LIVERPOOL
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UNIVERSITY
1844

Recovering from Blindness:

Learning to see after sight restoration from congenital cataracts

Irene Senna

The role of vision

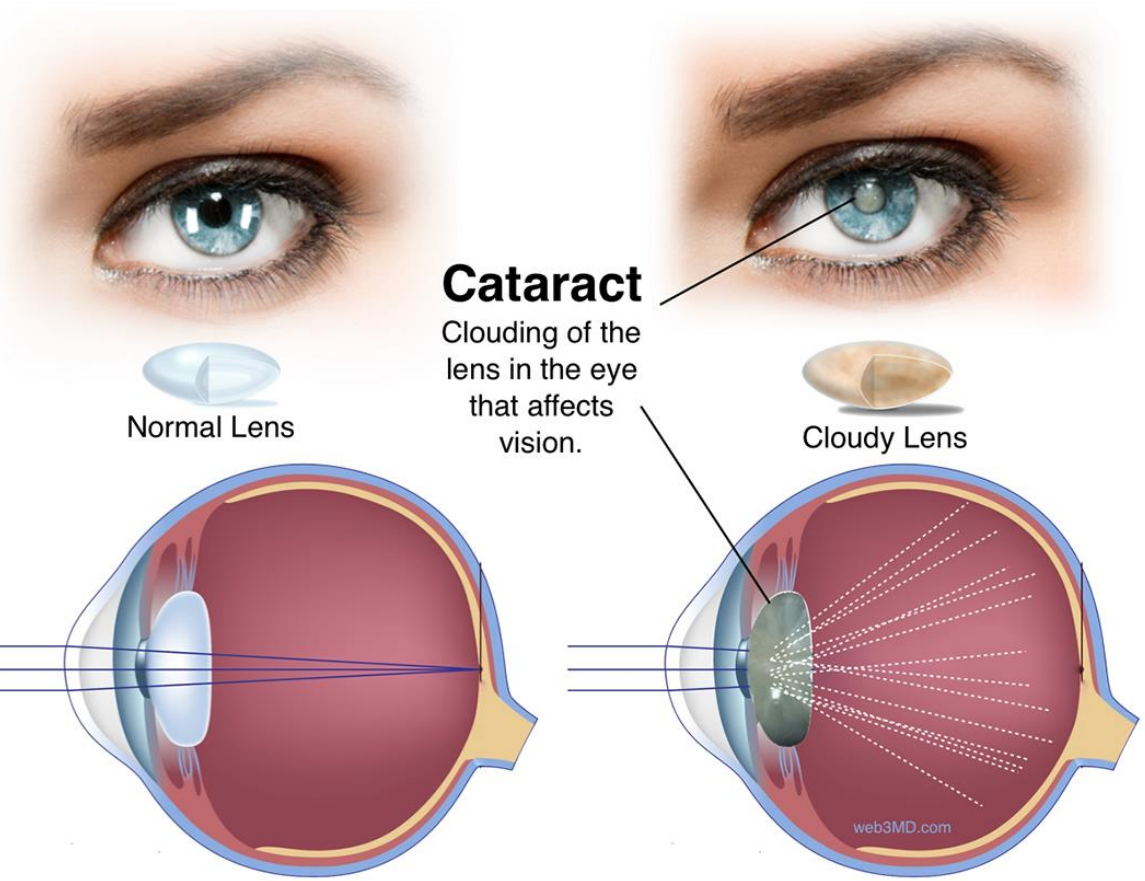
To build **perceptual knowledge** about the world

- Alone or in combination with other senses

To guide **actions**

- For navigating and interacting with the environment
- It provides feedback information for online control and sensorimotor learning
- It is used to generate predictions for feed-forward control of actions

Bilateral Cataracts



Cataracts cause ~ 51% of all cases of blindness

Congenital cataracts (at birth or within the first weeks of life): 1-4 cases per 10,000 live births

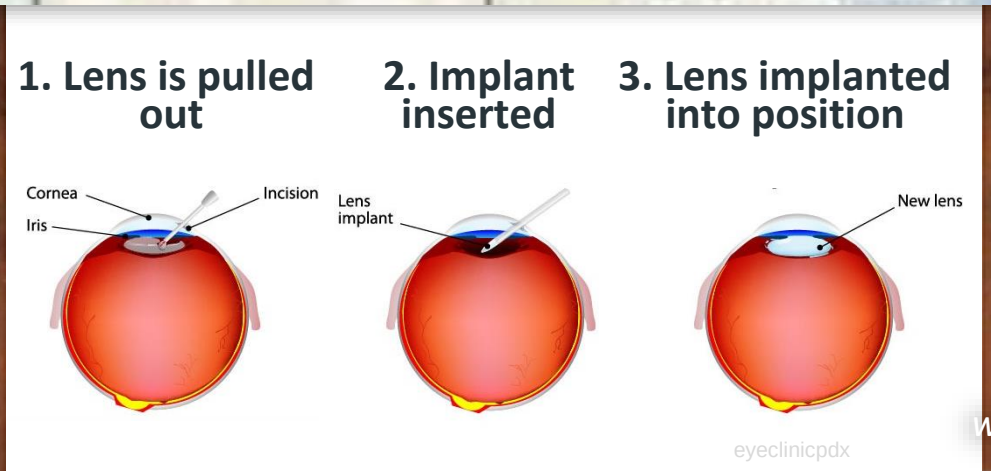
Heterogeneous causes:

-Mutations in genes coding for proteins involved in lens structure/clarity (familiar, new mutations)

-In ~2/3 of the cases they are associated with other diseases (e.g., metabolic), or intrauterine infections (e.g., rubella, toxoplasmosis, herpes simplex,…)

DIP

Gefördert durch
DFG Deutsche Forschungsgemeinschaft



with M.O. Ernst, E. Zohary, S. Uhlman, & U. Pola

Recovery from blindness

Scientific question

- Does the lack of early visual experience prevent from developing perceptual and visuomotor abilities following surgery?
- Can late visual and sensorimotor experience contribute to development?

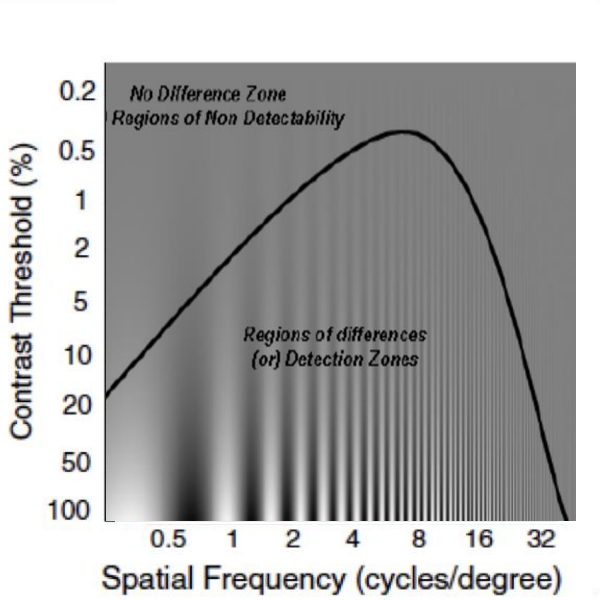
Application

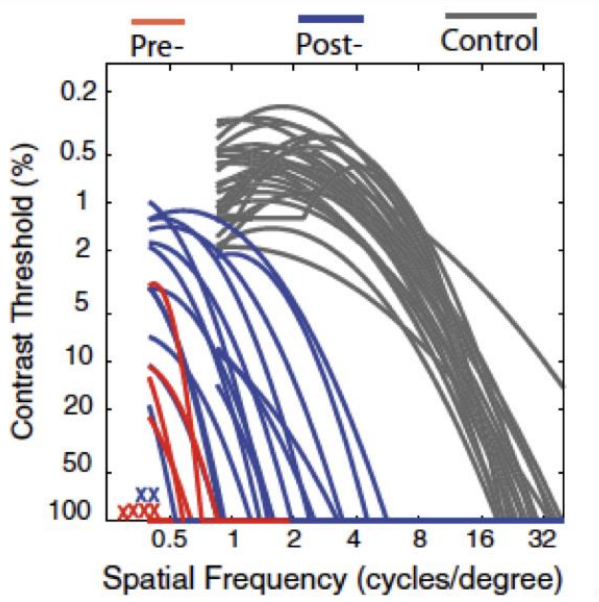
- Can we facilitate post surgical development with training procedures?

