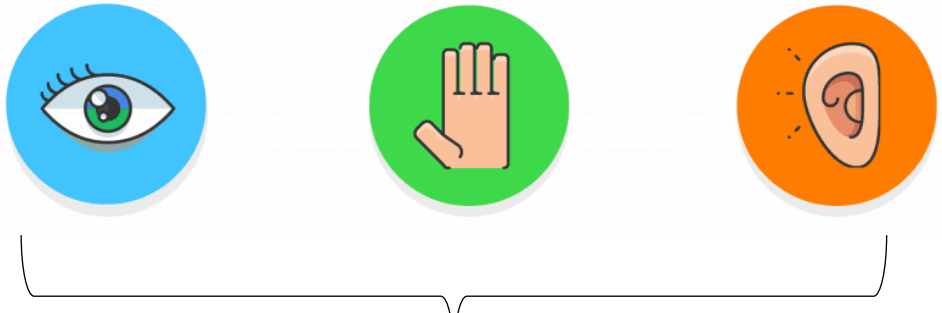
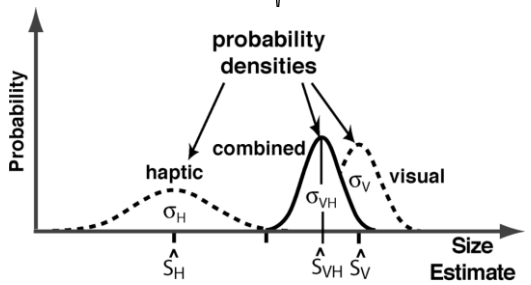
Early cortical sensory responses in typical but not in blind and deaf individuals

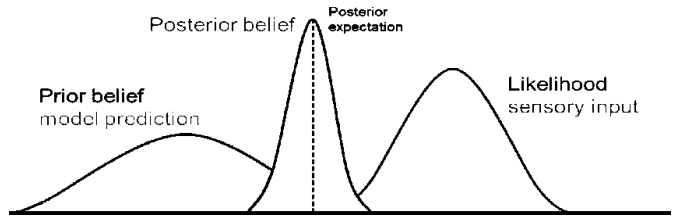
Monica Gori, Maria Bianca Amadeo, Francesco Pavani , Giorgia Bertonati & Claudio Campus

Multisensory processing





Multisensory Integration

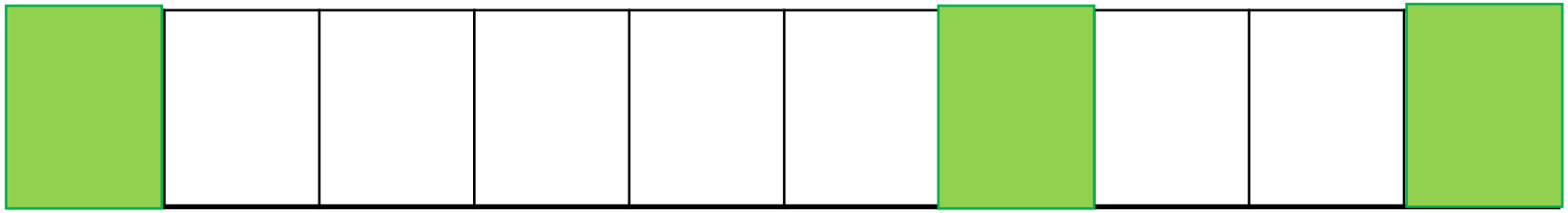


Cross-modal interaction

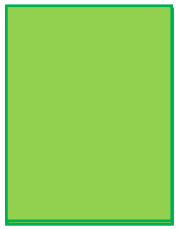
Visual space and time bisection

Visual

Space



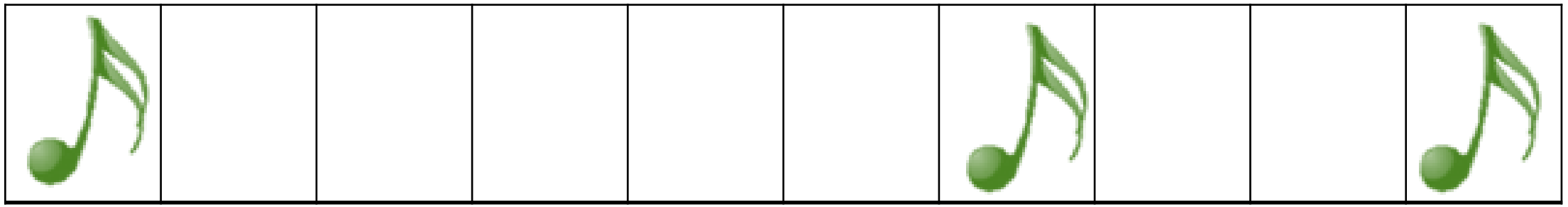
Time



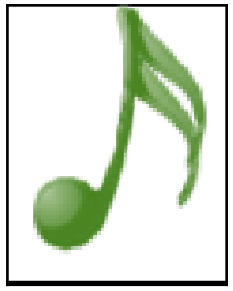
Audio space and time bisection

Audio

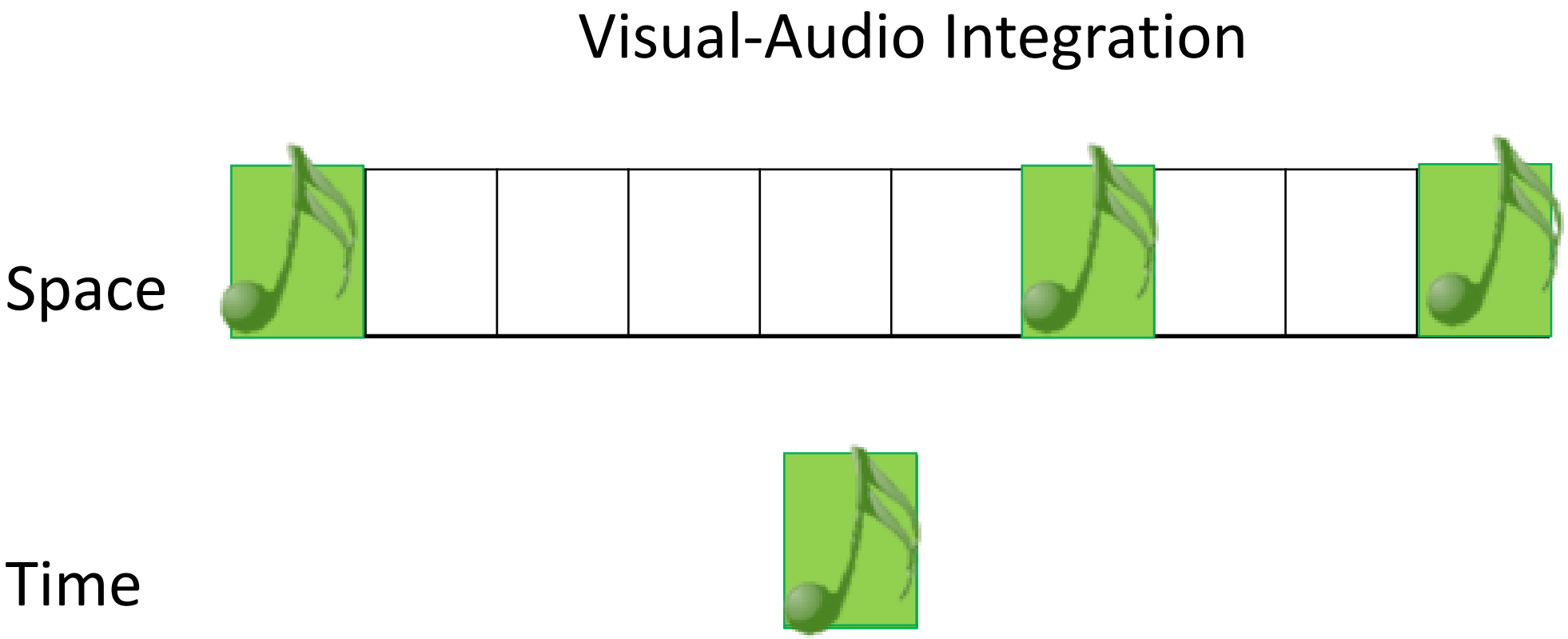
Space



Time

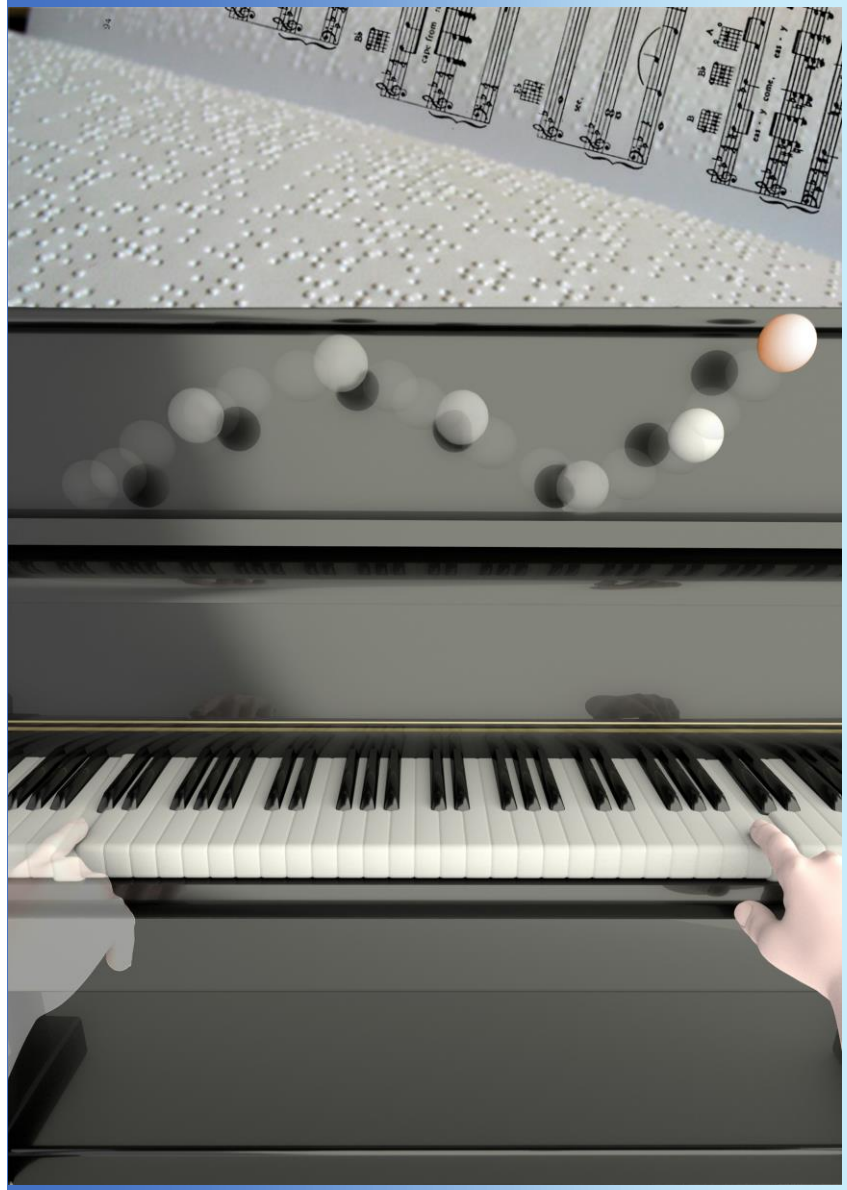


Visual-audio space and time bisection

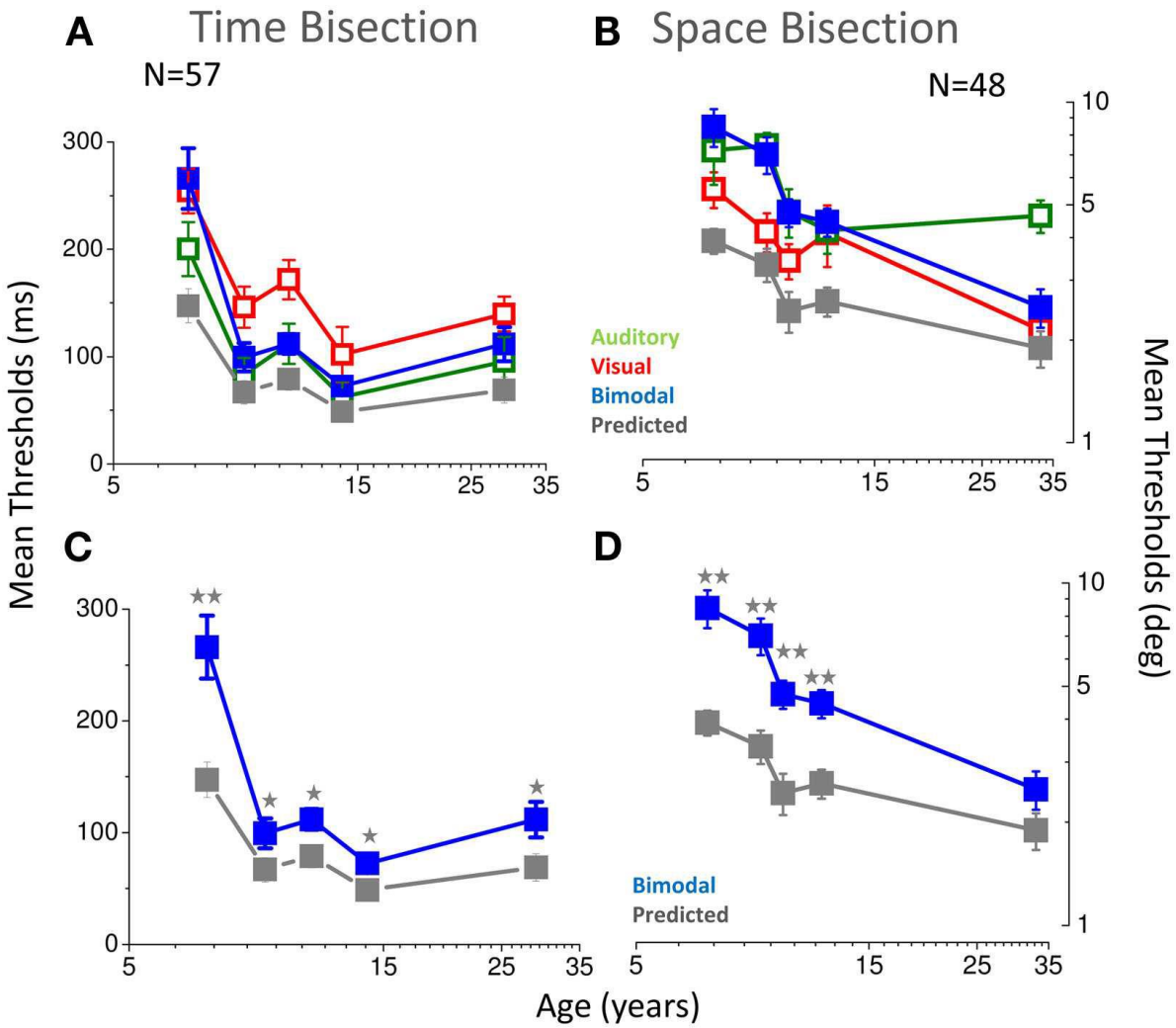


Audio Visual sensory dominance

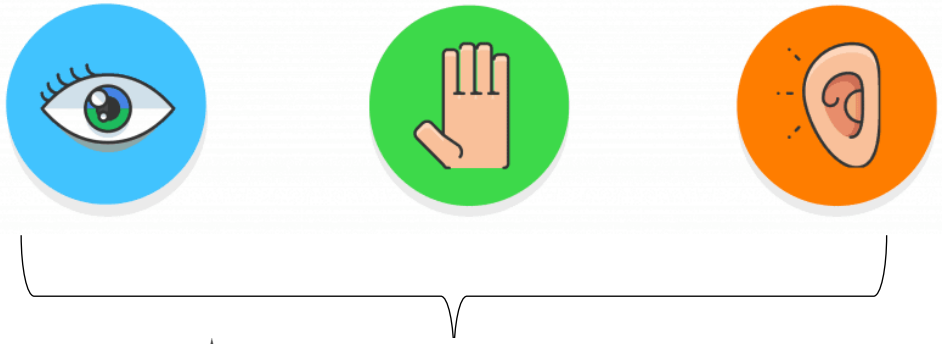
- Visual system visuospatial maps (Swisher et al., 2007; Wandell et al., 2007; Silver and Kastner, 2009)
- Audition spike timing information (e.g., Joris et al., 1994; Agmon-Snir et al., 1998; Adams, 2006);
- Vision dominates space and audition time (Welch & Warren, 1980; O'Connor & Hermelin, 1972; Alais & Burr, 2004)
- In children sensory dominance occurs before integration for the **bisection task** (Gori, Sandini and Burr 2012)

