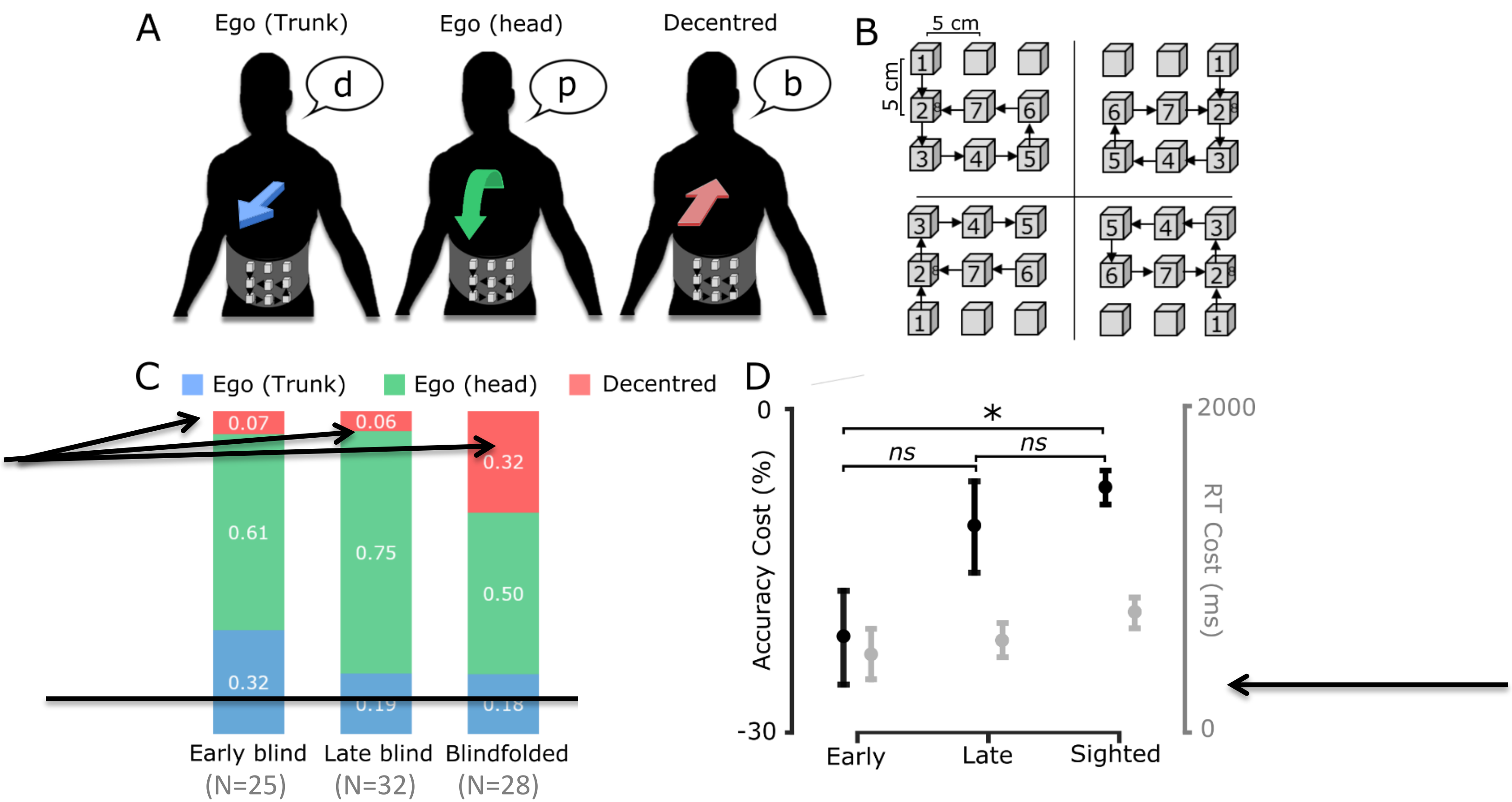
Spatial perspective taking





→ The cost varies as a function of the natural perspective. More important for natural centred than natural decentred.