Recovering from blindness

Project Prakash (2003, Pawan Sinha, MIT): first project in late cataract-treated individuals (operated 8-18y aftert birth)

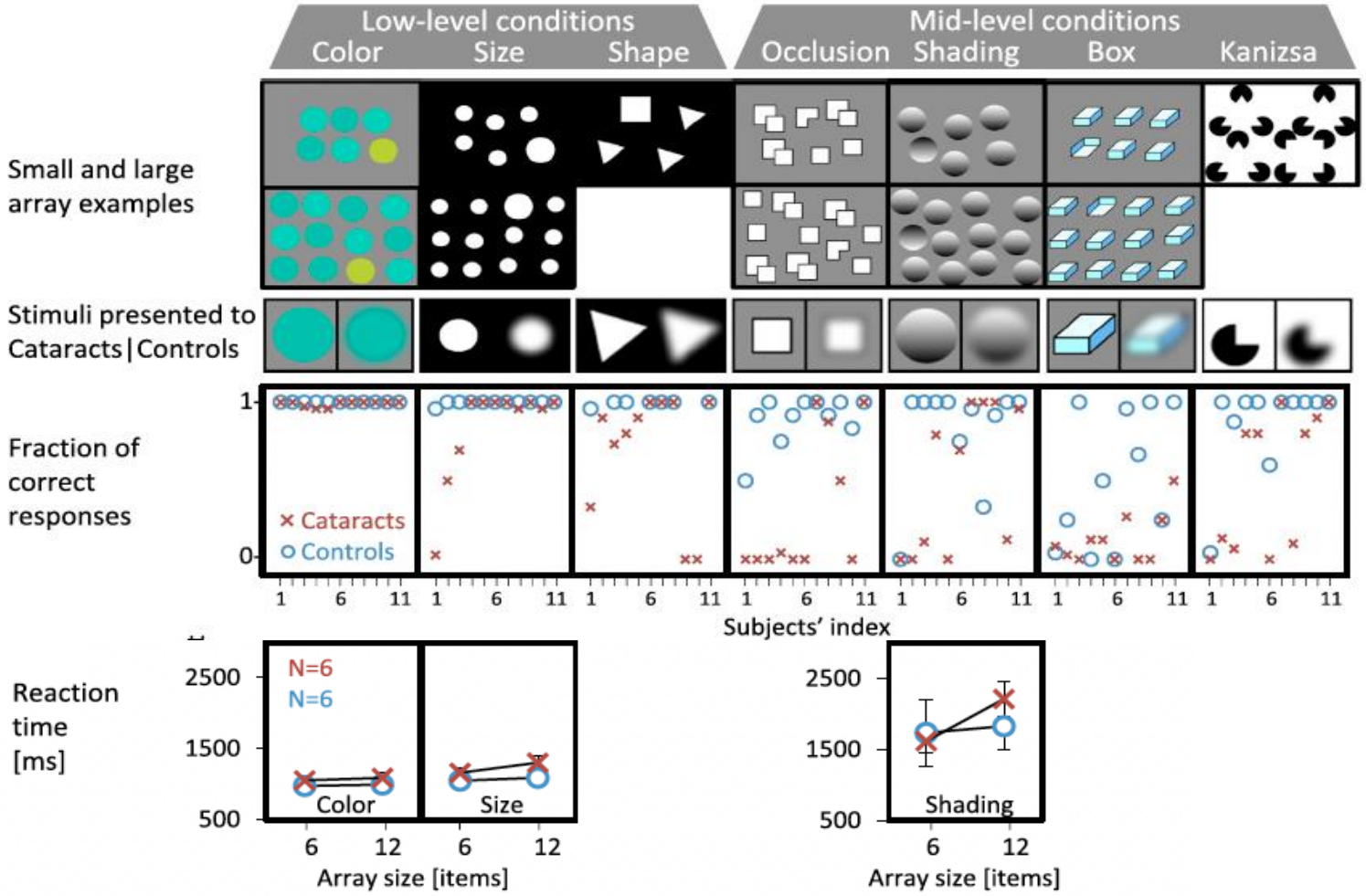
CSF (contrast sensitivity function)





Kalia et al., 2014, *PNAS*

Recovering from blindness



McKyton et al., 2015, *Curr Biol*

Poorer performance than sighted controls also in:

- Global motion perception
- Global form perception
- Holistic face processing
- Audio-visual speech perception
- …

Review: Röder et al., 2021, *Nat Neurosci*

Recovering from blindness

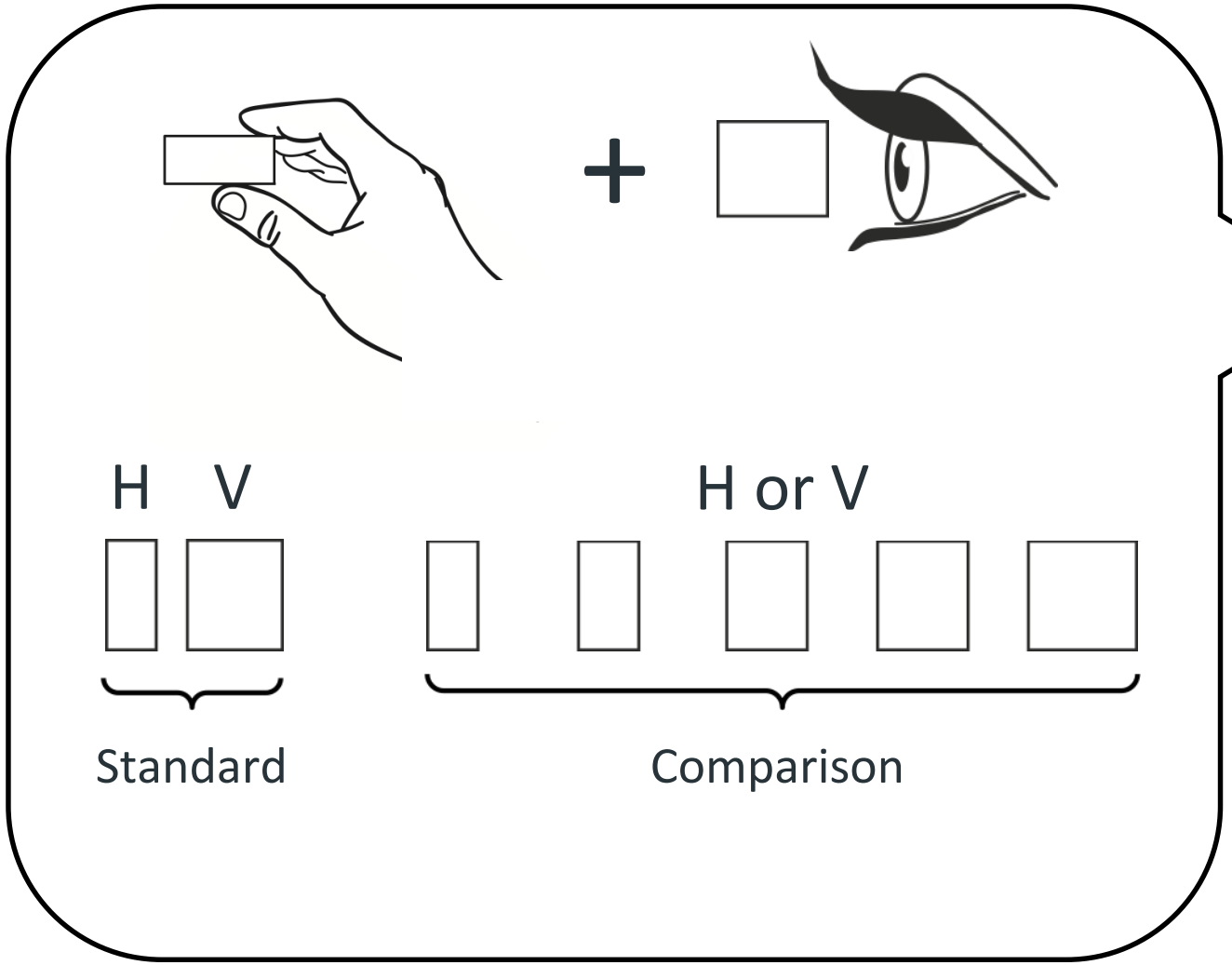
Multisensory Integration

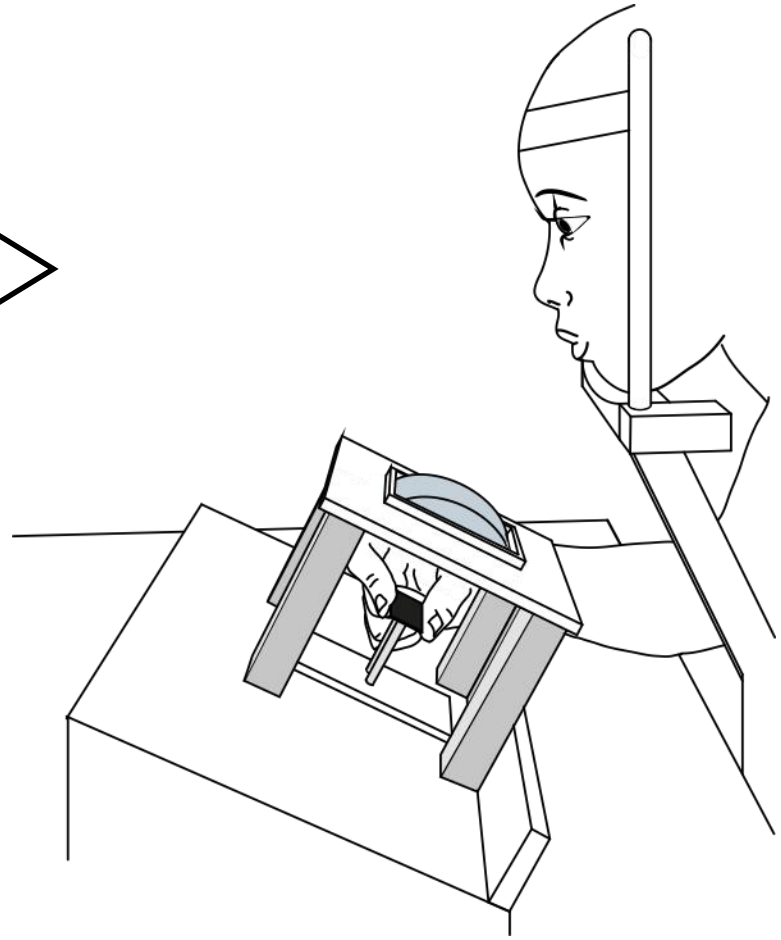
Action control and sensorimotor recalibration