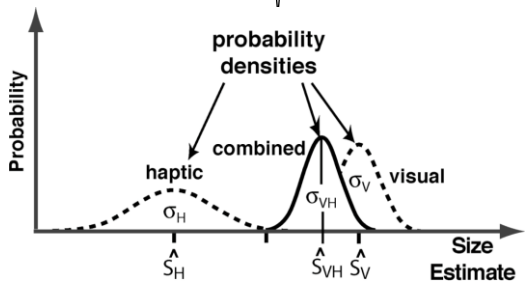


Late development: audio and visual space and time integration

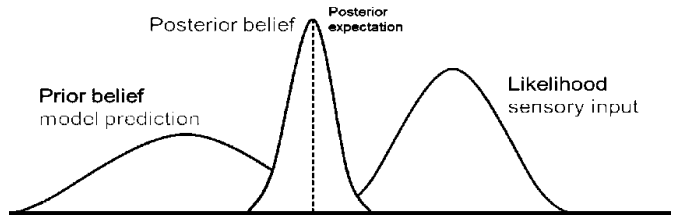


Gori et al. 2012





Multisensory Integration



Cross-modal interaction

Cross Modal Calibration Development

Vision

Space

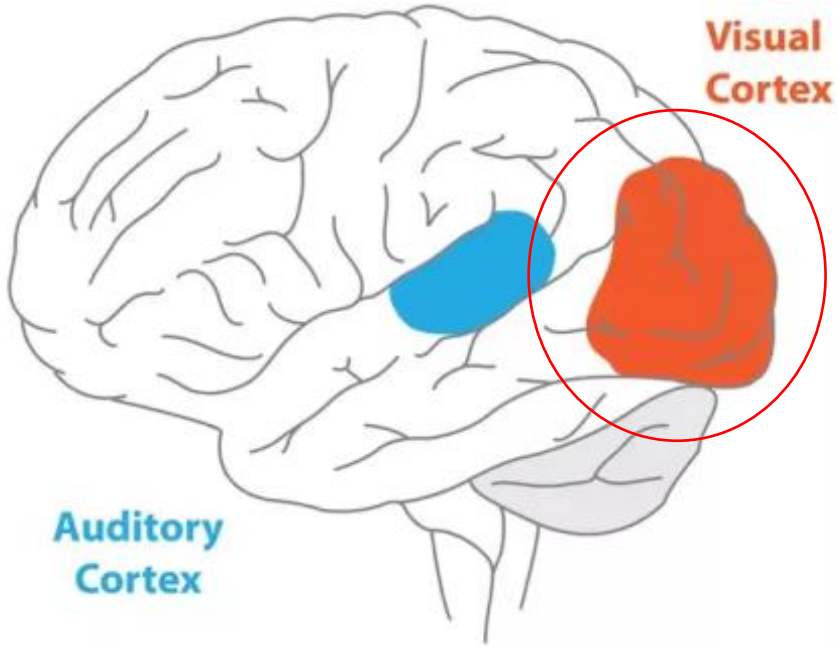
Audition

Time

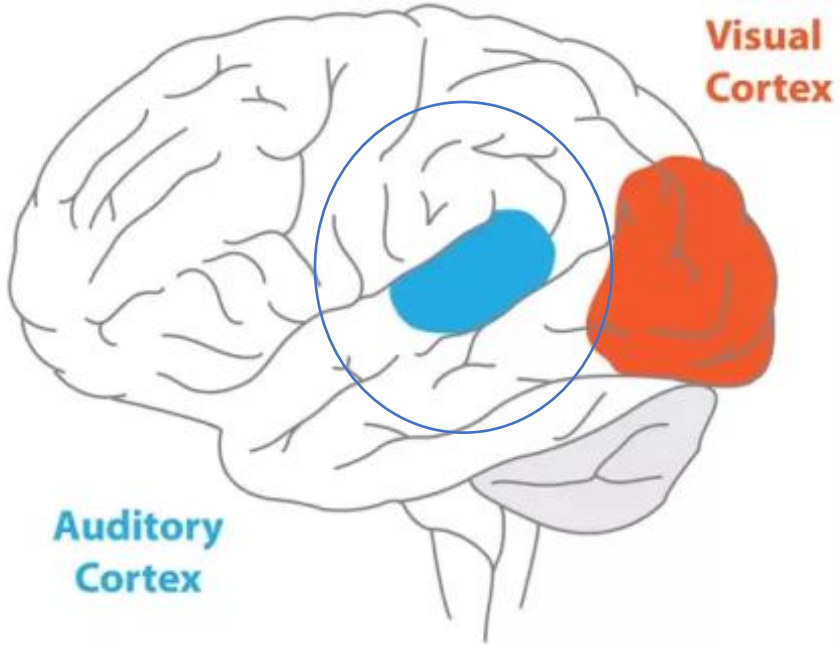
Gori et al. Frontiers 2012

Specific dominance also at cortical level?

Audio bisection space



Visual bisection time



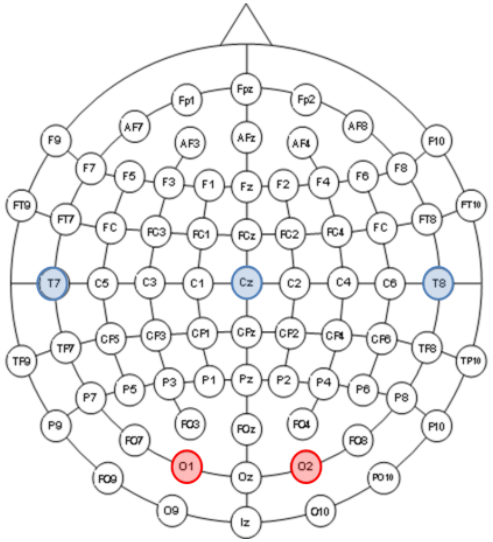
Methods

PARTICIPANTS

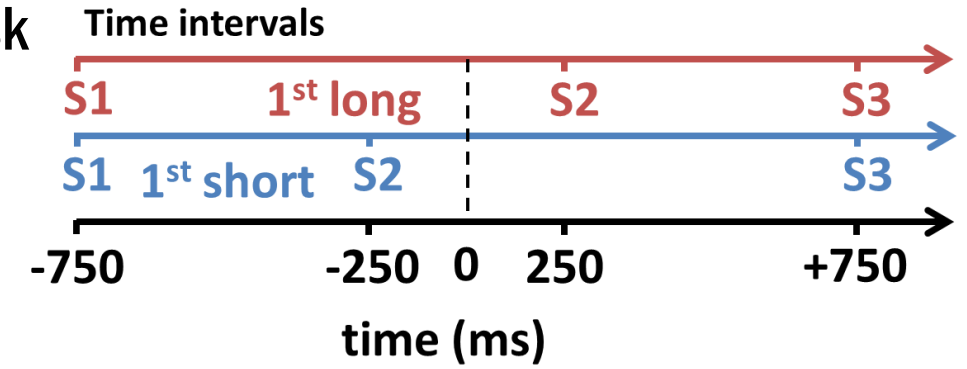
- 16 healthy participants

EXPERIMENTAL DESIGN

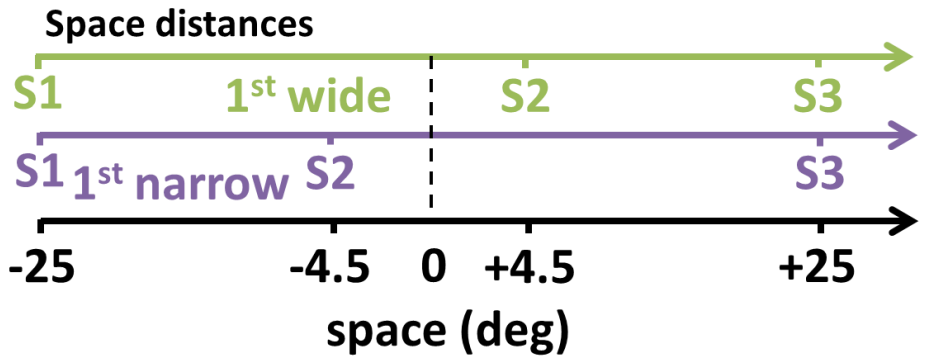
- EEG is continuously recorded



Temporal bisection task



Spatial bisection task



Vision

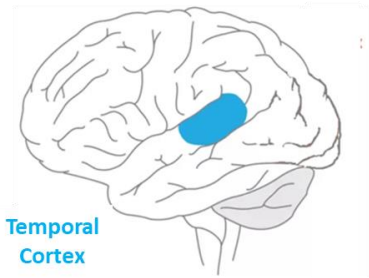
Audio space bisection

Audio Space

Temporal window: 50-90ms

Campus, Sandini, Morrone & Gori, SREP 2017

Audition



Visual time bisection

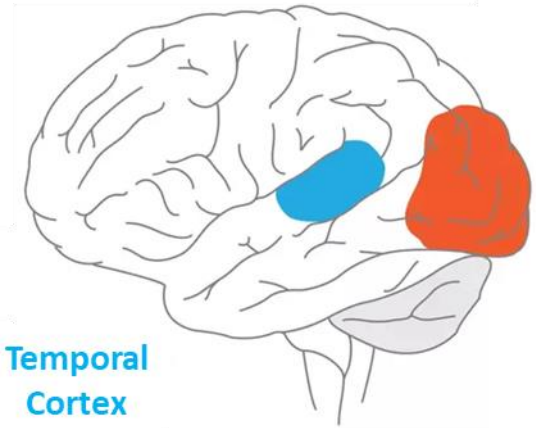
Visio Time

Temporal window: 50-90ms

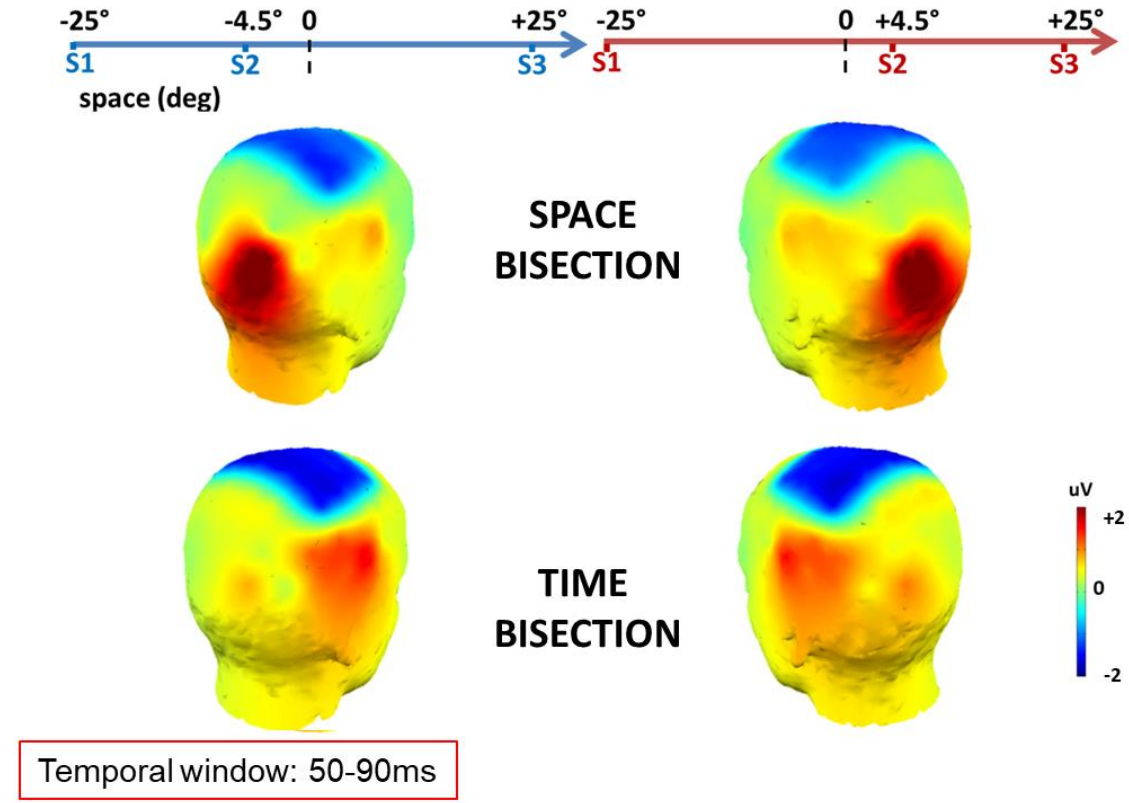
Amadeo, Campus & Gori, Neuroimage 2020

Vision → Space

Audition → Time

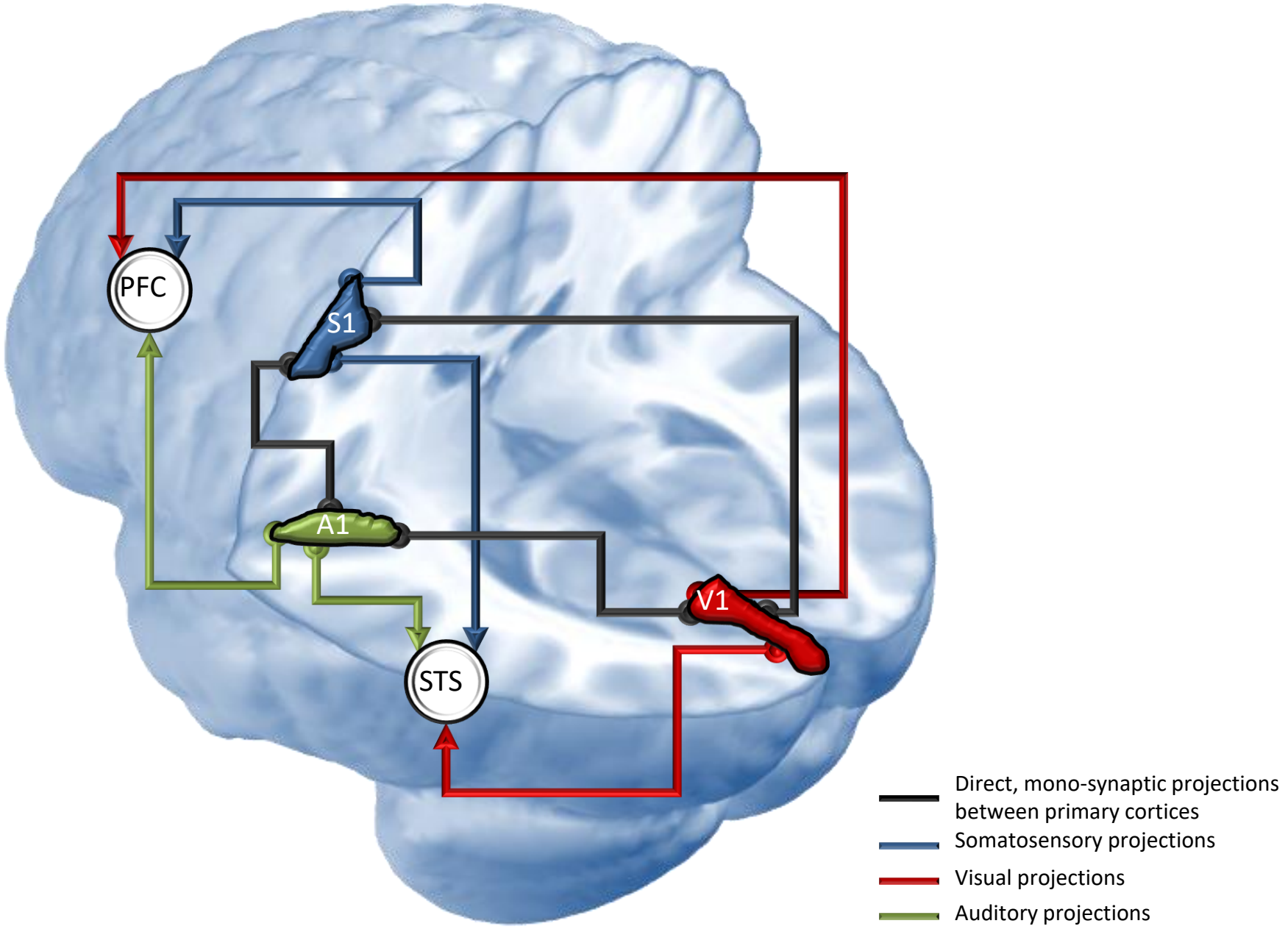


Audio-Visual Space and Time



Stronger early **occipital** response during **space** bisection and stronger early **fronto-central** and **temporal** during **time** bisection

Gori, Bertonati, Campus & Amadeo, Neuroimage 2023



Slide provided by Murray

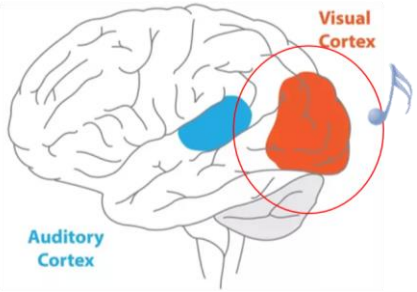
Murray et al. (2016) *Neuropsychologia*; Murray et al. (2016) *Trends in Neurosciences*

SPACE:

More visual responses modality independent

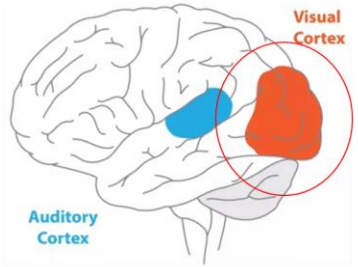
Early processing of visual areas task specific for space bisection

Audio Space



Campus et al. (2019)

Audio-Visual Space

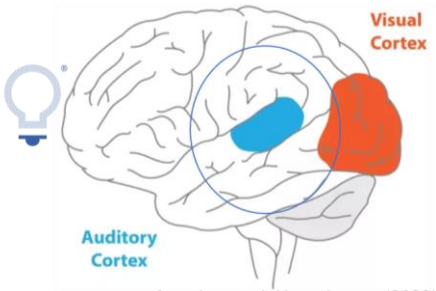


TIME:

More temporal responses modality independent

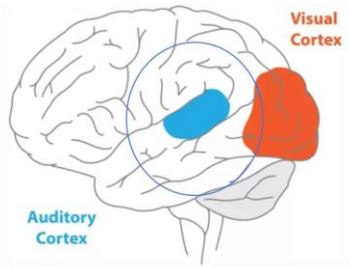
Early processing of auditory areas task specific for time bisection

Visual Time



Amadeo et al. NeuroImage (2020)

Audio-Visual Time



Gori, Bertonati, Campus & Amadeo, Submitted

Hypothesis

Vision

Space

Audition

Time

Visual Cortex

Auditory Cortex

?

Audio space bisection

?

Audio Space

Blindness

Visual Cortex

Auditory Cortex

?