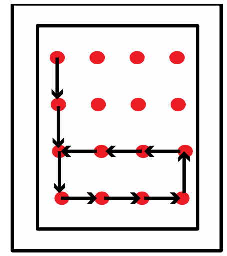
Spatial perspective in blind persons

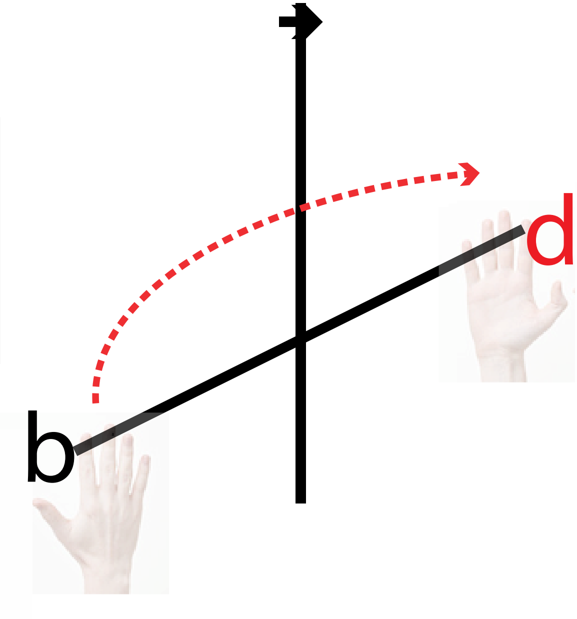


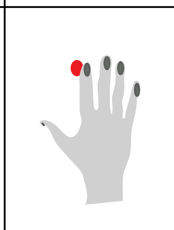
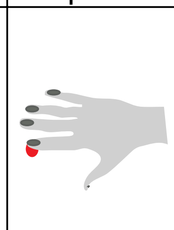
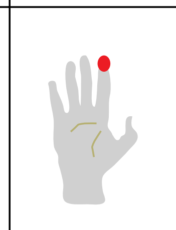
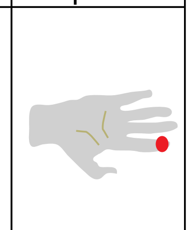
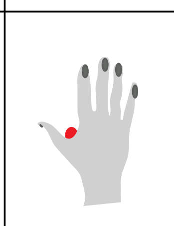
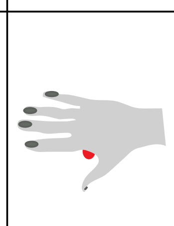
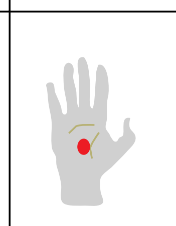
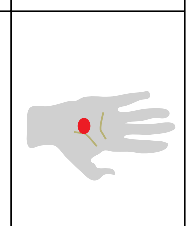
- ❑ Less decentred perspectives in the blind
- ❑ All conditions without vision bias toward the trunk-centred perspective.
- ❑ Greater cost (accuracy) when changing perspective for early blind.

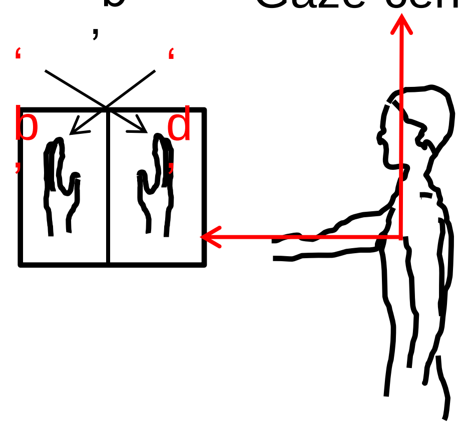
Spatial perspective on the hand

Hand: Role of exploration
Influence of the position and orientation of the effector



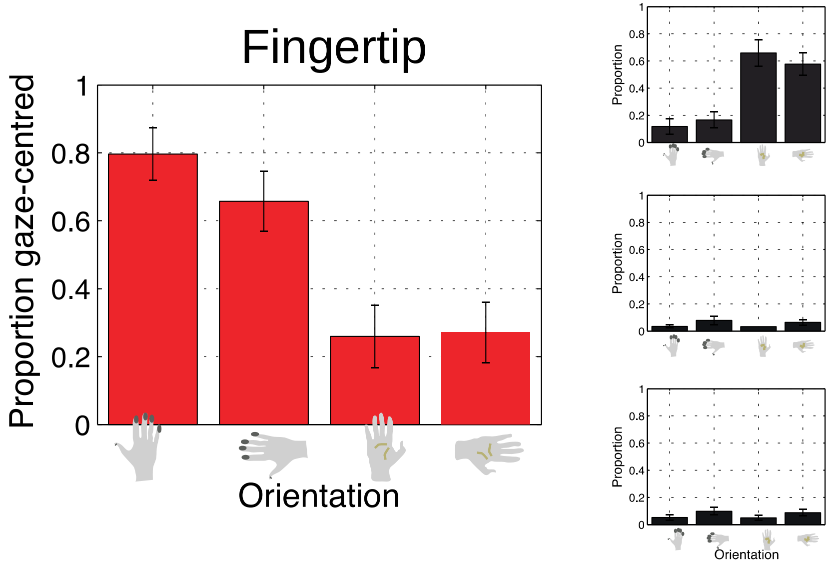


		Orientation			
		Away	Away Perpendic	Toward	Toward Perpendic
Location	Finger				
	Palm				