Predictions for feed-forward action control

Navigation and space representation

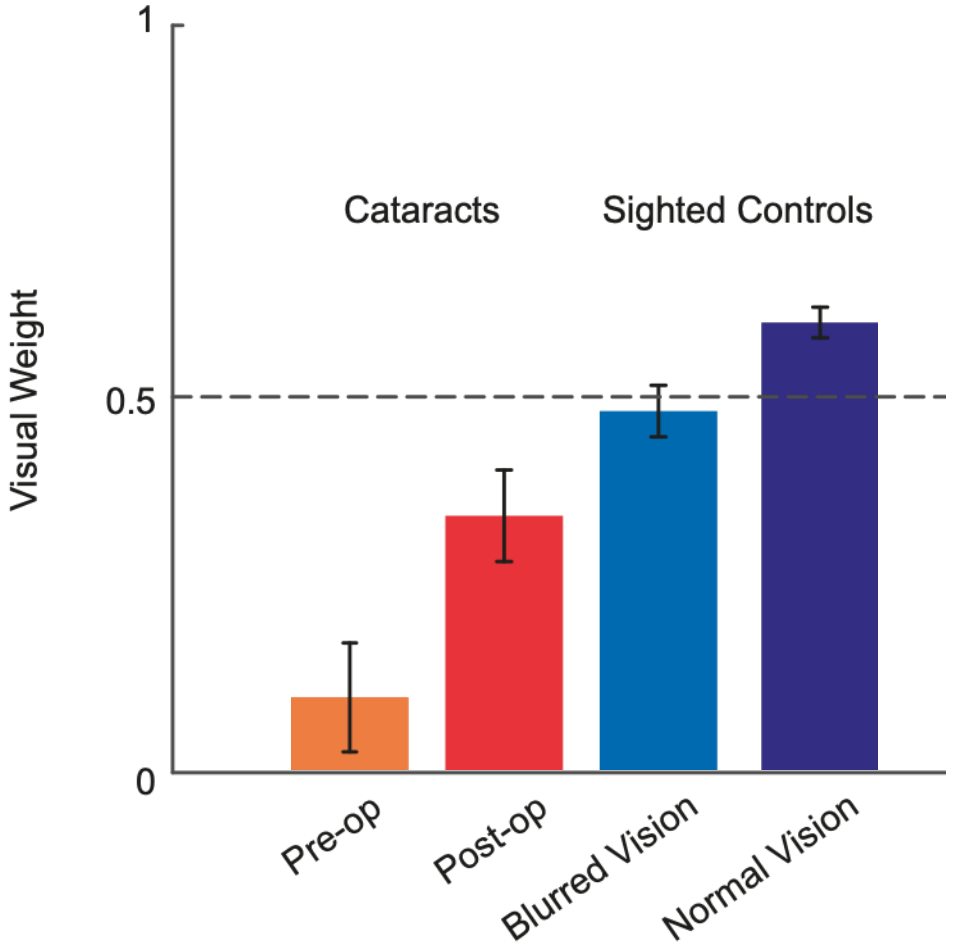
Multisensory integration

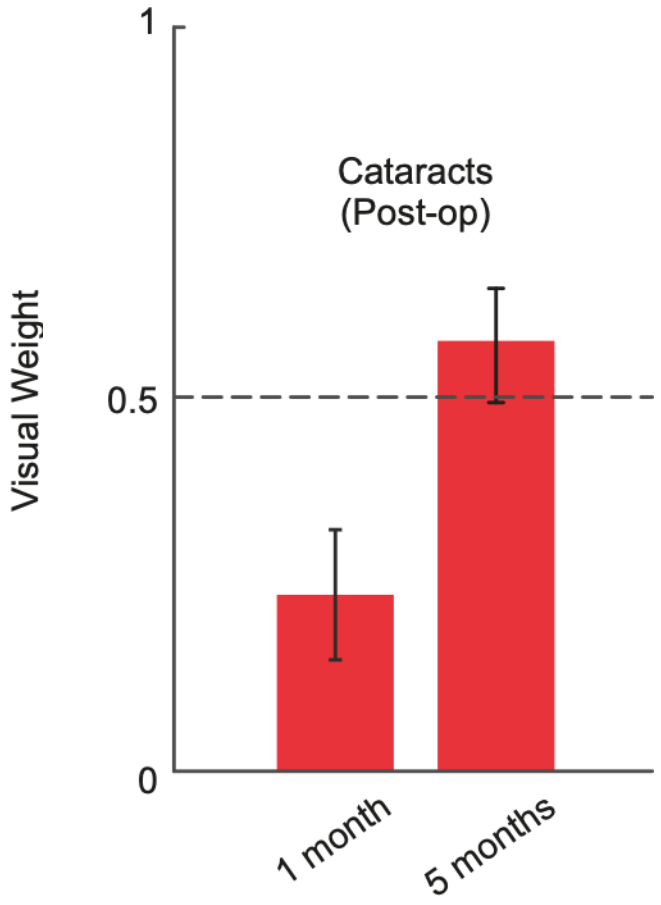




Senna et al., 2021, *Current Biology*

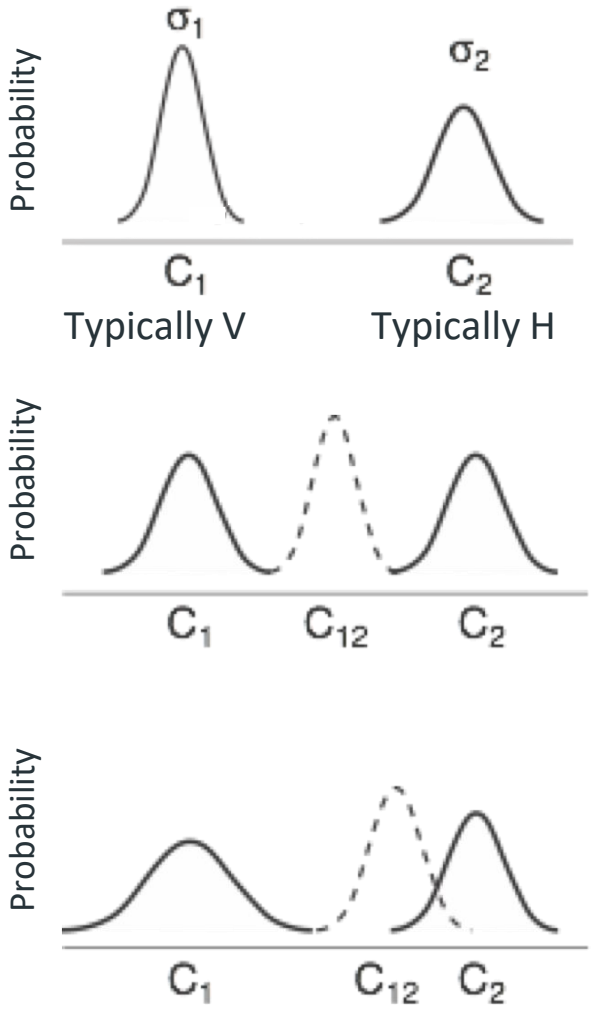
Multisensory integration



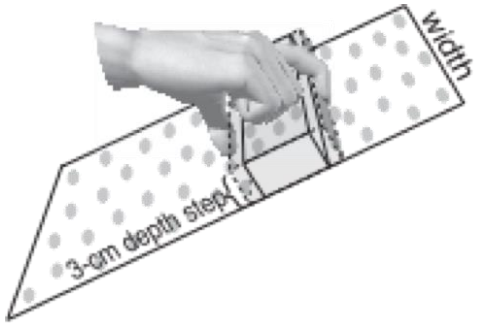


Senna et al., 2021, *Current Biology*

Multisensory integration: Optimal integration



Maximum likelihood estimation (MLE)