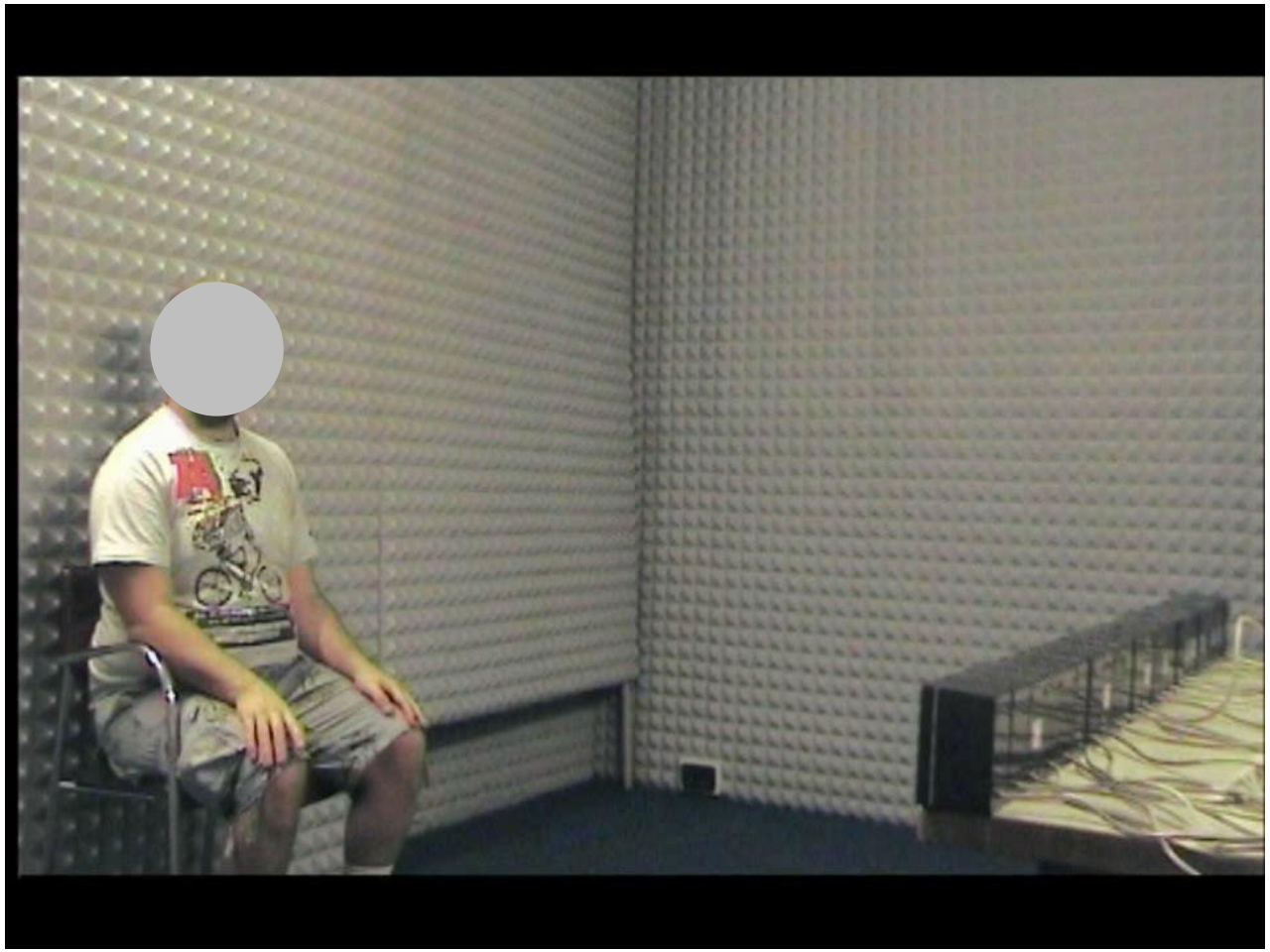
Visual time bisection

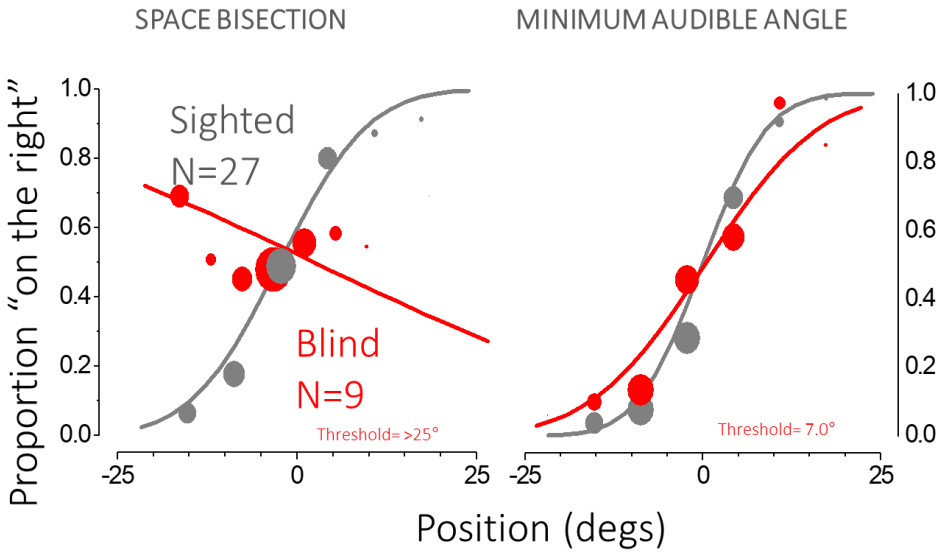
?

Visio Time

Deafness

Vision is important for spatial bisection: auditory space impaired in blind





Gori, Sandini, Marinoli and Burr, Brain 2014

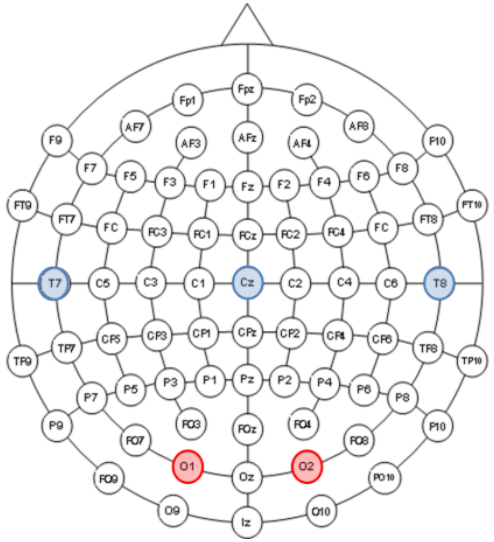
Methods

PARTICIPANTS

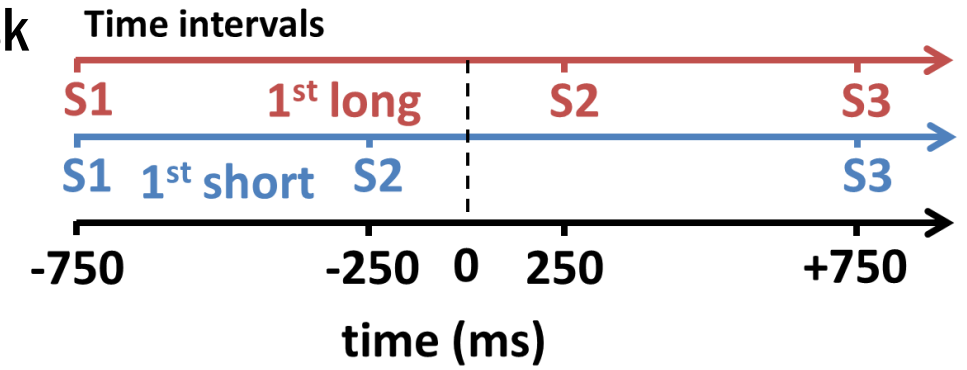
- 12 healthy participants
- 12 early blind participants

EXPERIMENTAL DESIGN

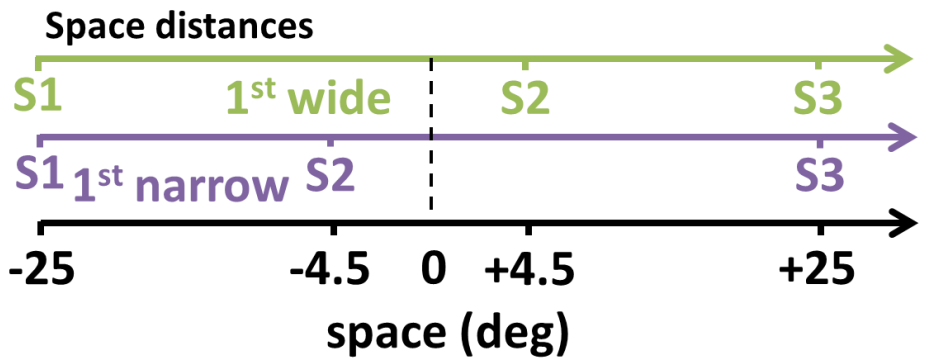
- EEG is continuously recorded-
- ERP Second stimulus



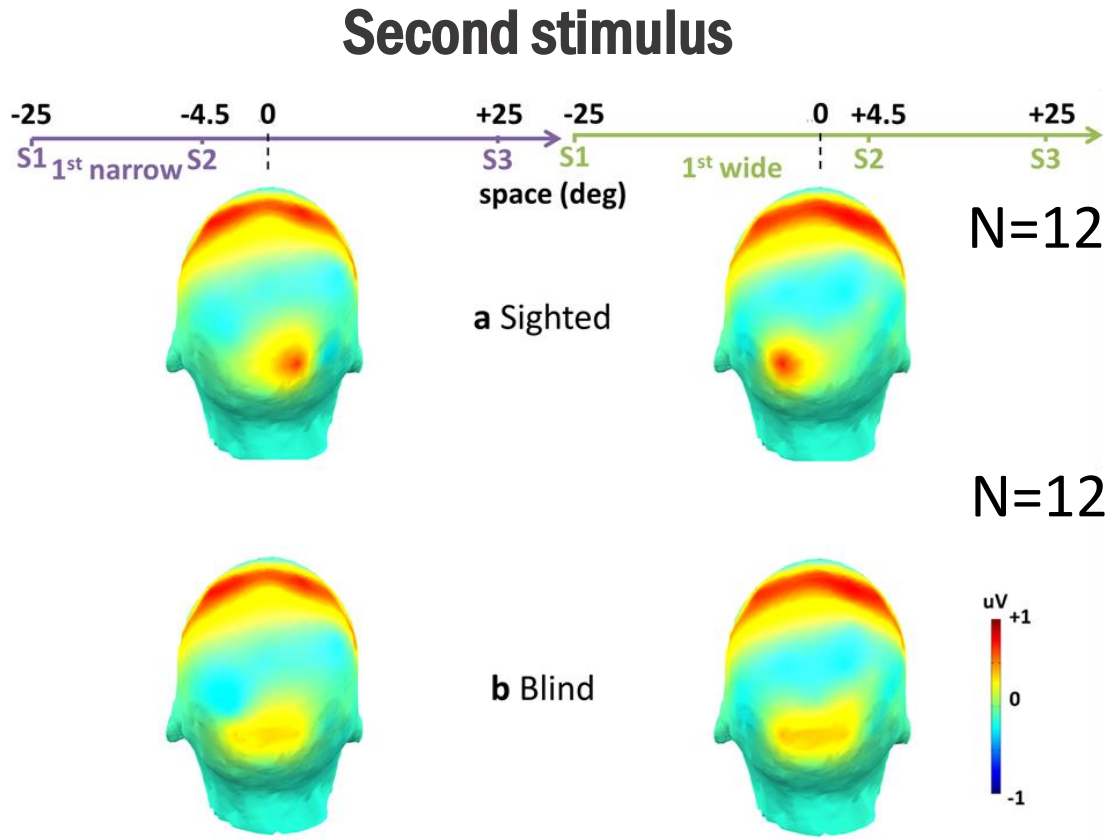
Temporal bisection task



Spatial bisection task



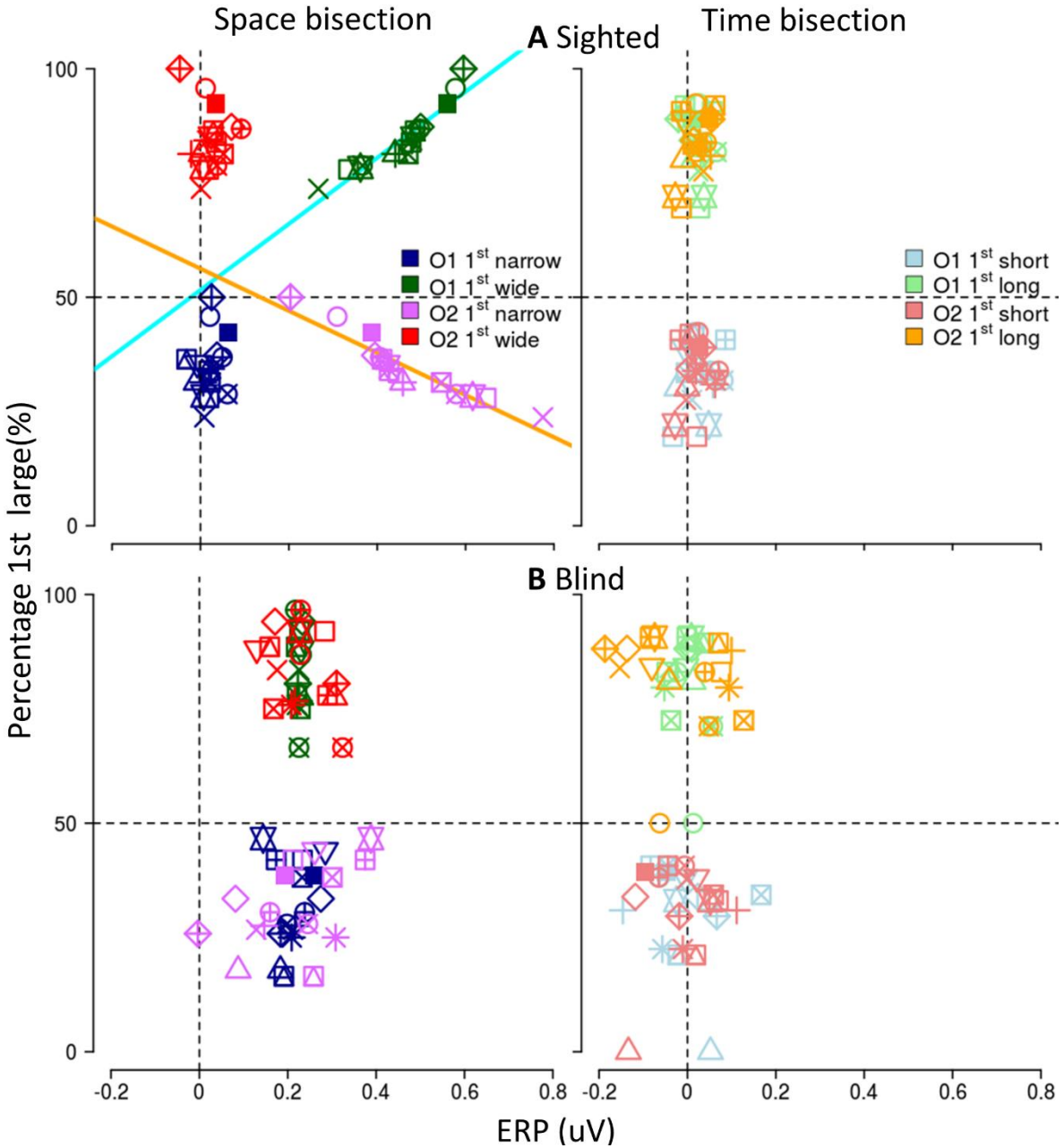
Early visual cortical processing for audio space bisection not in blind participants

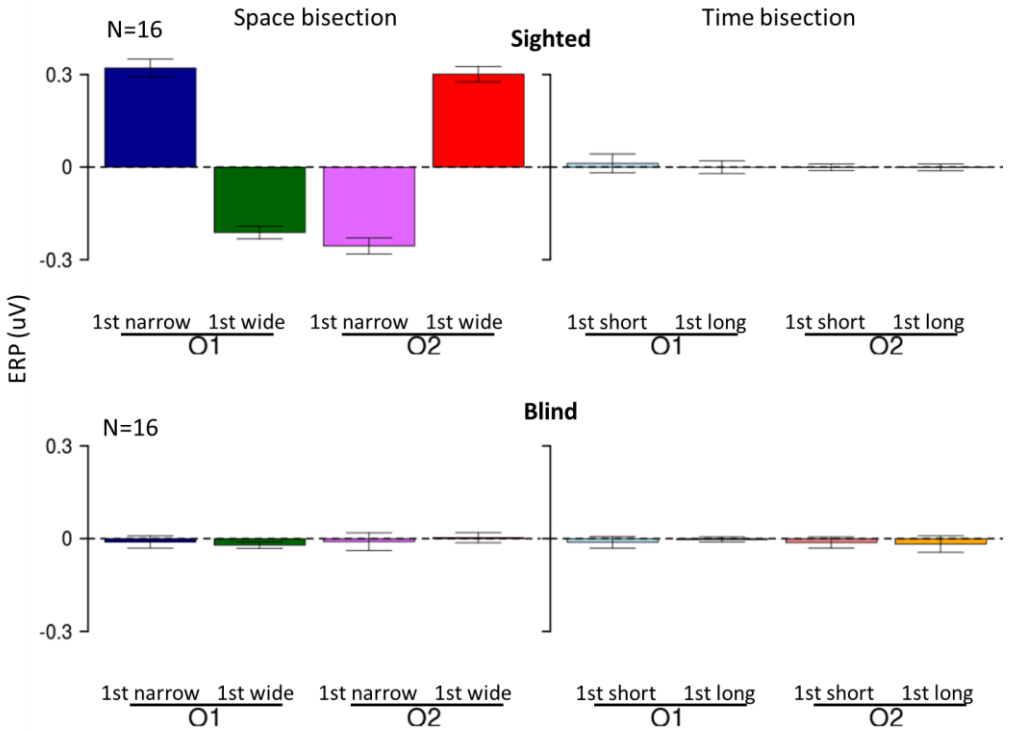


50-90ms time window

Occipital activation for audio space processing, mimicking the C1 ERP reseponse for visual stimuli only in sighted