Spatial perspective on the hands

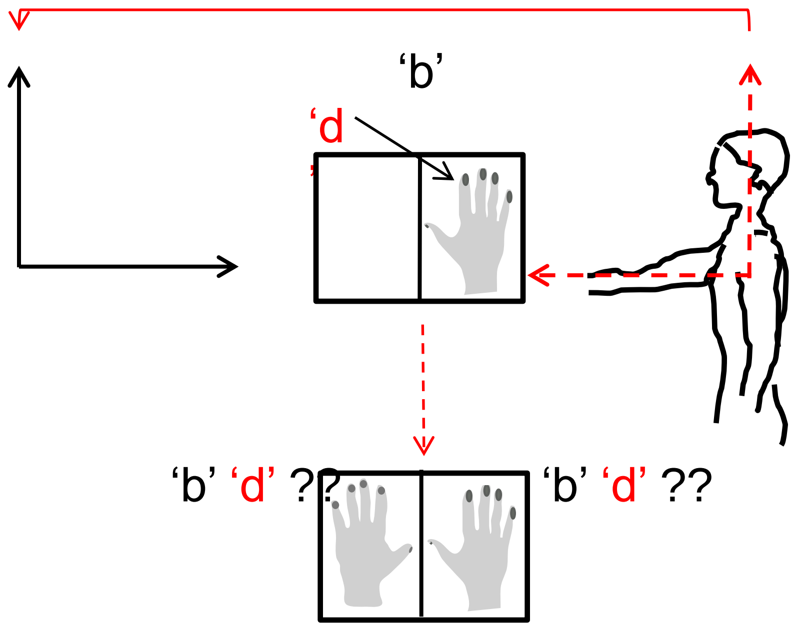
Results (N=12)

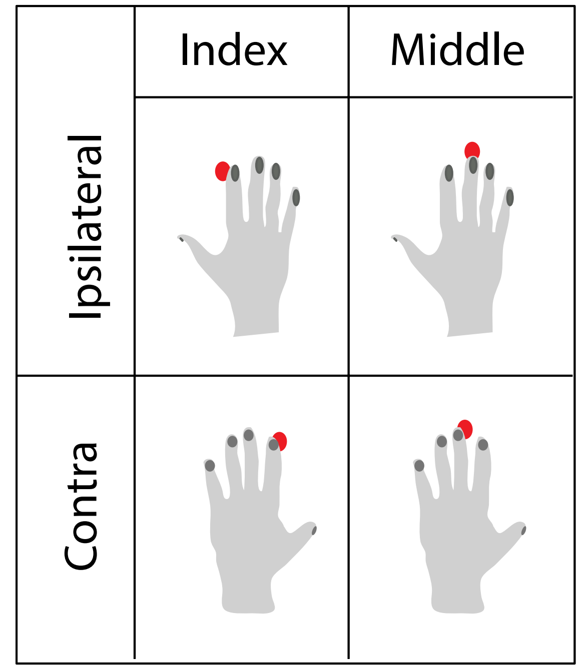


→ The adopted perspective depend on the orientation of the hand

Spatial perspective on the hands

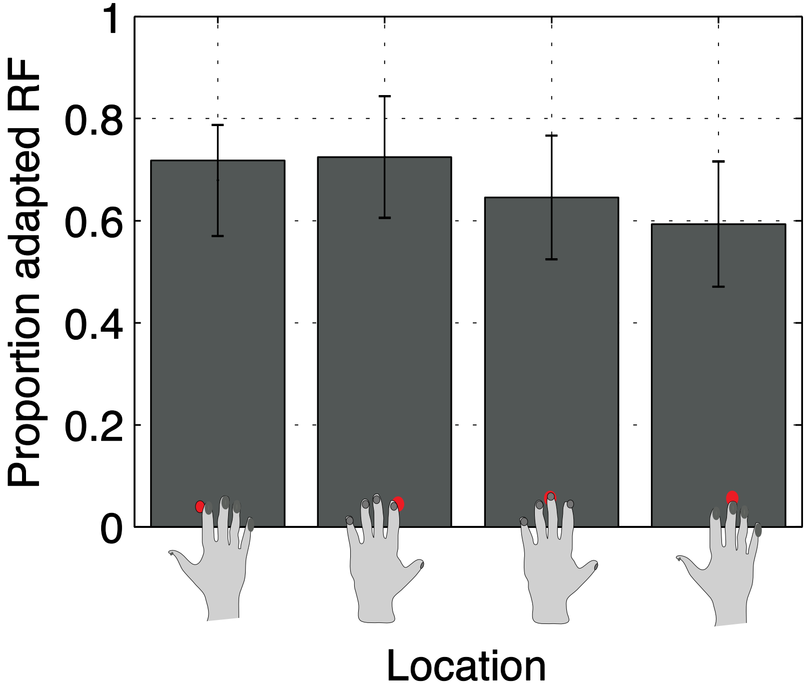
Generalisation of the learned perspective





- Transfer to another fingertip or hand?
- Centred -> Decentred

Spatial perspective on the hands



Post test

- Baseline / training on index / post test
- Transfer of the learned RF to adjacent and contralateral
- Residual interpretation in head-centered RF

→ **Plasticity in perspective taking**