Reliability

$$r_i = \frac{1}{\sigma_i^2}$$

Weighted average

$$C_{12} = w_1 C_1 + w_2 C_2$$

Weight

$$w_i = \frac{r_i}{\sum r_j}$$

$$\sigma_{VH}^2 = \frac{\sigma_V^2 \sigma_H^2}{\sigma_V^2 + \sigma_H^2}$$

Ernst & Banks, 2002, *Nature*

Optimal integration

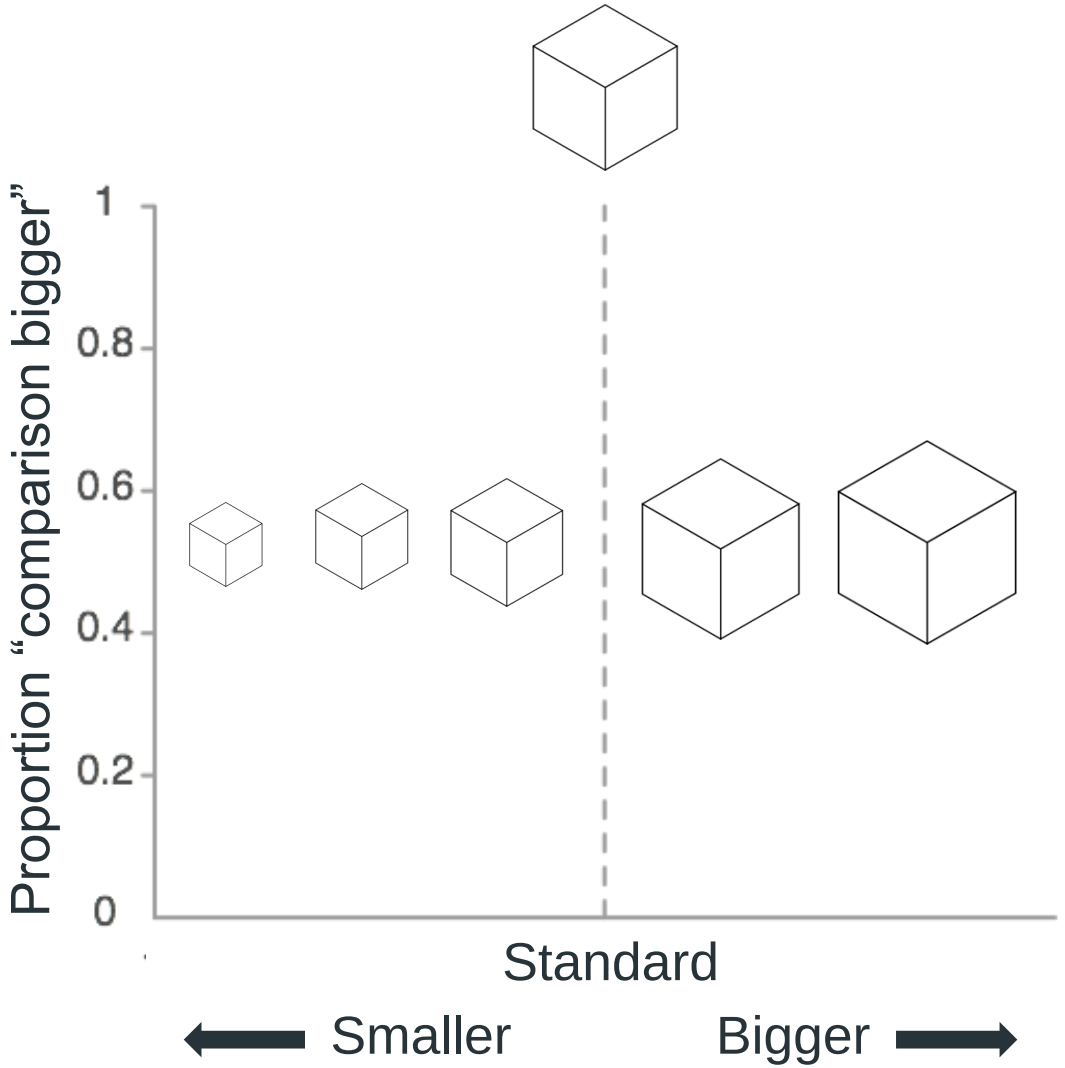
Haptics (H)

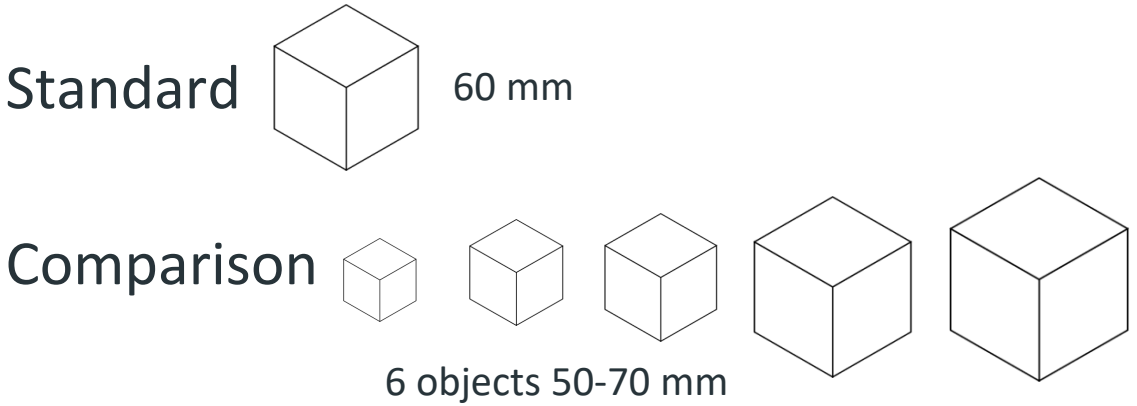
Visual (V)

Visual-haptics (VH)