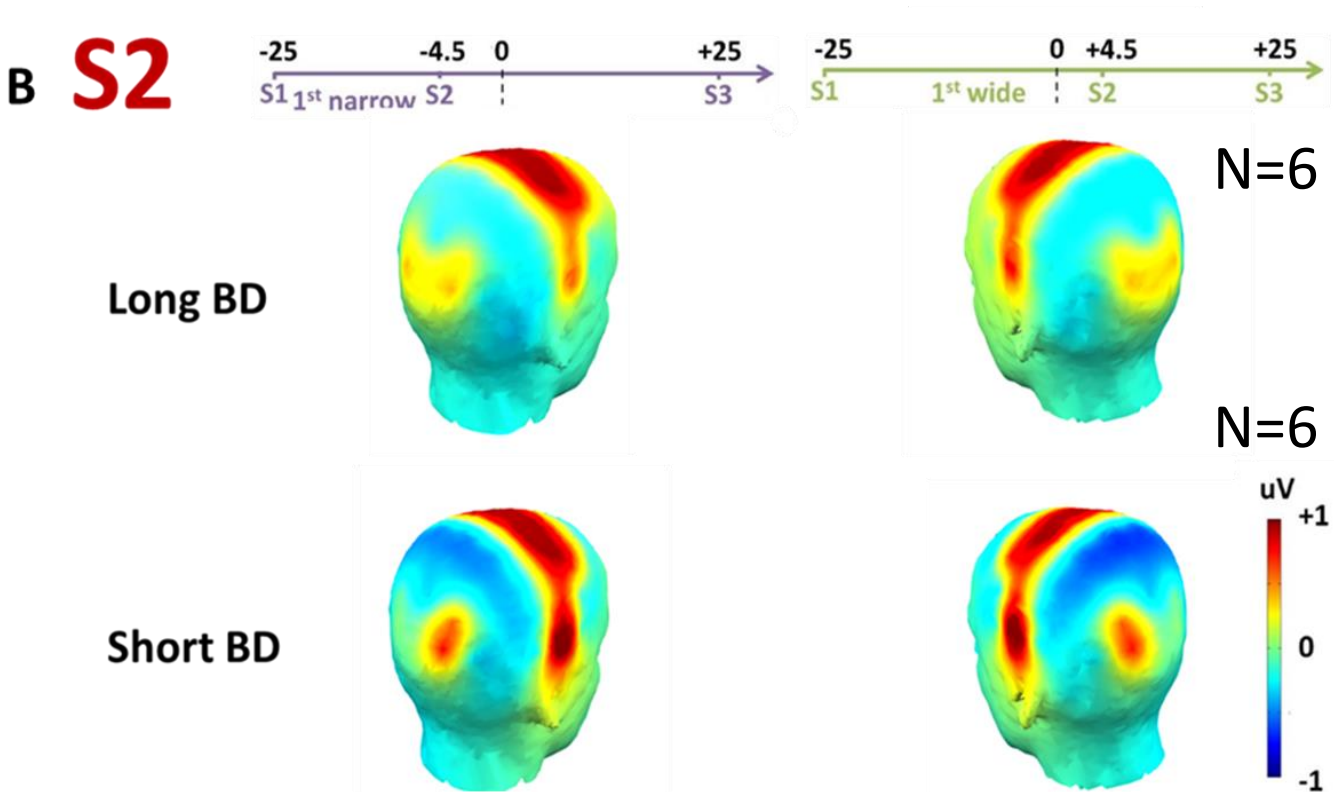
Campus, Sandini, Amadeo & Gori SREP (2019)

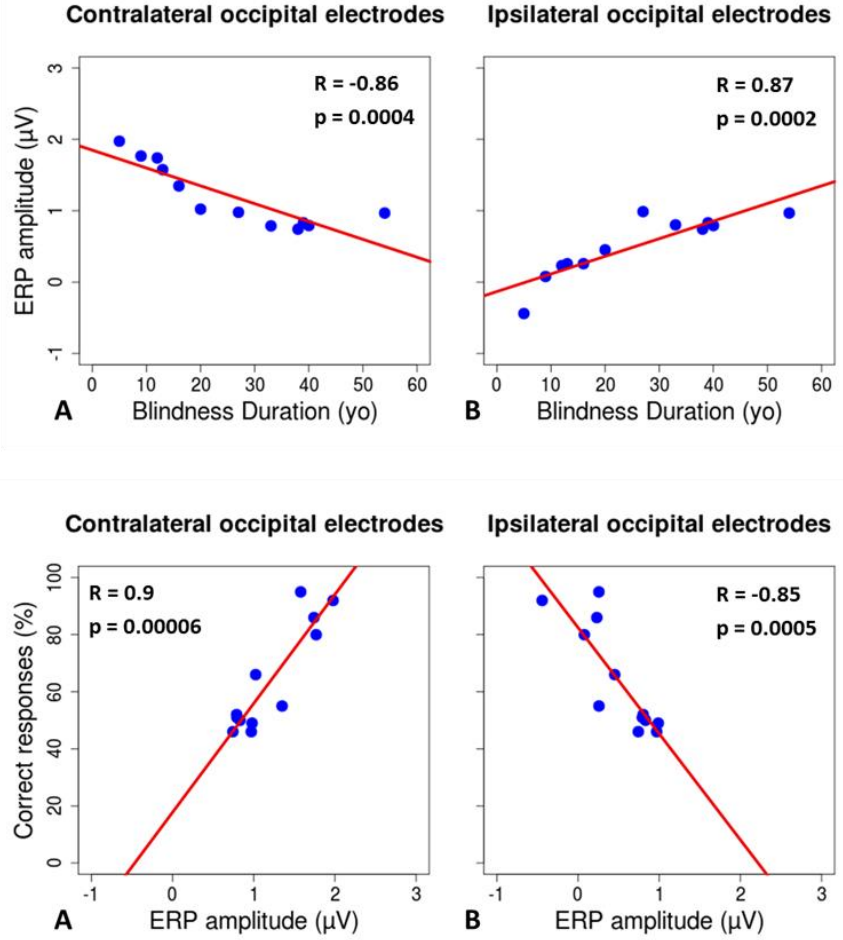




Campus, Sandini, Amadeo & Gori SREP (2019)

Importance of experience: visual cortical activation disappears after 20 years





Amadeo, Campus & Gori NeuroImage 2019

Audio Space

Audio space bisection

Blindness

Visual Cortex

Auditory Cortex

Audition

Visual time bisection

Visio Time

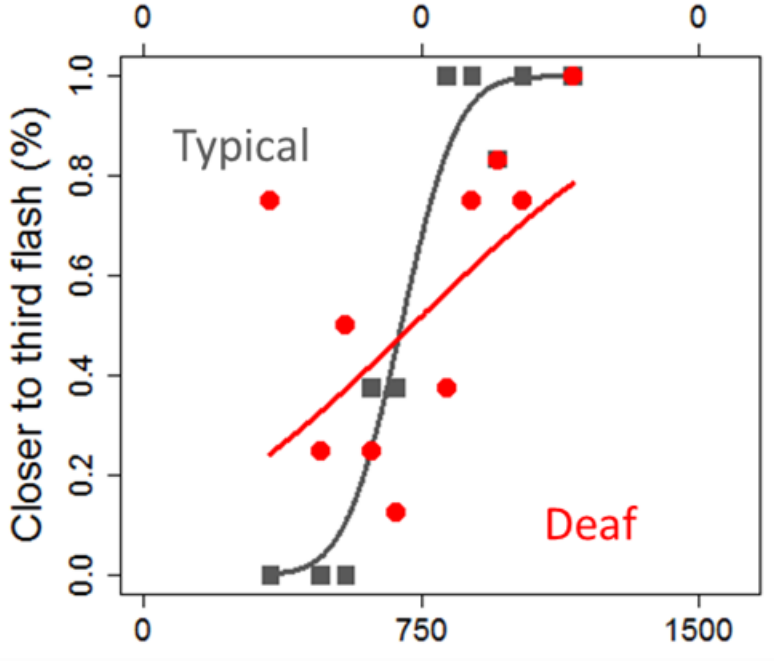
Deafness

Visual Cortex

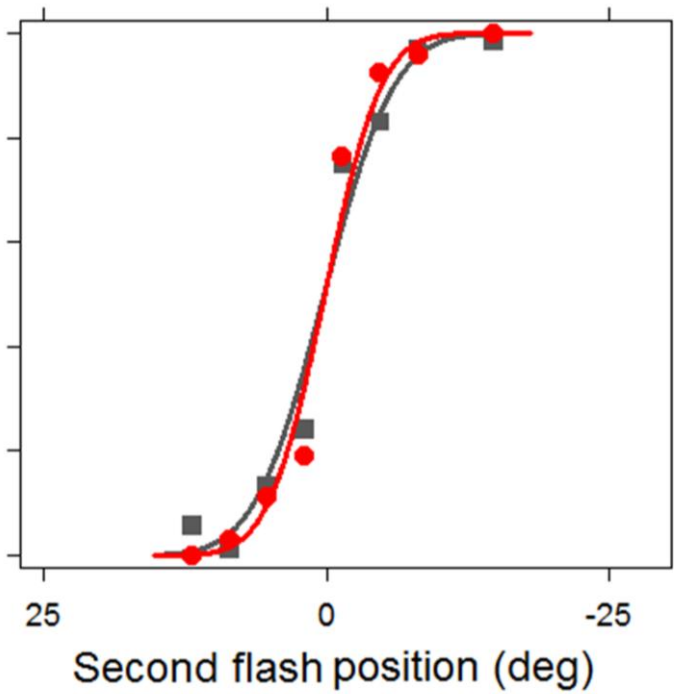
Auditory Cortex

Audition is important for temporal bisection: visually time impaired in deaf

Visual time bisection



Visual space bisection

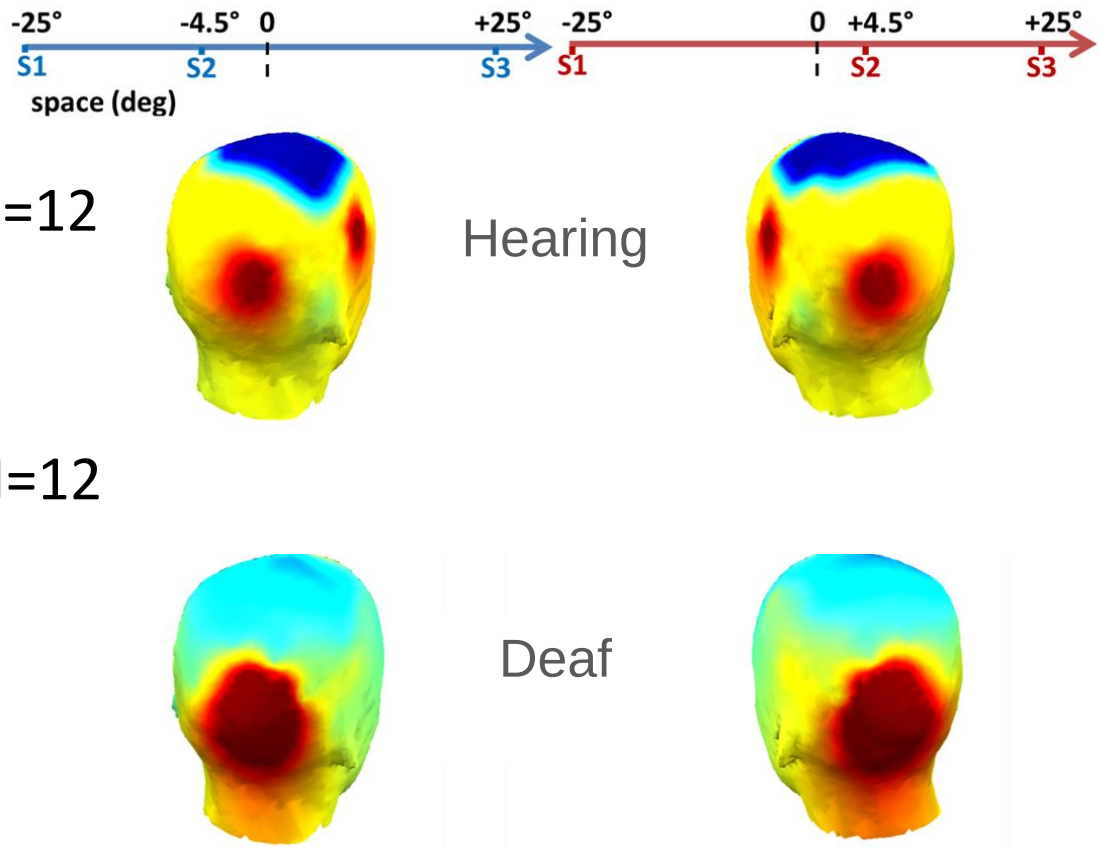


Gori, Chilosi, Forli and Burr Neuropsycholgia (2017)
Amadeo, Campus, Pavani, Gori, iScience 2020

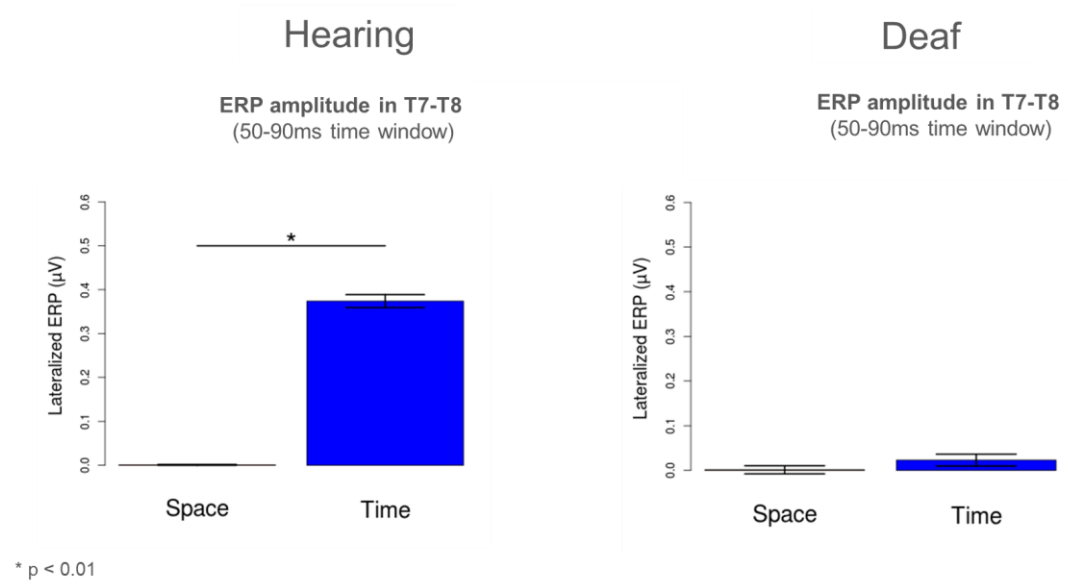
Early temporal cortical processing for visual time bisection not in deaf participants

Auditory activation: fronto-central and contralateral temporal activation in hearing for visual temporal processing, mimicking the N1a ERP reseponse of audio in visual temporal stimuli

50-90ms time window, fronto-central and contralateral temporal activation in hearing and not in deaf