Senna et al., 2021, *Current Biology*

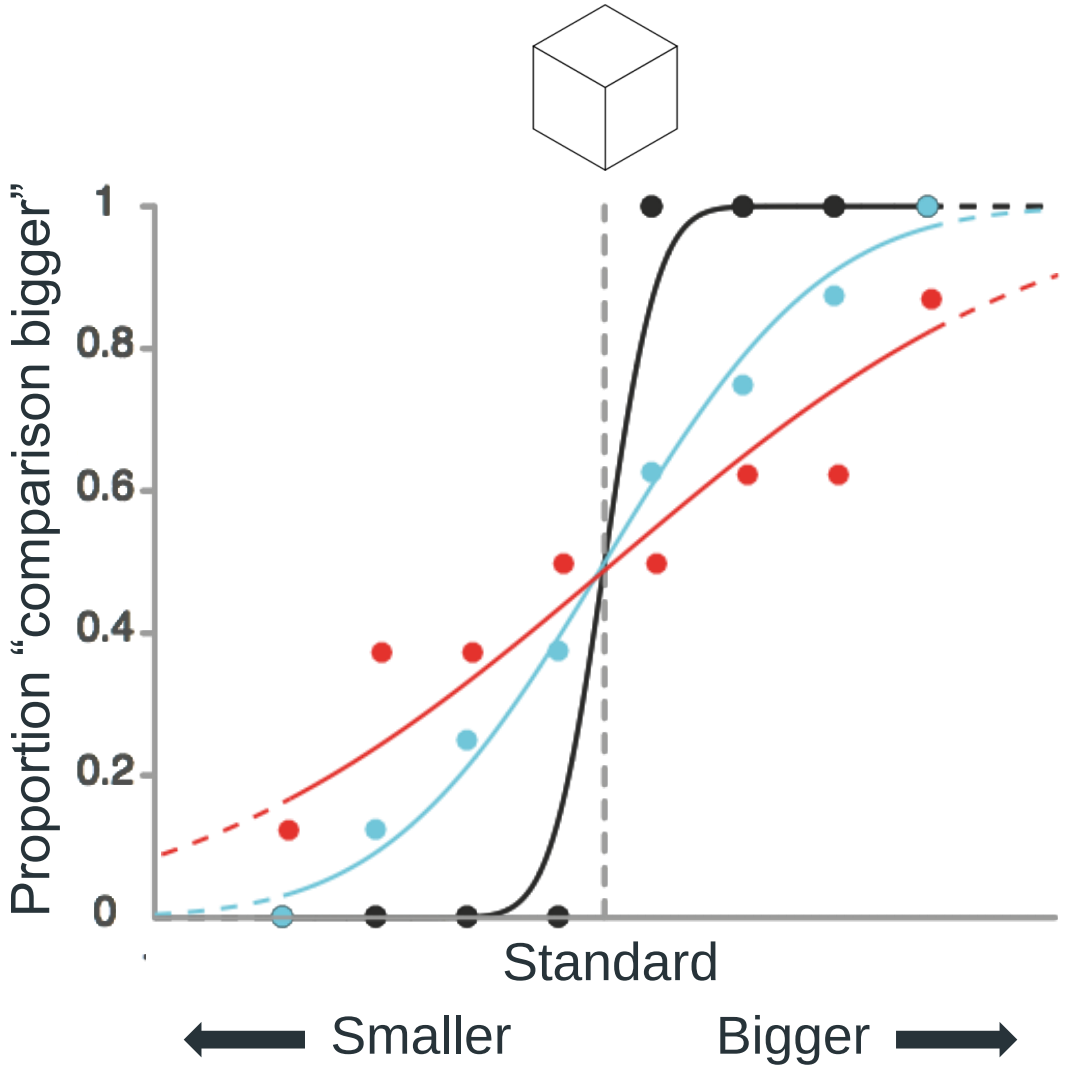
Optimal integration

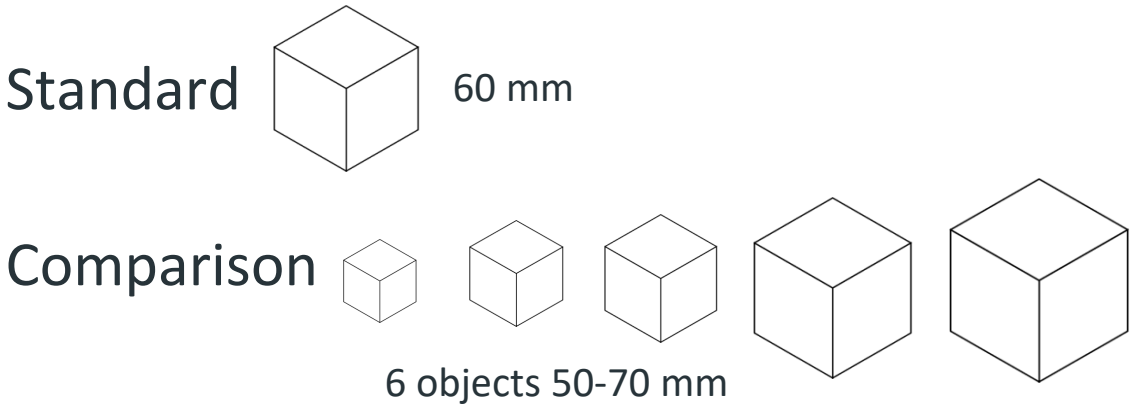




Senna et al., 2021, *Current Biology*

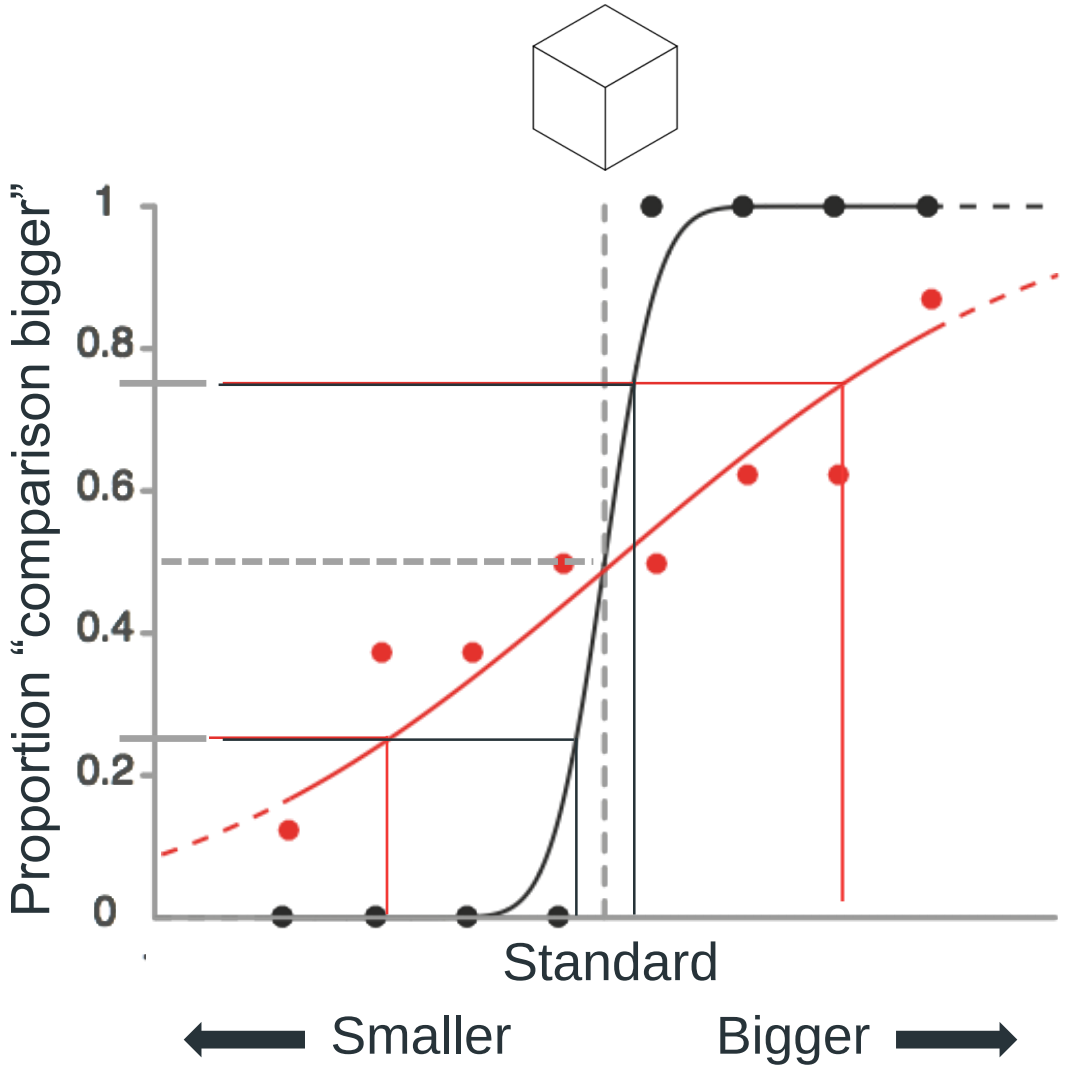
Optimal integration

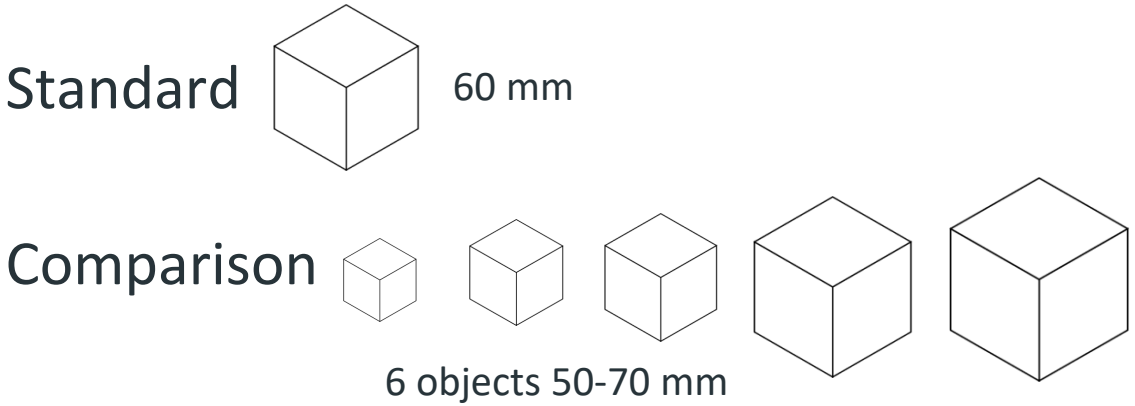




Senna et al., 2021, *Current Biology*

Optimal integration

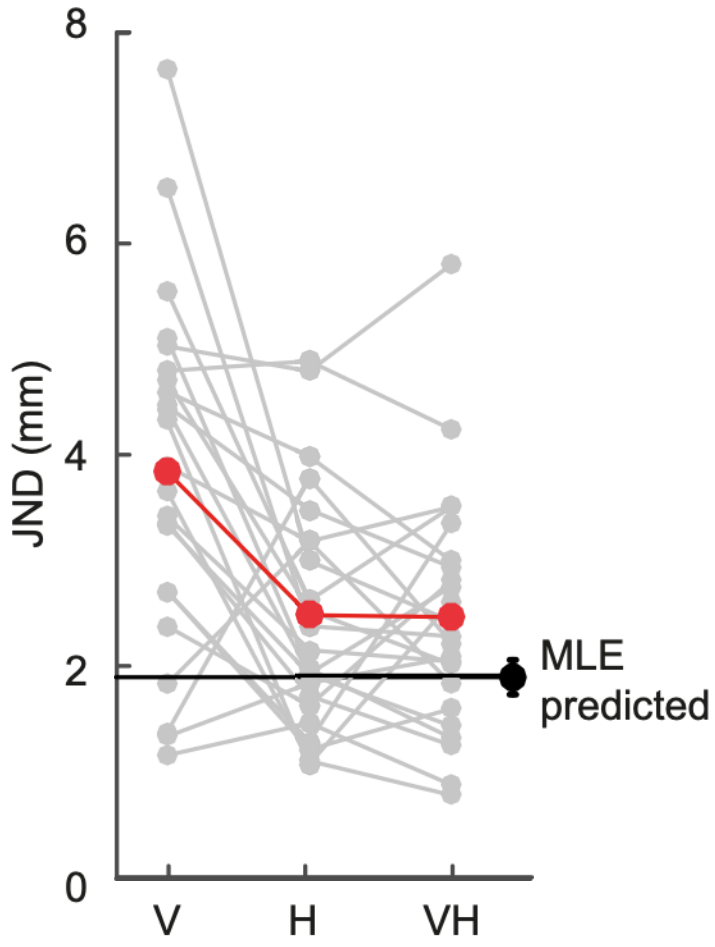


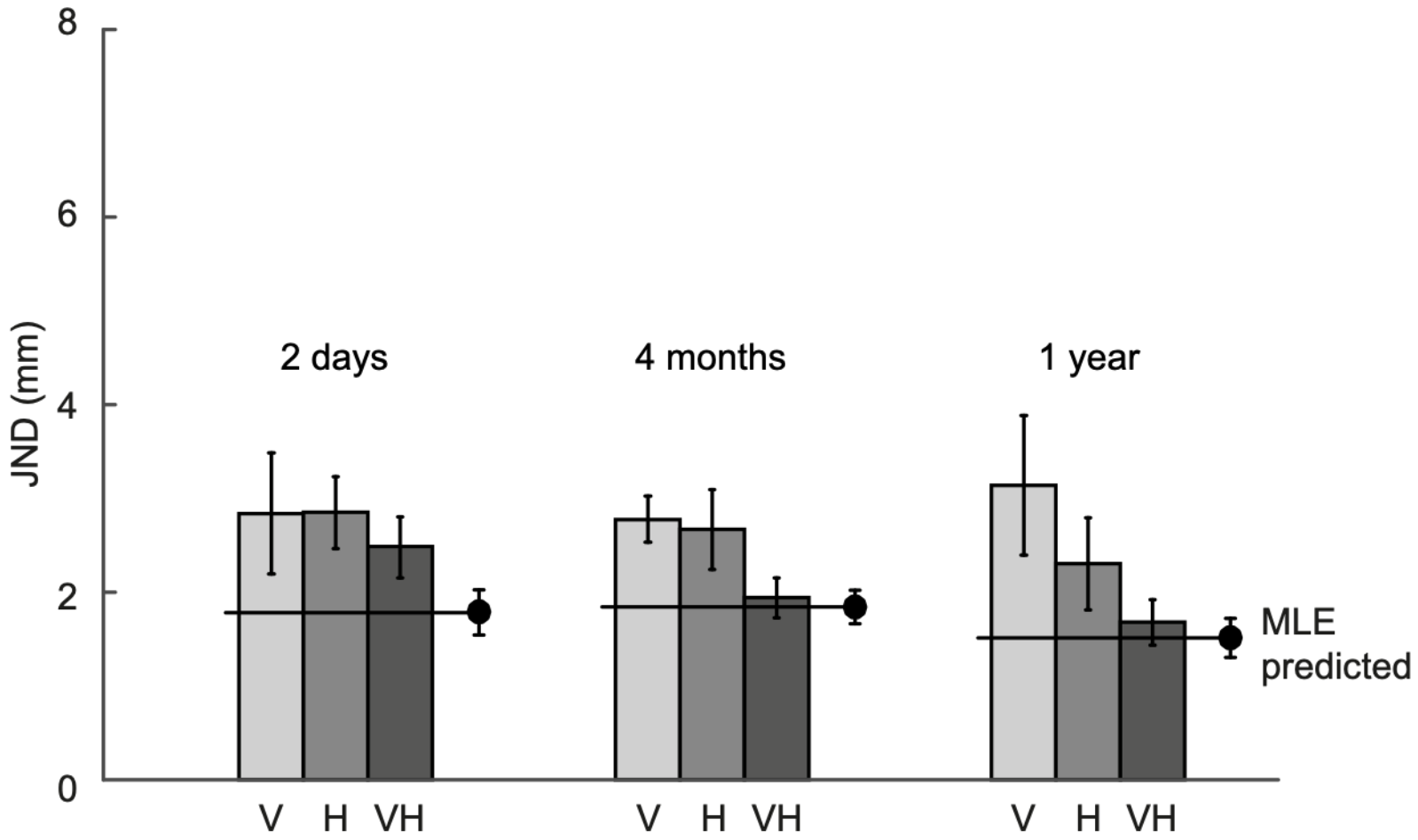


Just Noticeable Difference (JND): the difference in size that is perceivable above chance

Senna et al., 2021, *Current Biology*

Optimal integration





Senna et al., 2021, *Current Biology*

Recovering from blindness

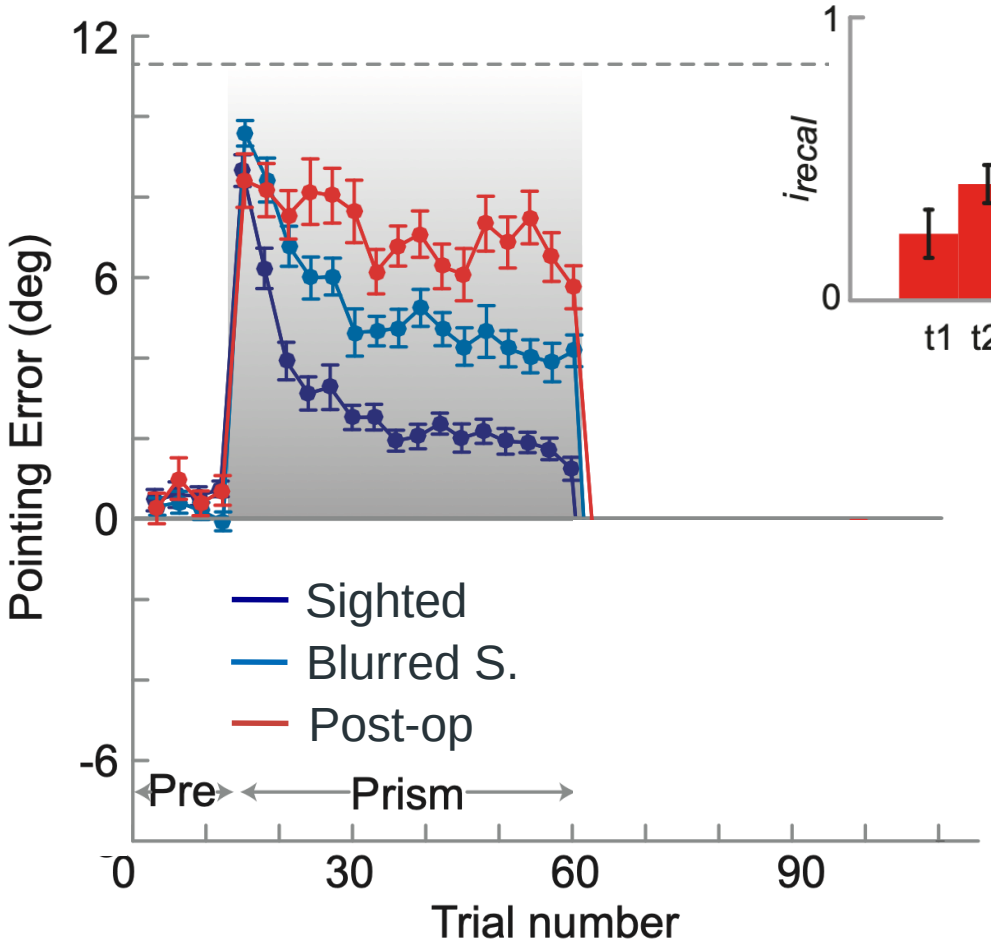
Multisensory Integration 

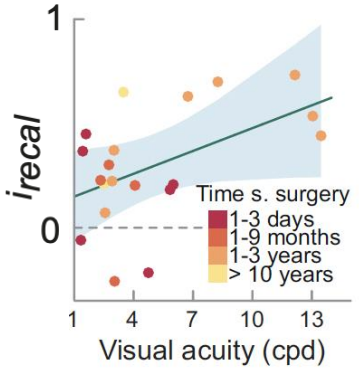
Action control and sensorimotor recalibration

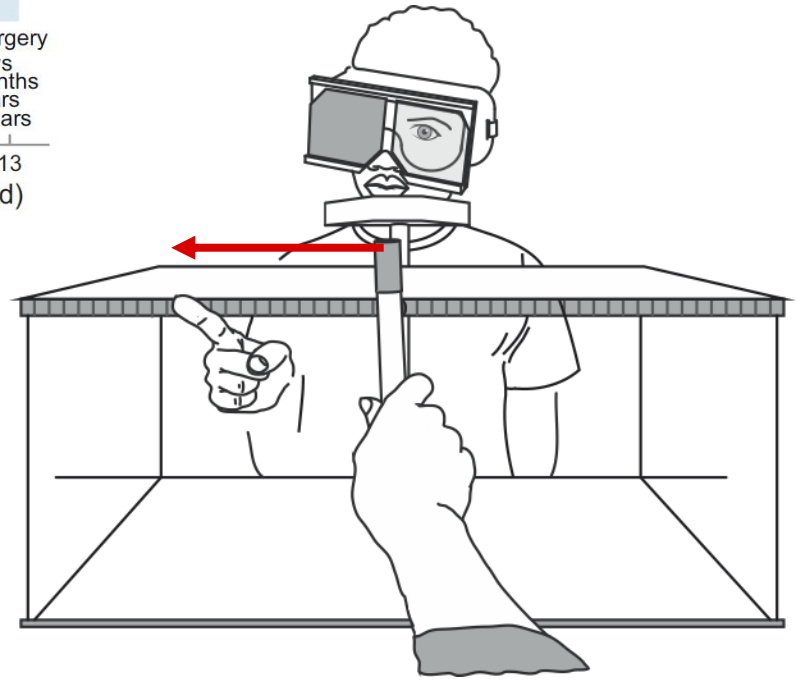
Predictions for feed-forward action control

Navigation and space representation

Vision for action: Sensorimotor recalibration







Senna et al., 2022, *eLife*

Recovering from blindness

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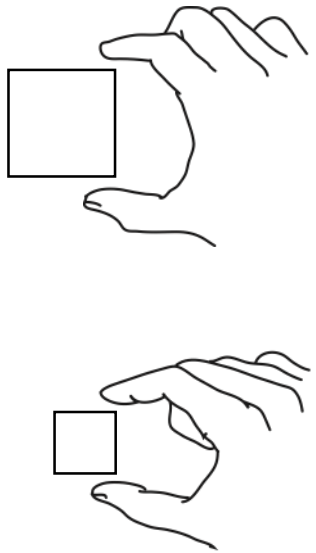
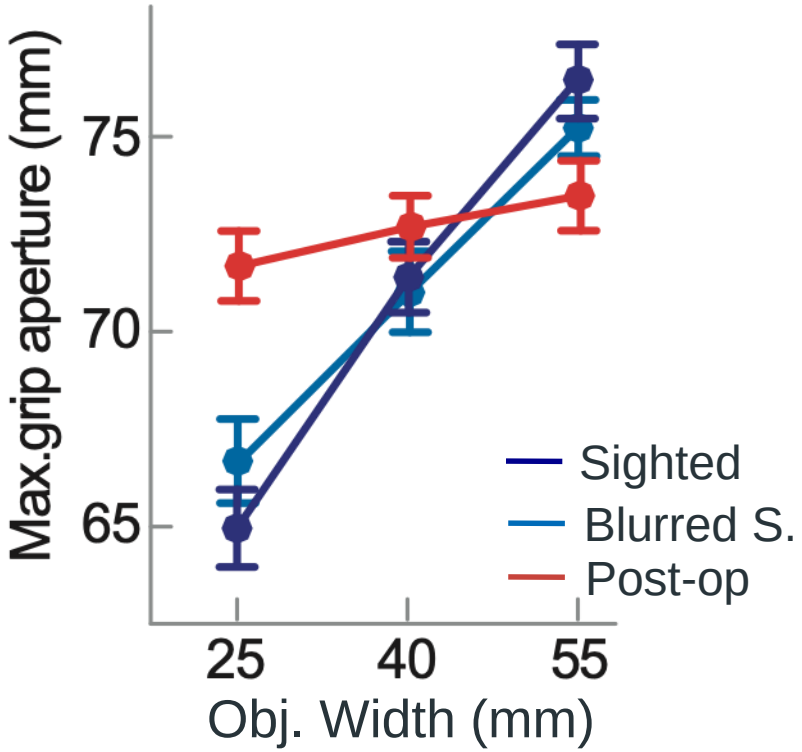
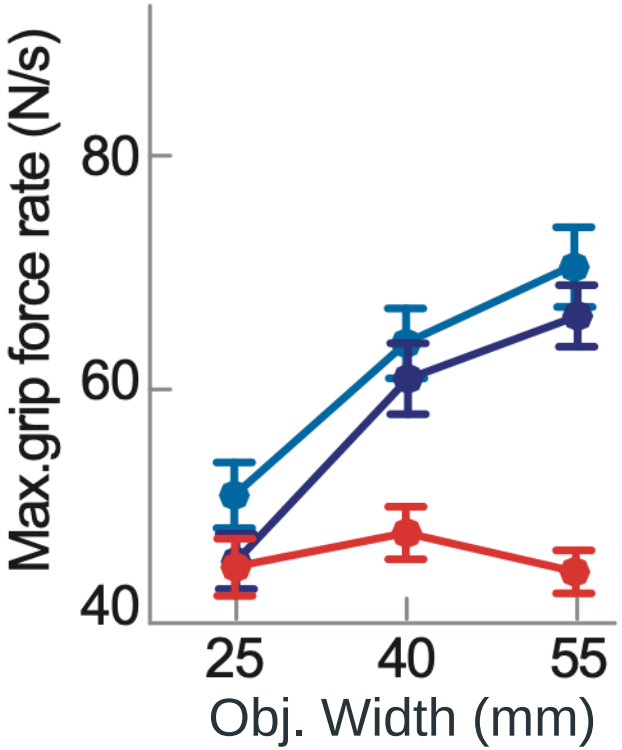
Predictions for grasping