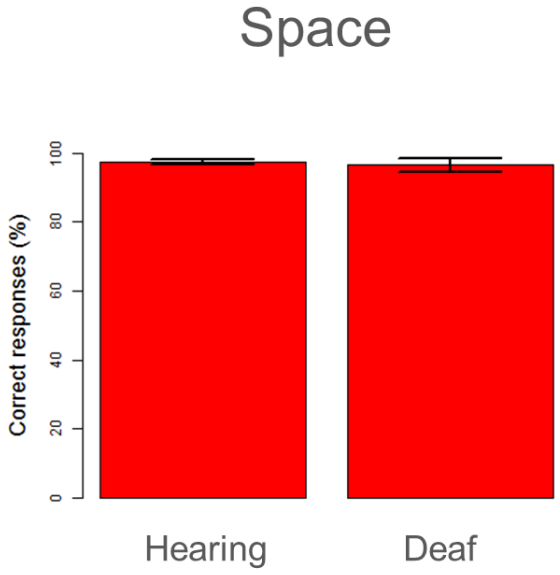


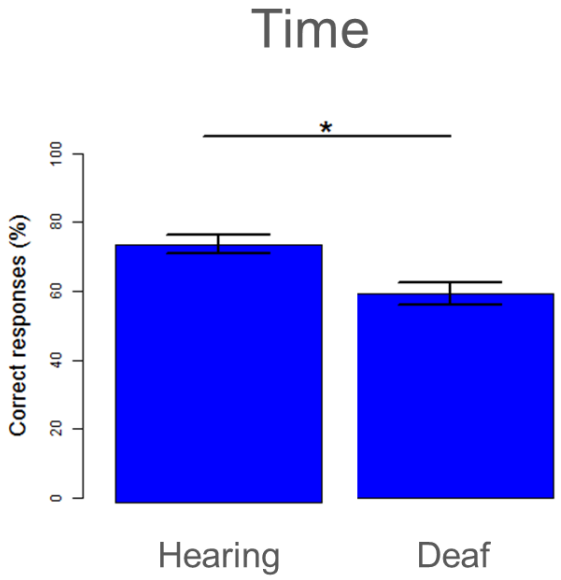
Second stimulus: temporal electrodes

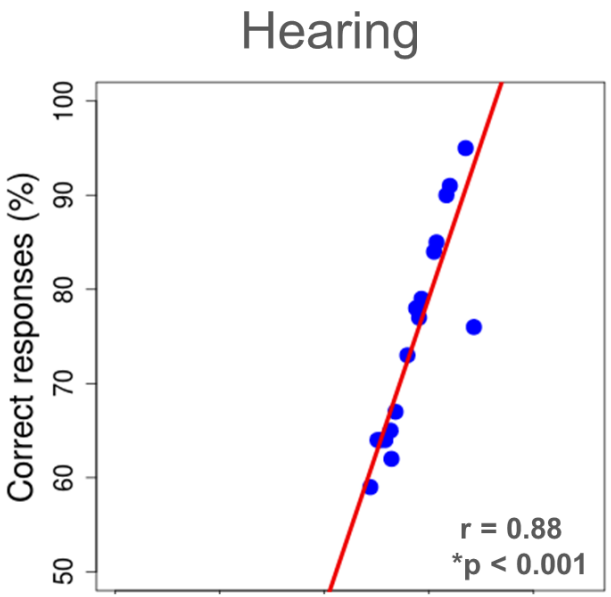


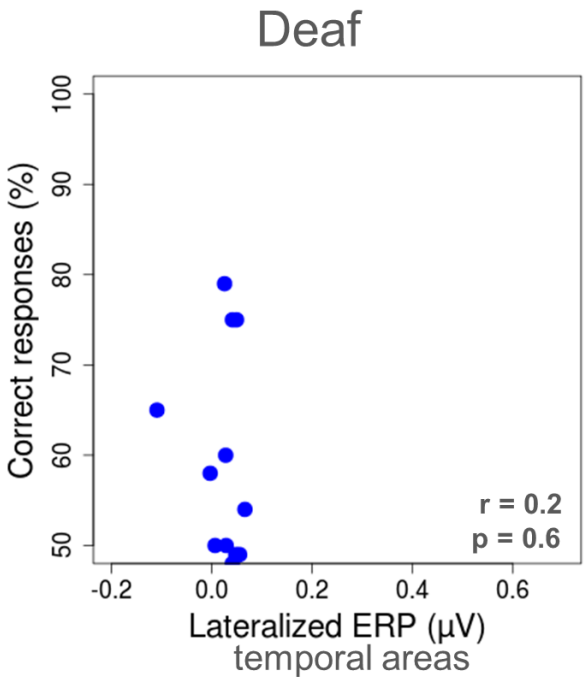
Gori, Amadeo, Pavani, Valzolgher, Campus STREP 2022

Behavioral vs cortical responses







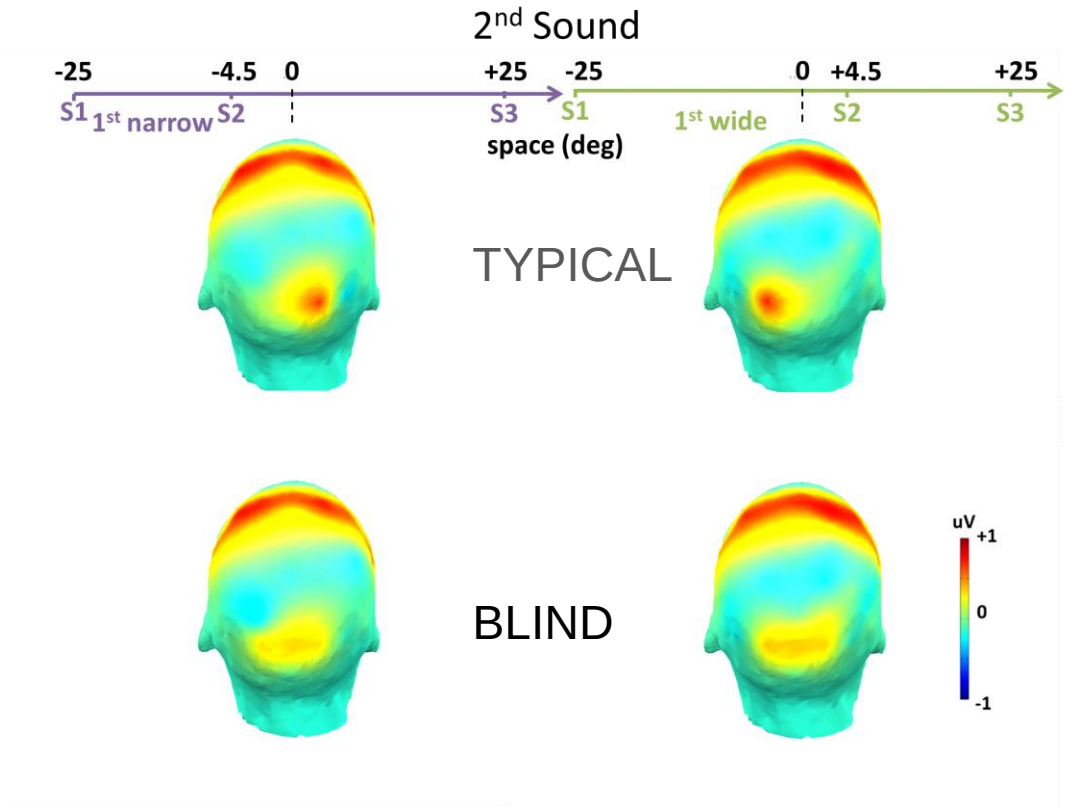


* p < 0.01

The contralateral auditory activation correlates with performance in hearing and not in deaf

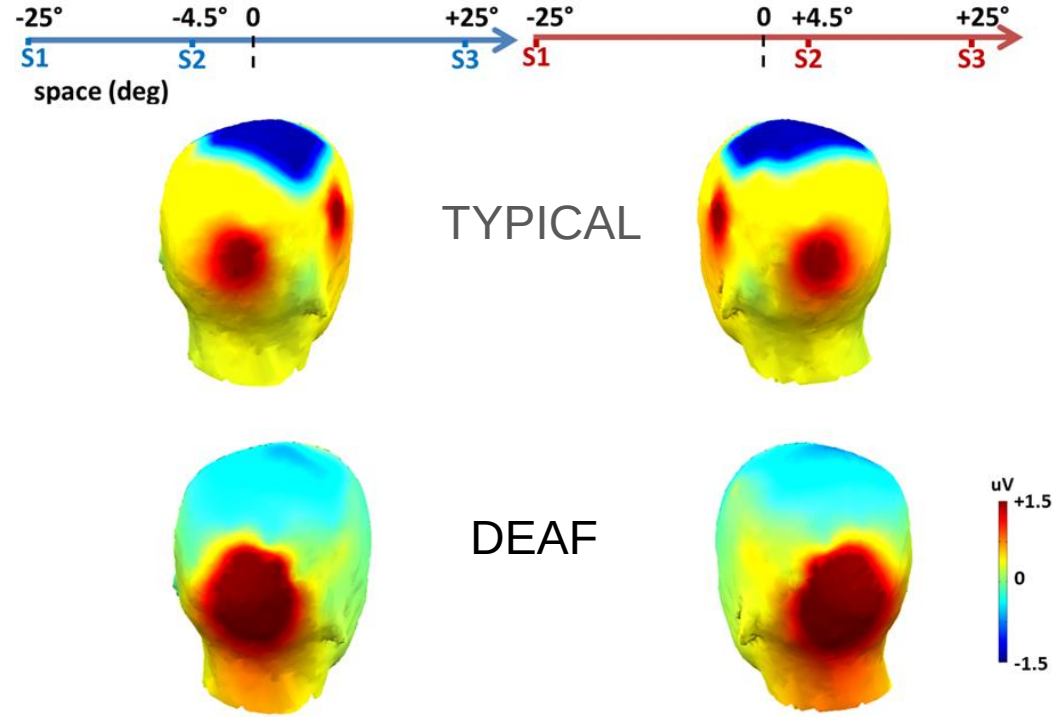
Gori, Amadeo, Pavani, Valzolgher, Campus STREP 2022

Audio space bisection



Related to visual input

Visual temporal bisection



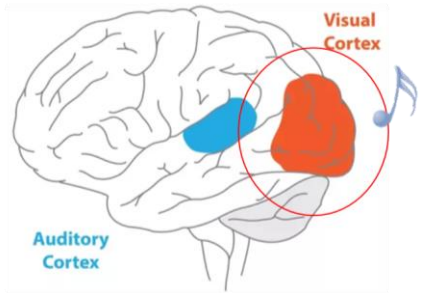
Related to auditory input

SPACE:

More visual responses modality independent

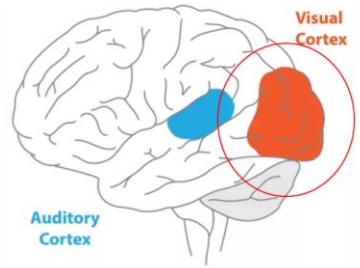
Early processing of visual areas task specific for space bisection

Audio Space



Campus et al. (2019)

Audio-Visual Space

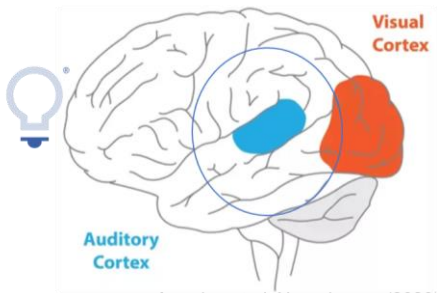


TIME:

More temporal responses modality independent

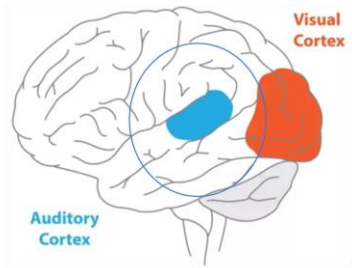
Early processing of auditory areas task specific for time bisection

Visual Time



Amadeo et al. NeuroImage (2020)

Audio-Visual Time



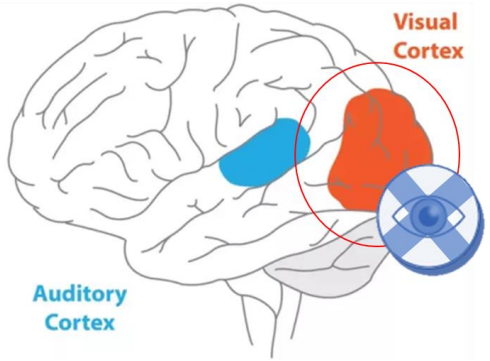
Gori, Bertonati, Campus & Amadeo, Submitted

BLINDNESS:

NO visual responses to audio

The lack of vision affects the early processing of visual areas for audio space

Audio Space

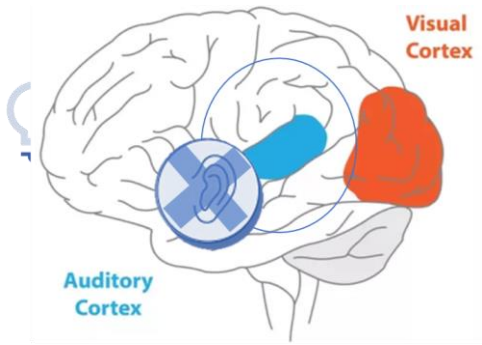


DEAFNESS:

NO audio responses to vision

The lack of audition affects the early processing of auditory areas for visual space

Visual Time



Interim Discussion

Early processing of sensory areas for audio-visual space and time processing:

Vision processes audio space and visual-audio space information

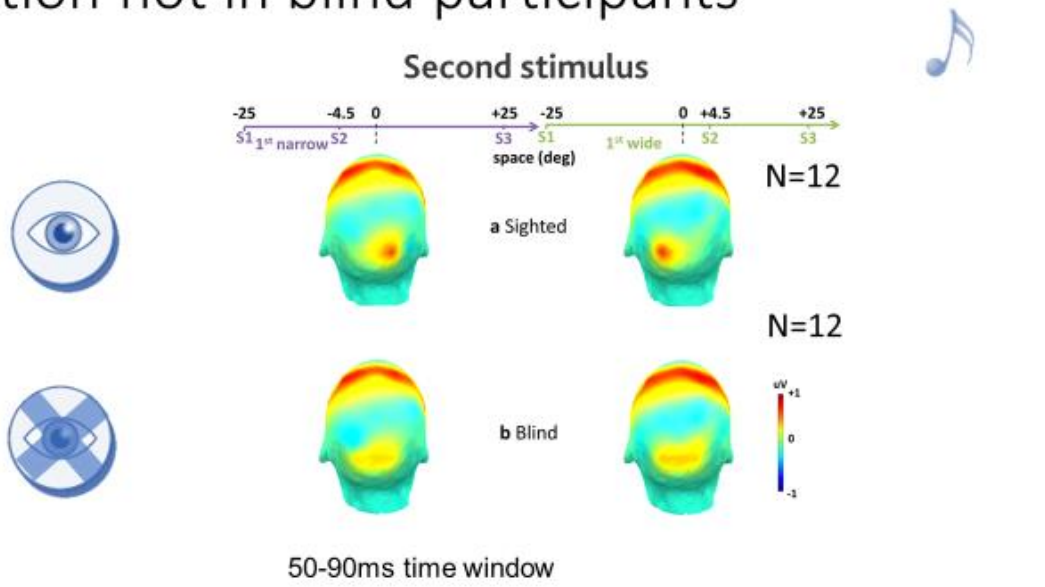
Audition processes visual time and visual-audio temporal information

The lack of vision affects this audio space processing and the lack of audition the visual temporal processing.

Domain-specific early sensory processing seems to be evident for unisensory and multisensory audio and visual space and time processing.

WHY IN BLINDNESS?

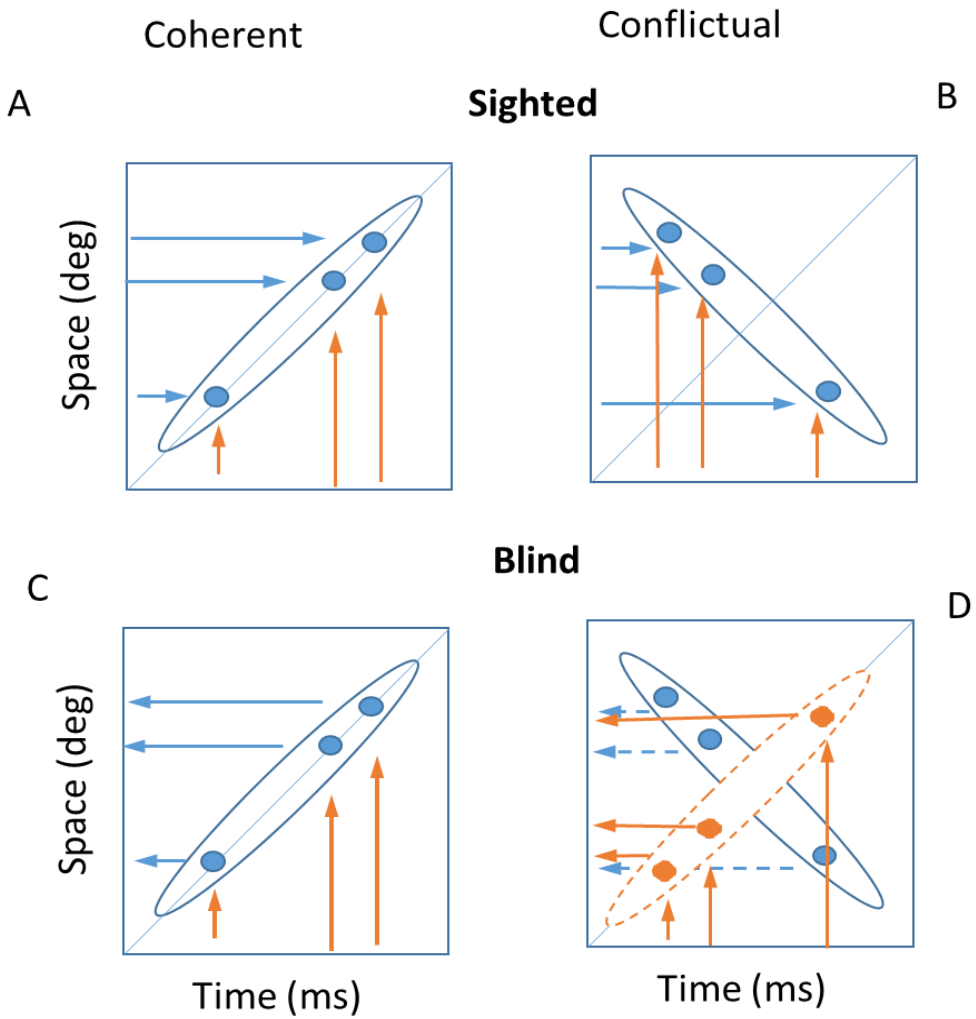
- Early visual cortical processing for audio space bisection not in blind participants



Campus, Sandini, Amadeo & Gori SREP (2019)

Prior on constant velocity?

In blind individuals, spatial information might be inferred by the temporal coordinates of the stimulus assuming constant velocity.