Hand Aperture



Applied Force

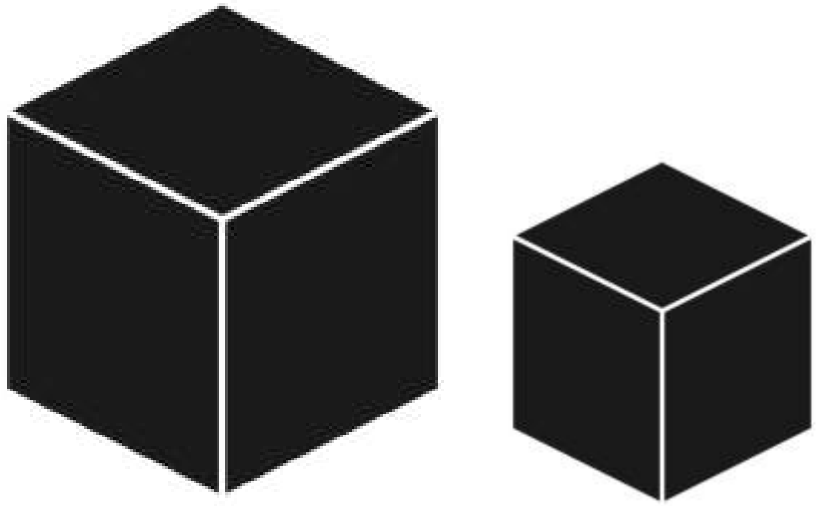


Piller et al., 2023, *Current Biology*

3 Objects: same weight: ca. 200g each - different sizes: 2.5, 4.0, 5.5 cm

Size-weight illusion

Which one of equal-weight objects feels heavier?



Smaller feels heavier

	Visuo-haptics	Haptics
Sighted	93%	48%
Blind		53%
Cataract	73%	
	60% (<6m)	91% (>6m)

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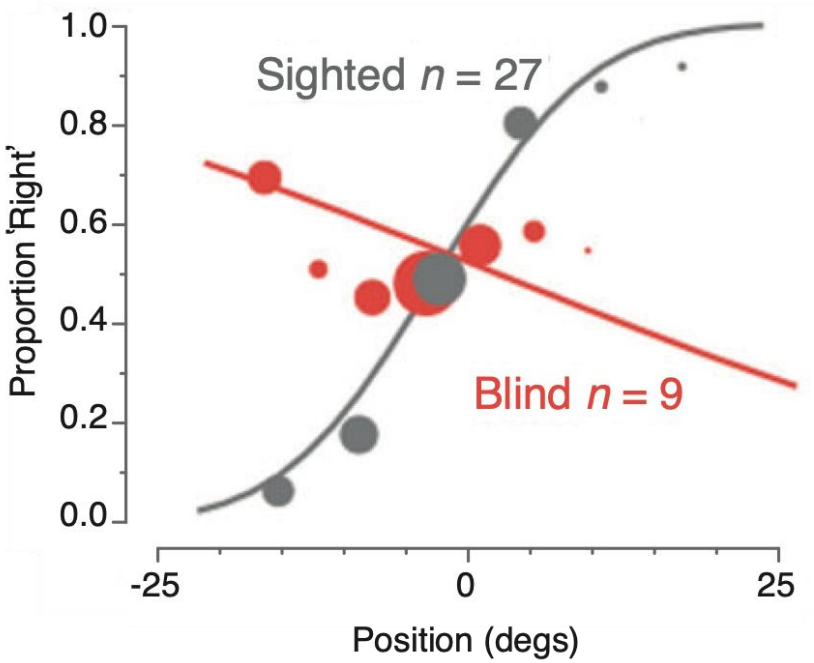
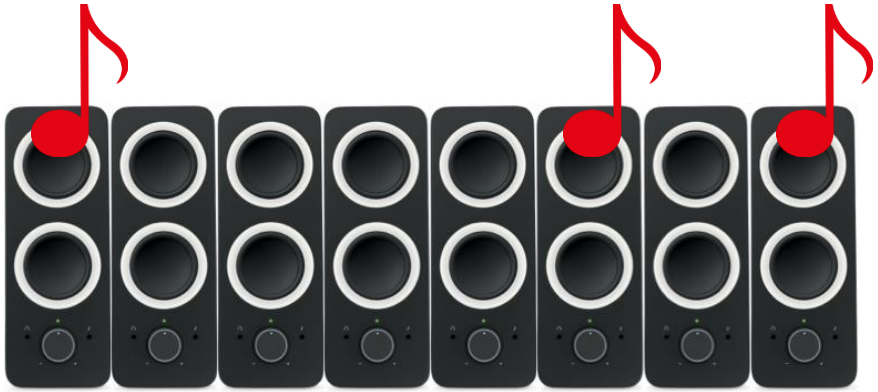
Navigation and space representation

Auditory space representation in the blind

Understanding spatial relationships among sounds, and spatial cognition in general are impaired in the blind





Auditory space bisection

Gori et al., 2014*; Brain*

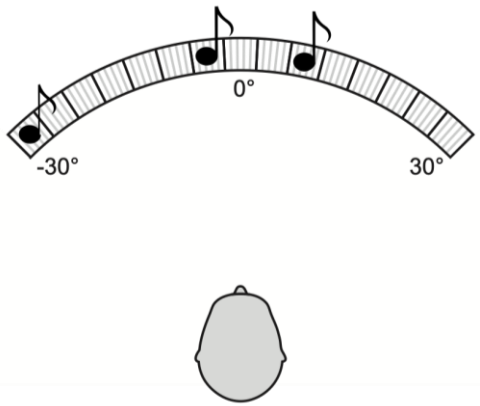
Auditory space representation in the blind

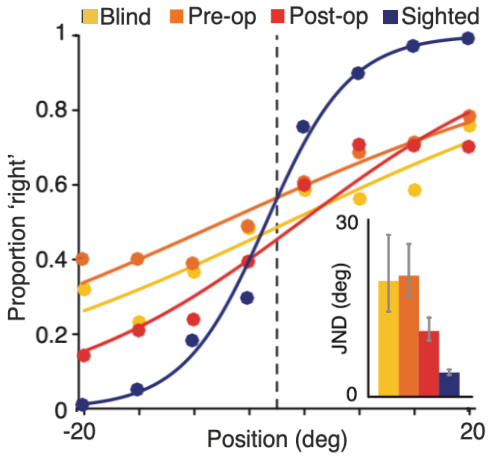
Vision is crucial in building spatial representations, and in **calibrating** the other senses to process spatial information

(Knudsen & Knudsen, 1985)