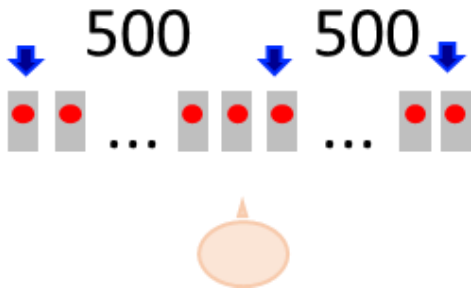
Gori, Amadeo & Campus Neurosci Biobehav Rev (2020)

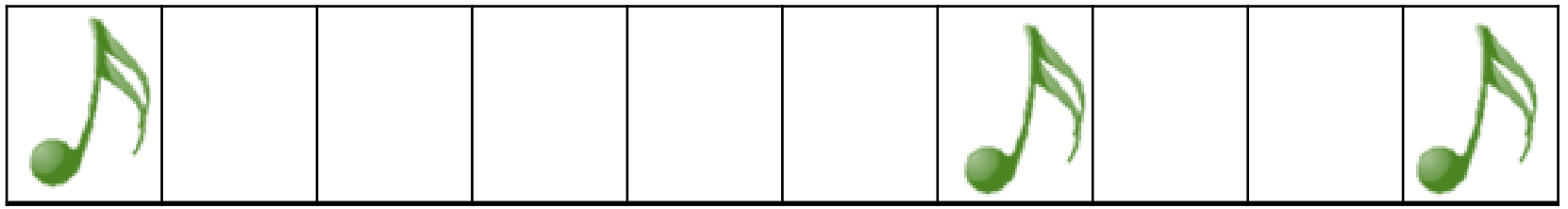
“

““Space is a still of time, while time is space in motion”

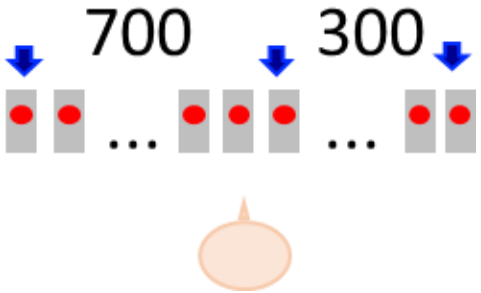
Piaget

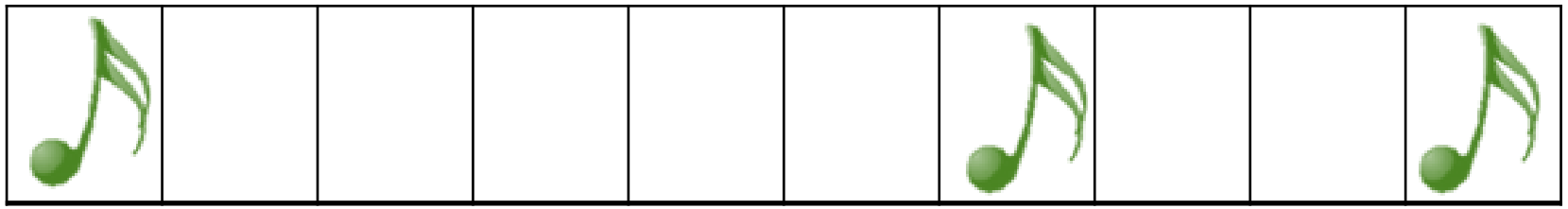
Equal Bisection



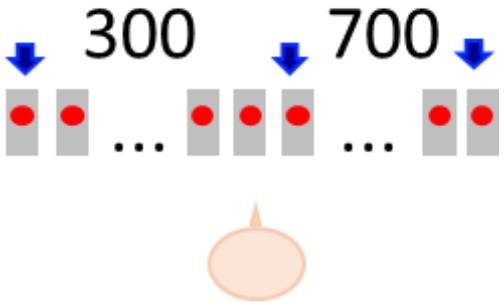


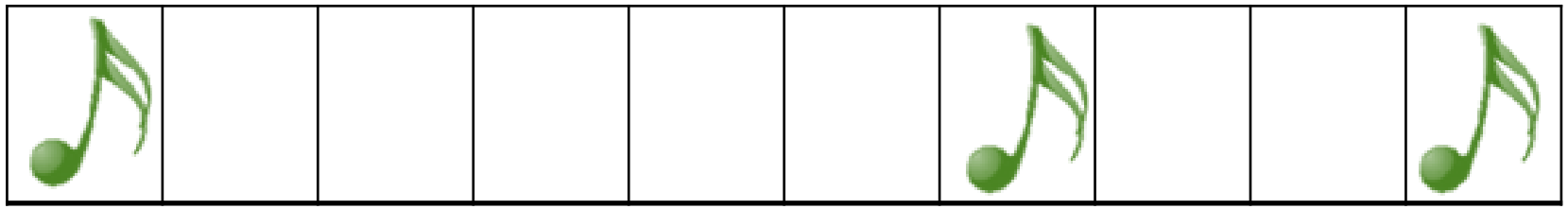
Coherent Bisection



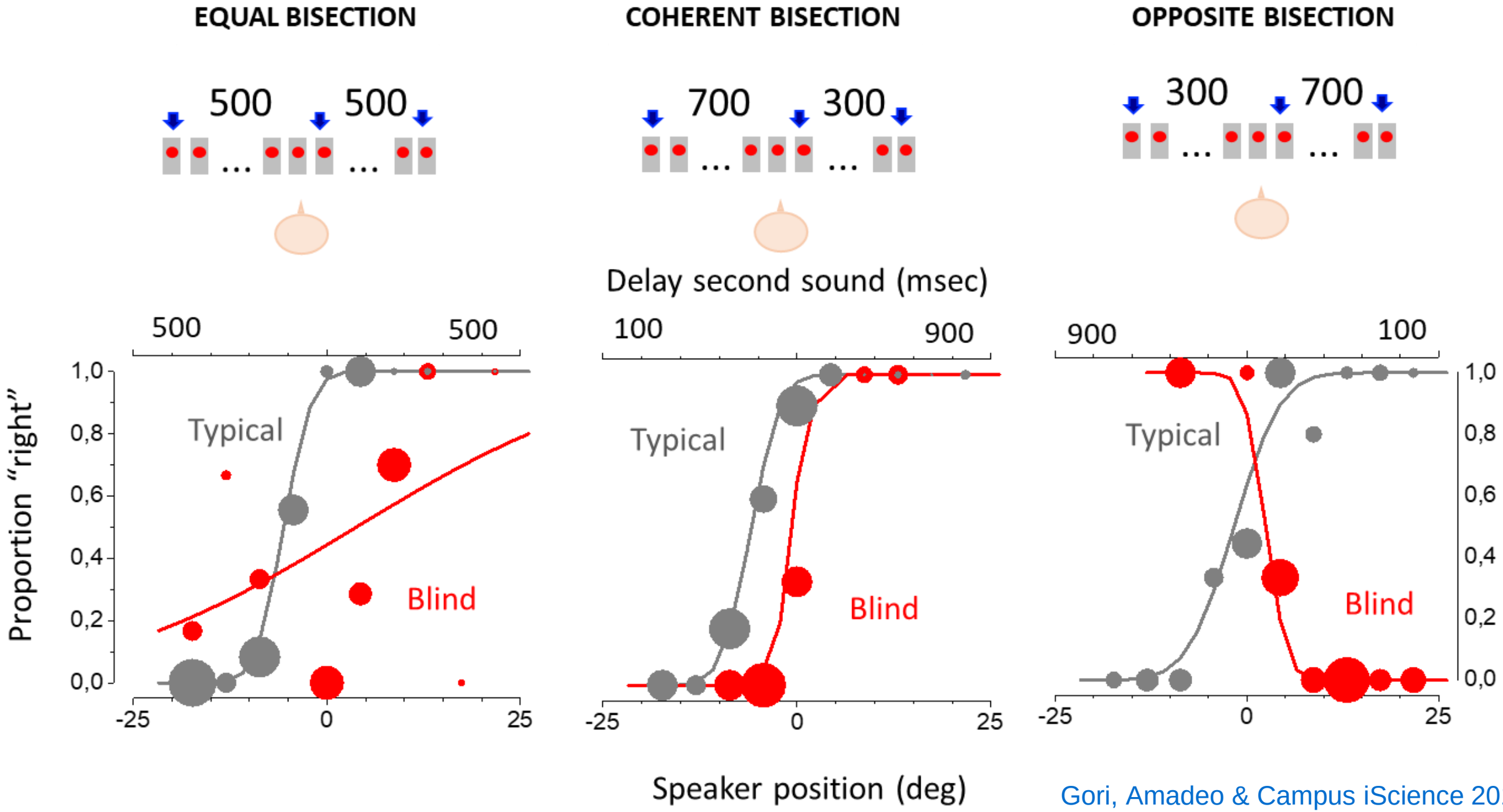


Opposite Bisection





Gori, Amadeo, Campus, iScience 2018



Gori, Amadeo & Campus iScience 2018

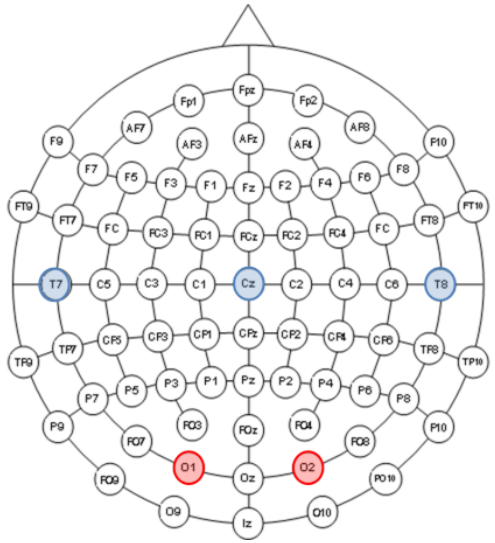
Methods

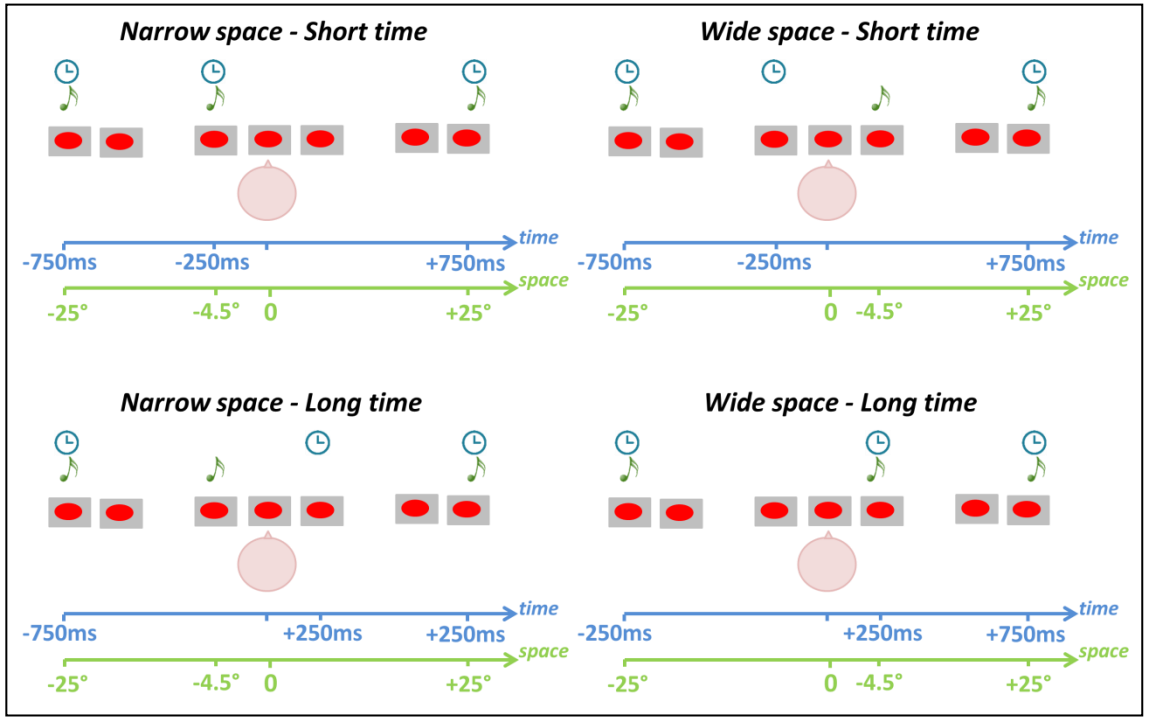
PARTICIPANTS

- 17 Sighted
- 16 Early Blind
- 12 Late Blind

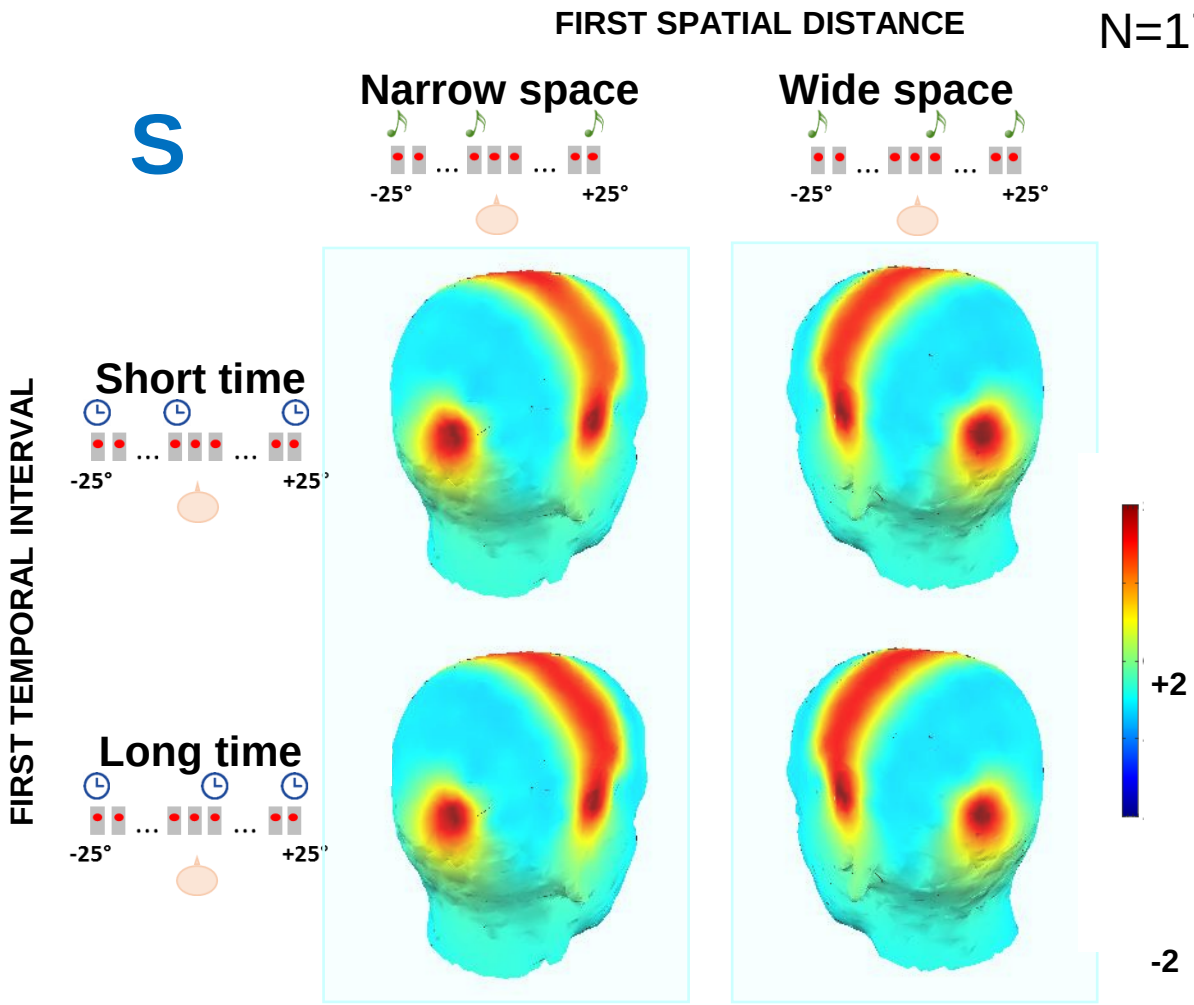
EXPERIMENTAL DESIGN

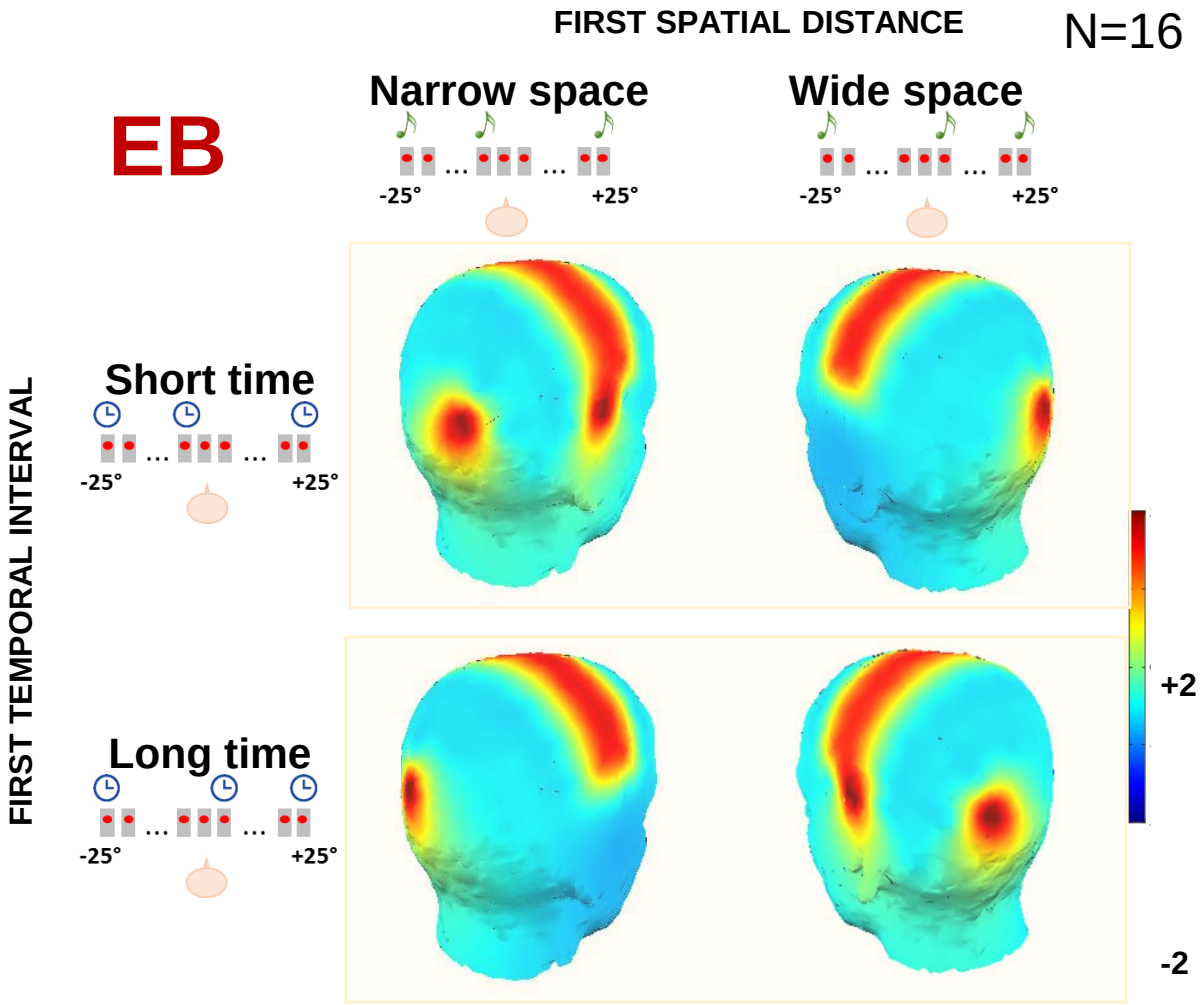
- EEG is continuously recorded
- Temporal bisection task
- Spatial bisection task





The visual cortex of early blind individuals responds to temporal instead of spatial cues

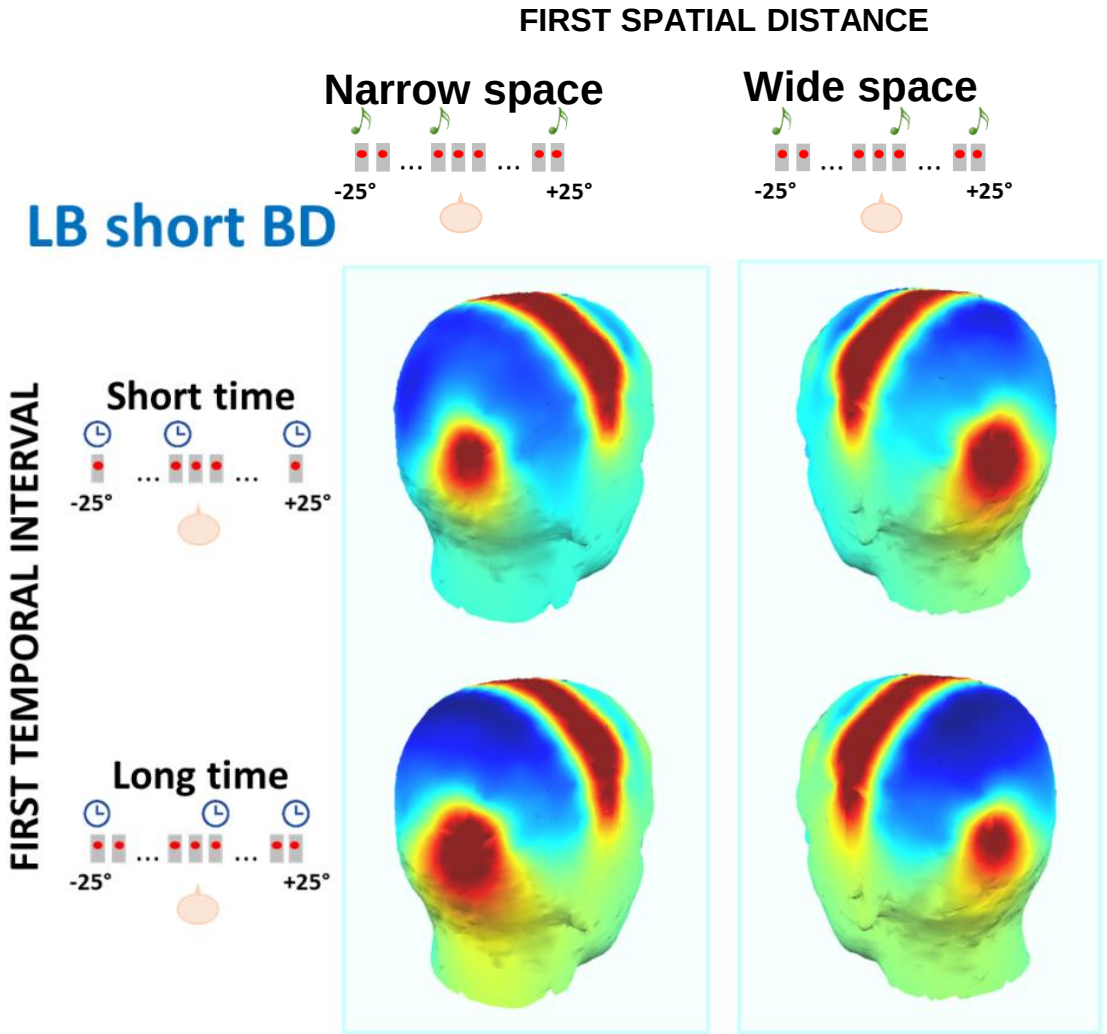


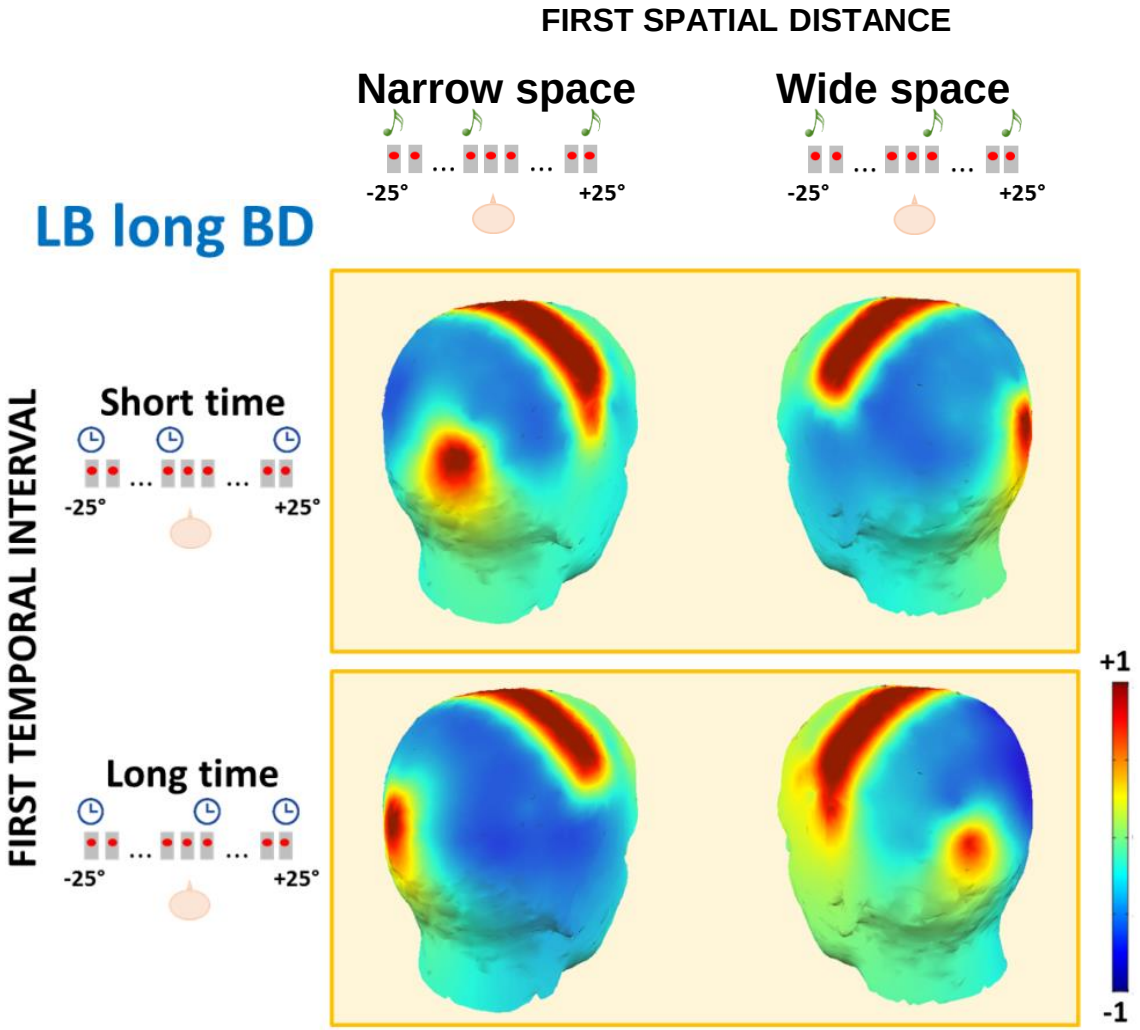


Gori, Amadeo & Campus Brain Mapping 2020

Temporal cortical processing also in late blind with long blindness duration: 25 years

N=12

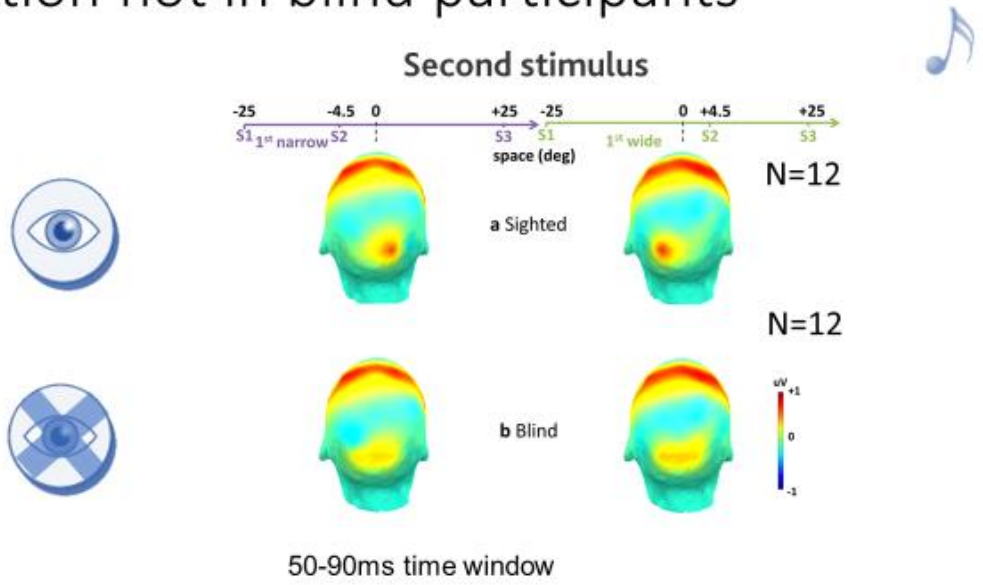




Amadeo, Campus & Gori Front. Neurosci. (2020)

CAN WE RECOVER?

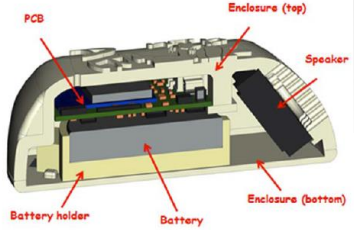
- Early visual cortical processing for audio space bisection not in blind participants



Campus, Sandini, Amadeo & Gori SREP (2019)

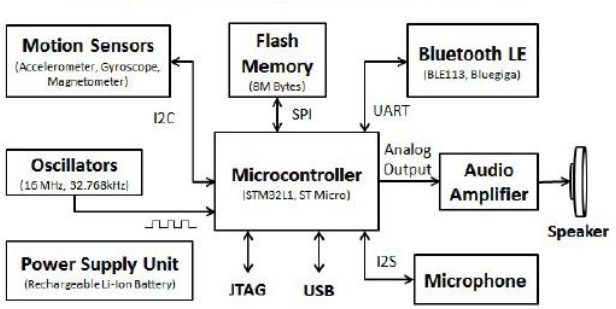
ABBI (Audio Bracelet for Blind Interaction): a wearable device for improving spatial cognition in visually-impaired children

Mechanical system

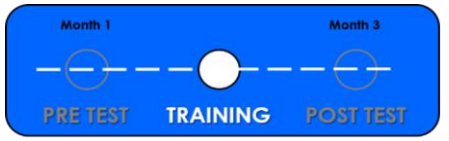


SEVENTH FRAMEWORK PROGRAMME

Actuation system



Validation



	PRE	POST
Auditory distance	NO	NO
Auditory localization	NO	YES
Auditory reaching	NO	YES
Auditory bisection	NO	YES
Proprioceptive localization	NO	YES
Proprioceptive reaching	NO	YES
Go and come test	NO	YES