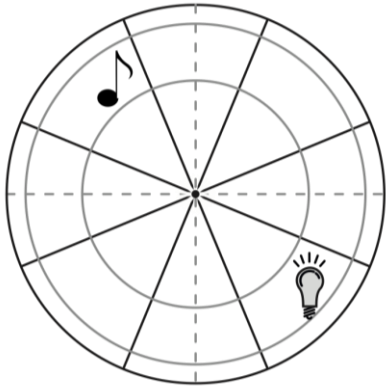
Space representation and Navigation

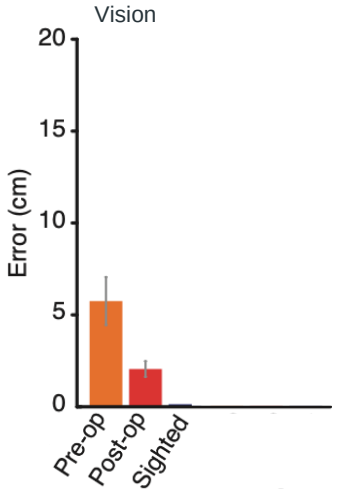
Auditory bisection



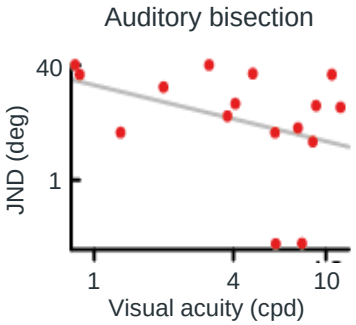


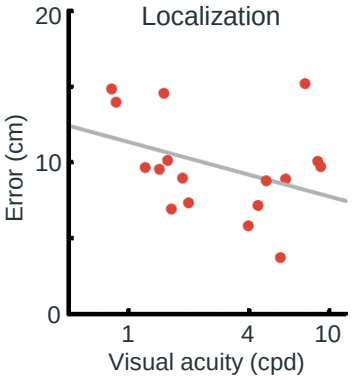
Localization



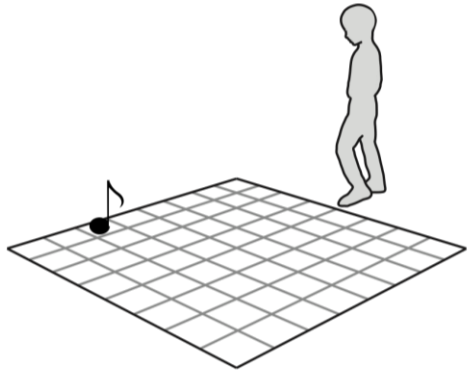


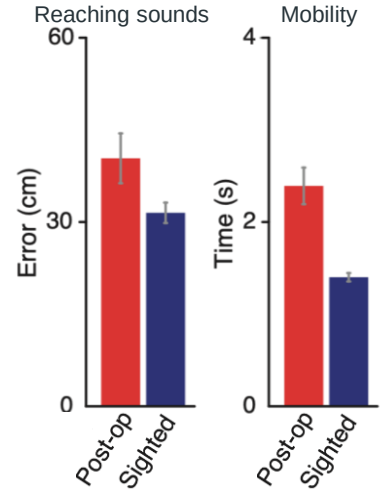
Auditory tasks & visual acuity





Mobility & Navigation





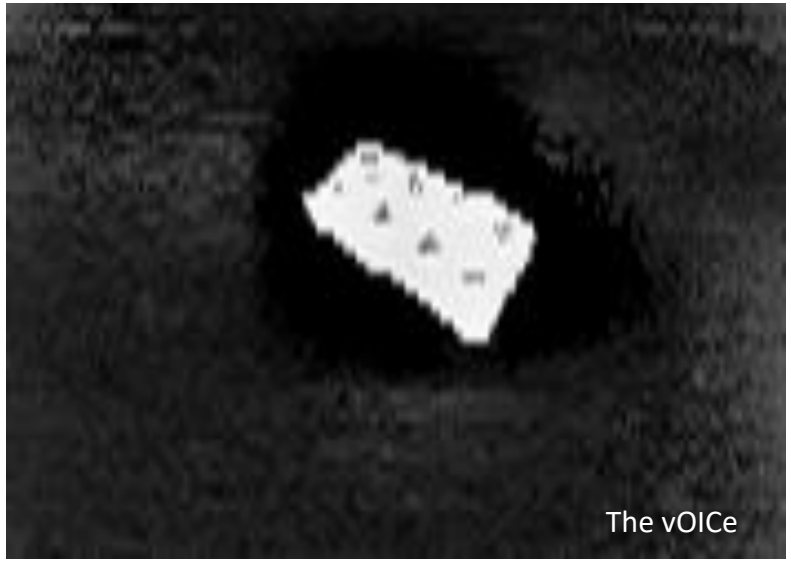
Senna et al., 2022, *Proc. R. Soc. B*

Space representation and Navigation

Sensory-motor training

ABBI (Audio Bracelet for Blind Interaction)

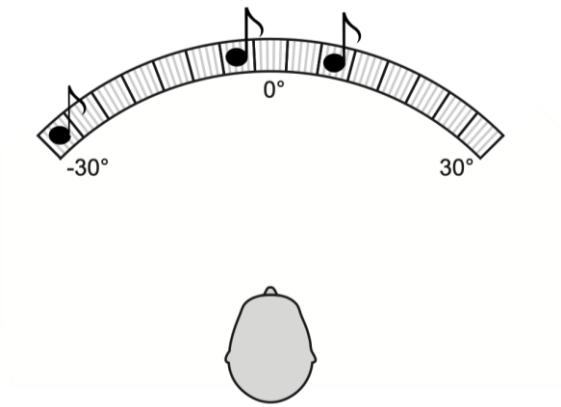
with M. Gori, IIT, Italy

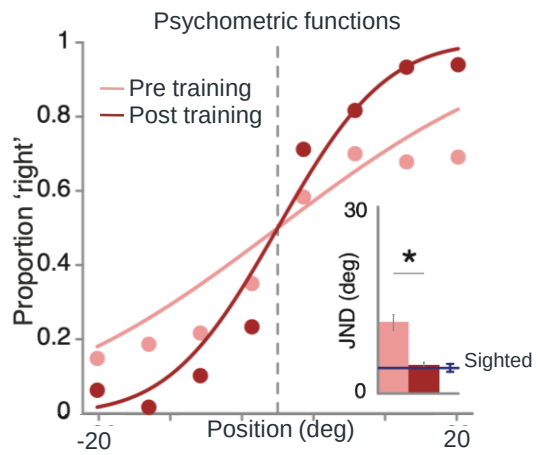


Senna et al., unded review, *iScience*

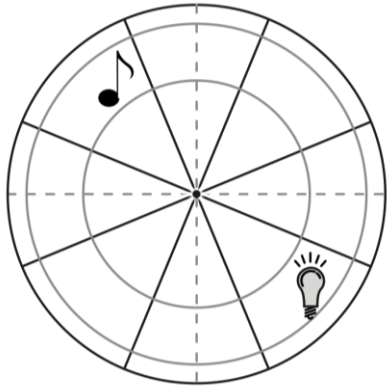
Space representation and Navigation

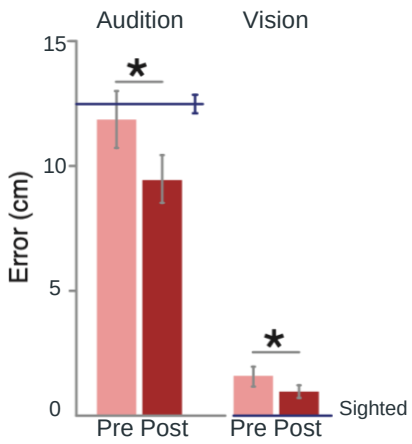
Auditory bisection



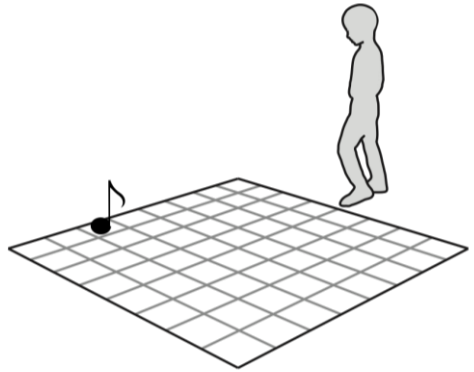


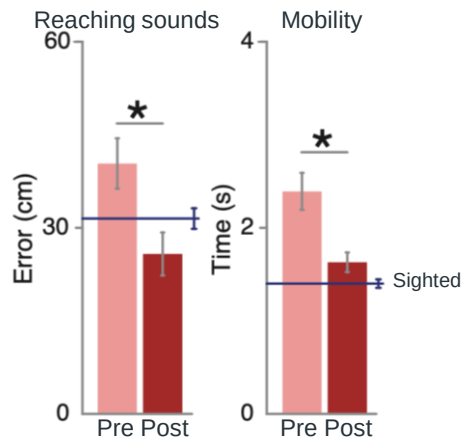
Localization





Mobility & Navigation





Senna et al., unded review, *iScience*

Conclusions

Perceptual abilities (multisensory integration, space perception) start improving quickly after surgery

Greater improvements with longer time since surgery and higher post-op visual acuity

Vision for action develops more slowly (if at all)

A short training reinforcing audio-visuo-motor associations improves mobility and spatial cognition

Conclusions

Research impact: the demonstrable contribution that research makes to society and the economy (Economic and Social Research Council, UK)

Knowledge transfer to promote independency

- Surgery training at the Hawassa Referral Hospital (Dr Itay Ben-Zion, pediatric ophthalmologist)

- Sensorimotor training to improve space perception and mobility in the Shashemene School for the Blind

Thank you for the attention


Marc Ernst

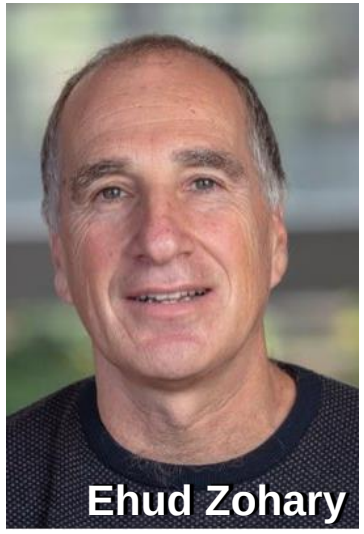

Sophia Piller


Ayelet McKyton


Monica Gori


Chiara Martolini


Zemene Zeleke


Ehud Zohary


Elena Andres


Itay Ben-Zion

DIP

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