Coordinators: **Monica Gori** and **Gabriel Boud-Bovy.**

Finocchietti et al., IEEE, EMBC 2015

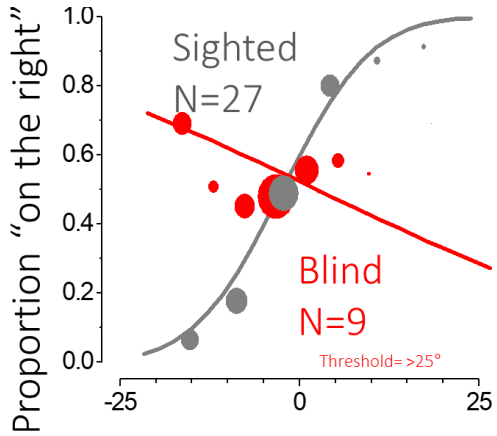
Multisensory training

ABBI

Science Based

User centered

Measurable

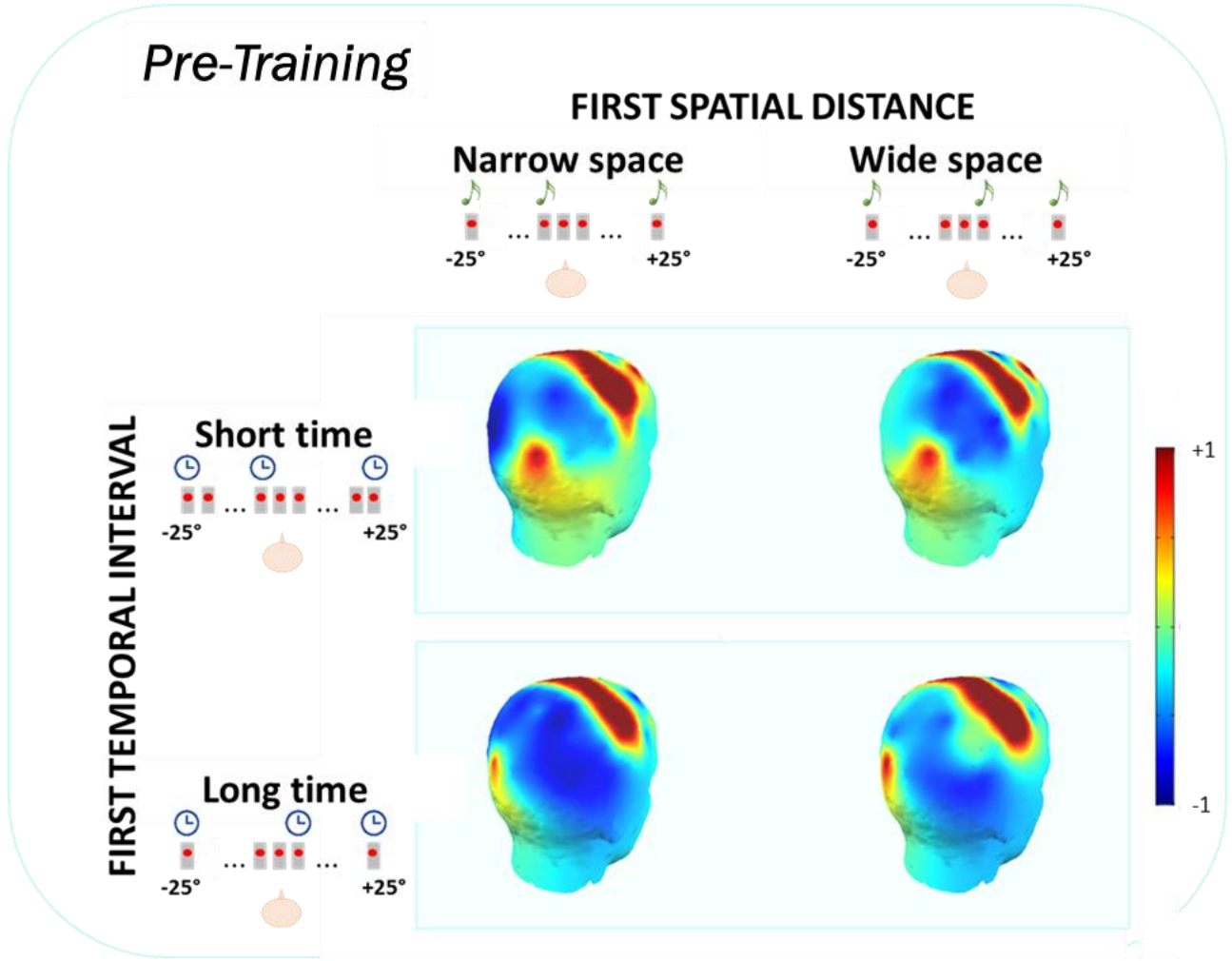


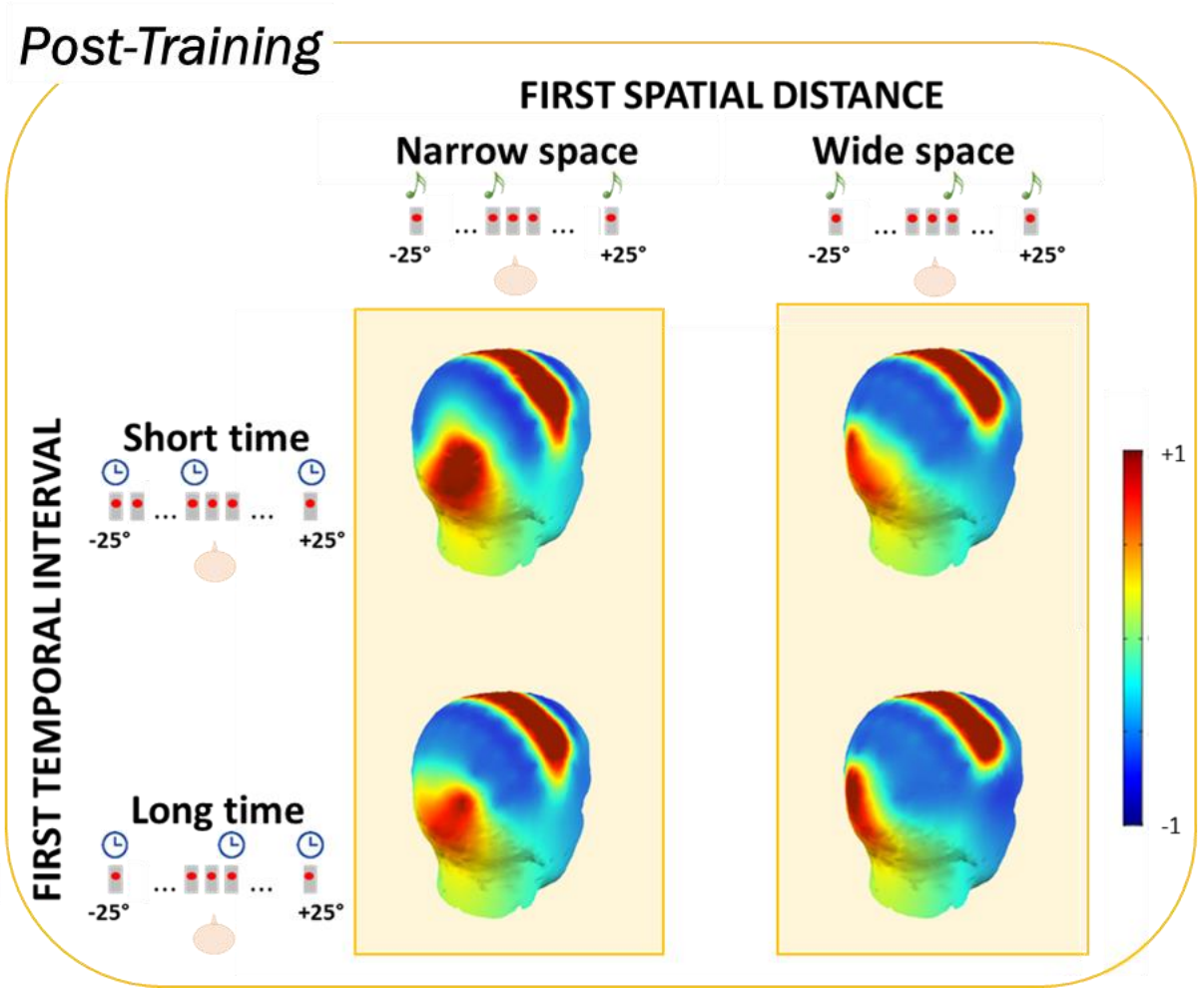
After 1 year

Gori, Sandini and Burr, Brain 2014
Gori et al Neurosci Biobehav Rev 2020

Cappagli et al, SREP 2020

After Training the reorganize the visual cortex to space and not time processing as sighted



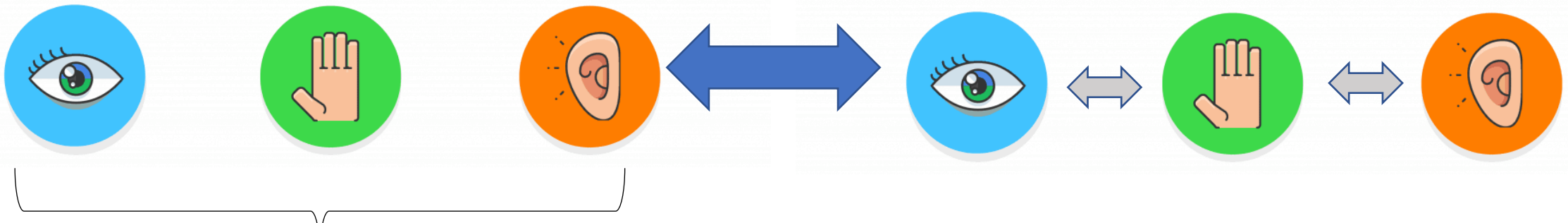


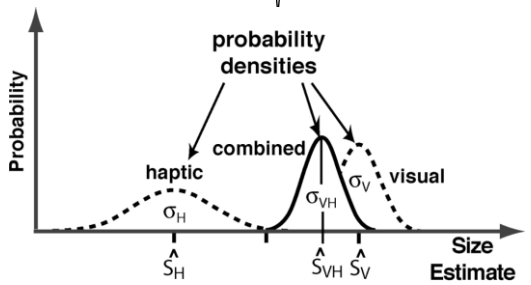
Martolini, Amadeo, Cappagli, Campus & Gori Neuropsychologia 2022

Interim discussion

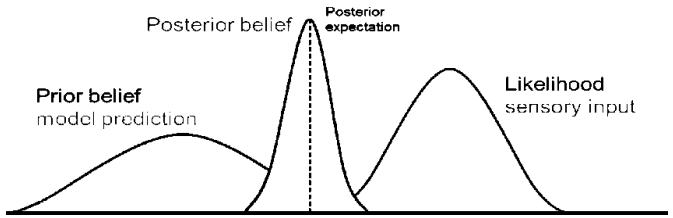
- Space and time are strictly linked to our everyday interaction with the environment.
- The results of this work show that the visual modality is fundamental to develop a spatial metric representation.
- Without vision spatial representation is impaired in some tasks and temporal cues can be used to infer space.
- This temporal organization strategy is evident at the behavioral and cortical levels.
- Spatial reorganization can be improved through temporal cues and sensory motor training at behavioral and cortical levels.

Acquisition of priors
Restoring priors
Integrating senses





Multisensory Integration



Cross-modal interaction

Infants and children

Thank you

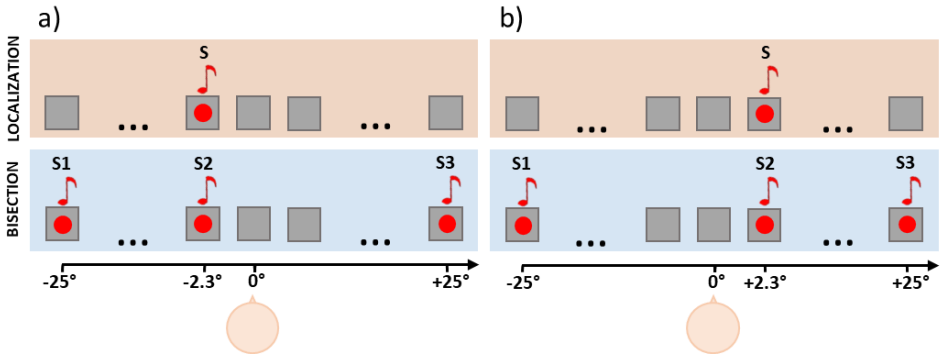
Post Doc position on haptics open
Contact me if you are interested

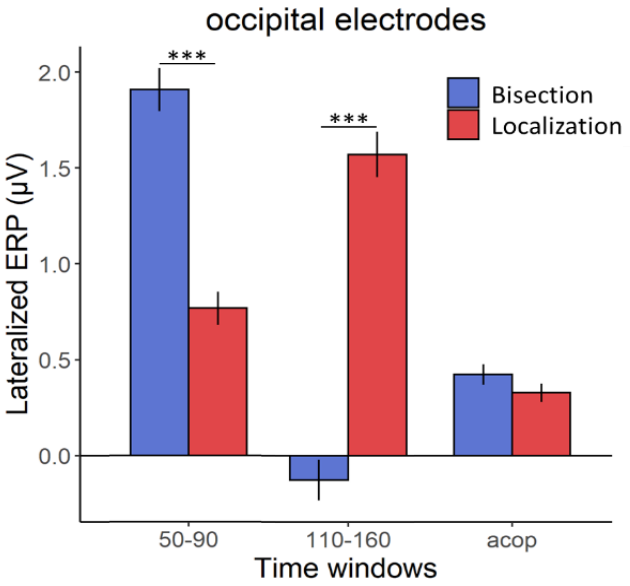
Monica.gori@iit.it

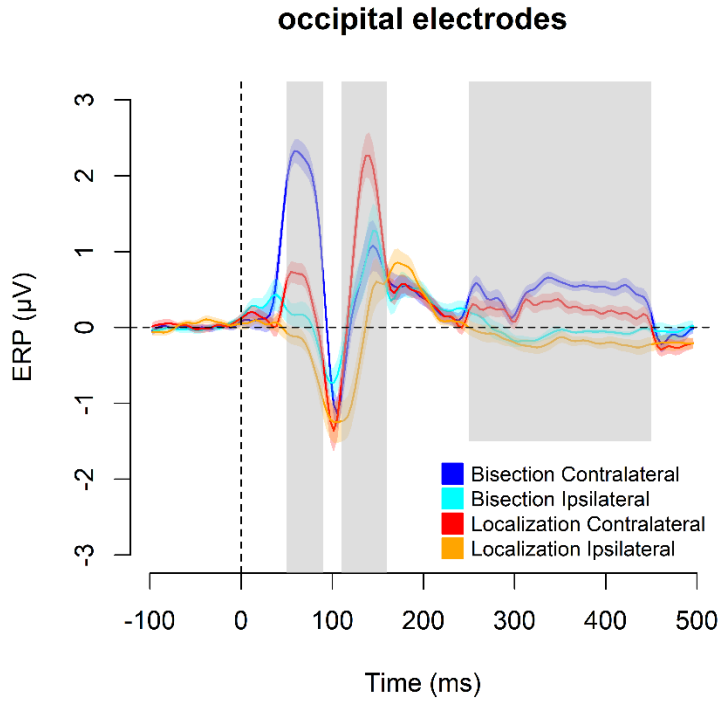
www.myspaceproject.eu ERC StG

iREACH
PoC

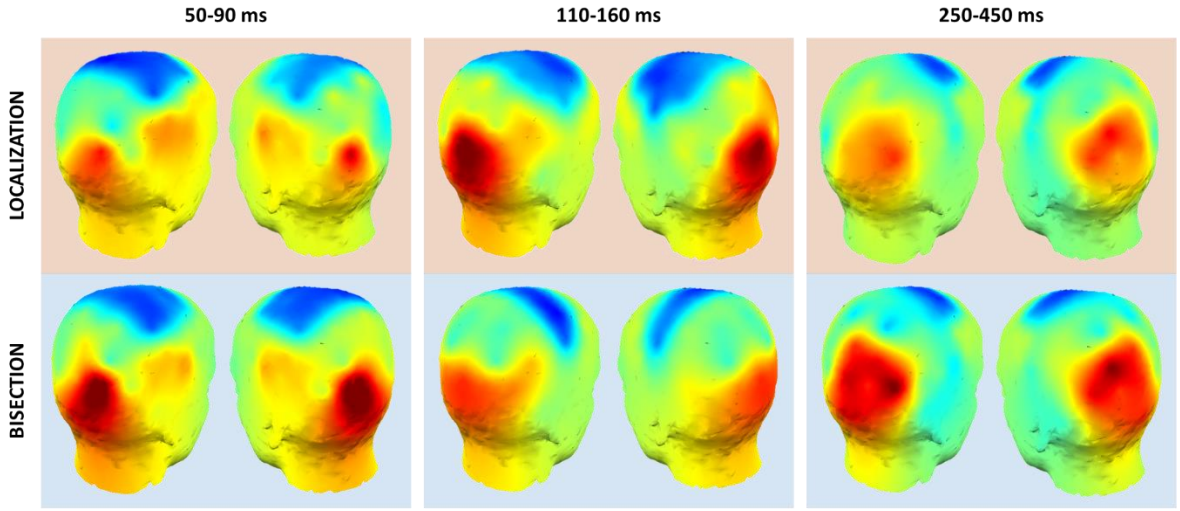
Localizzazione vs bisection

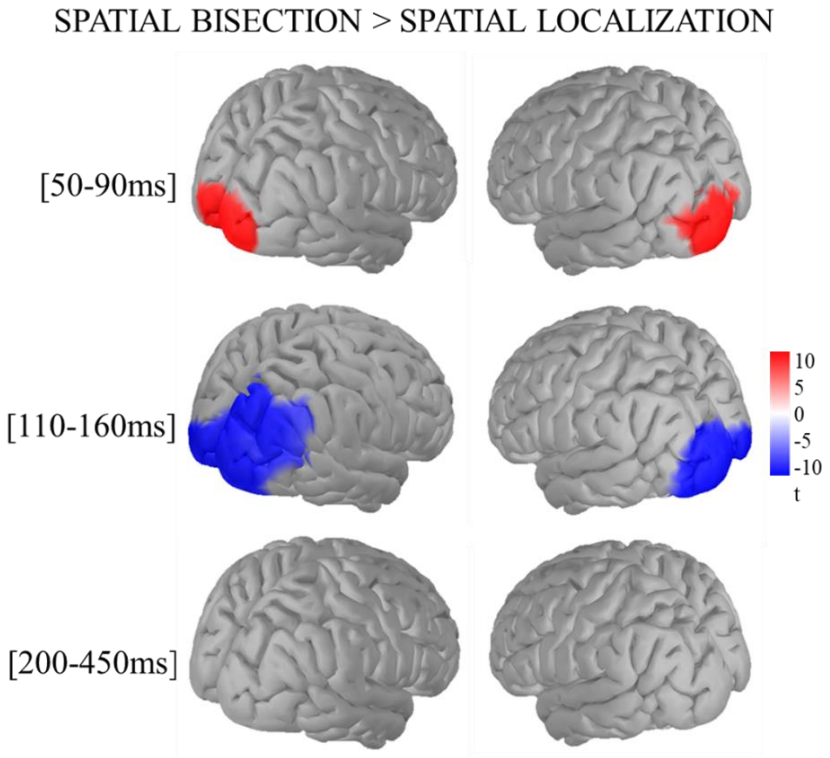




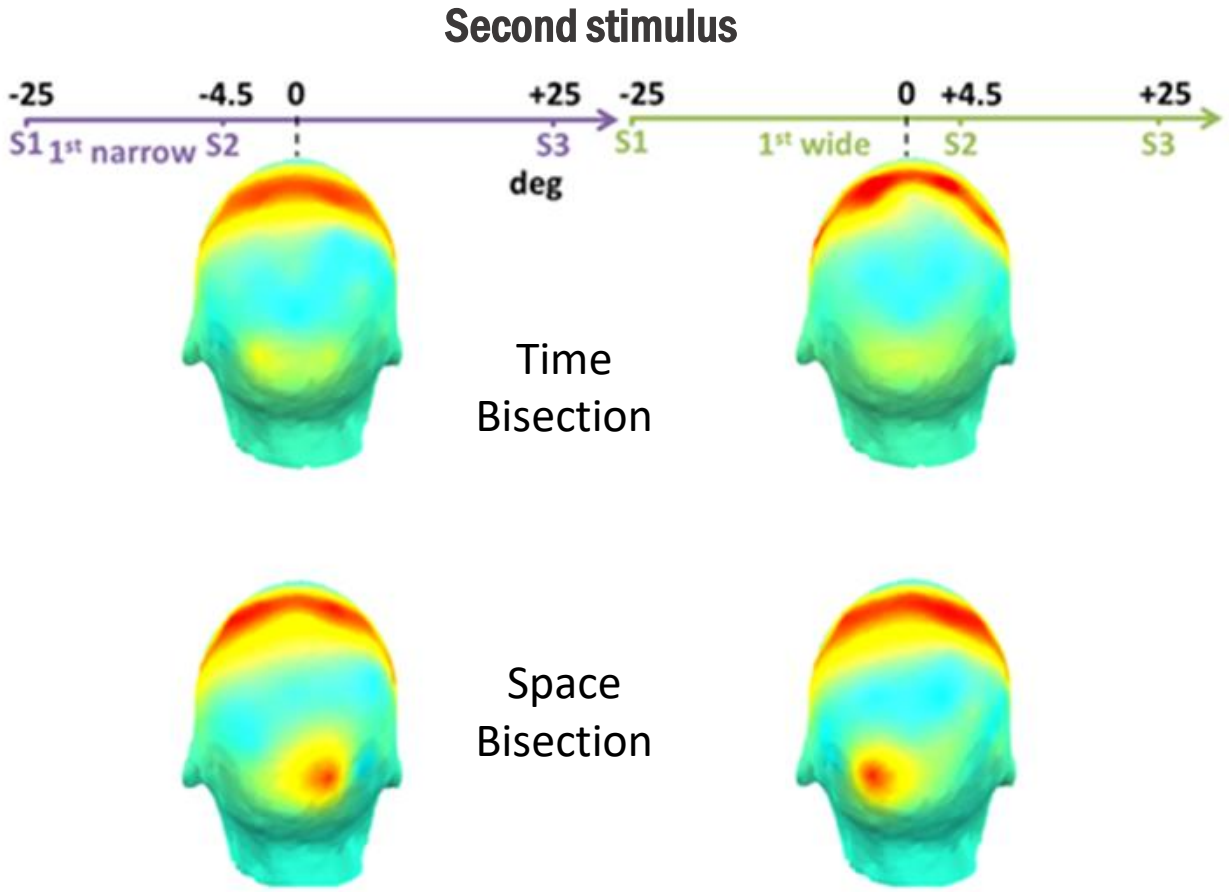


Localizzazione vs bisection





Contralateral occipital activation during auditory space bisection

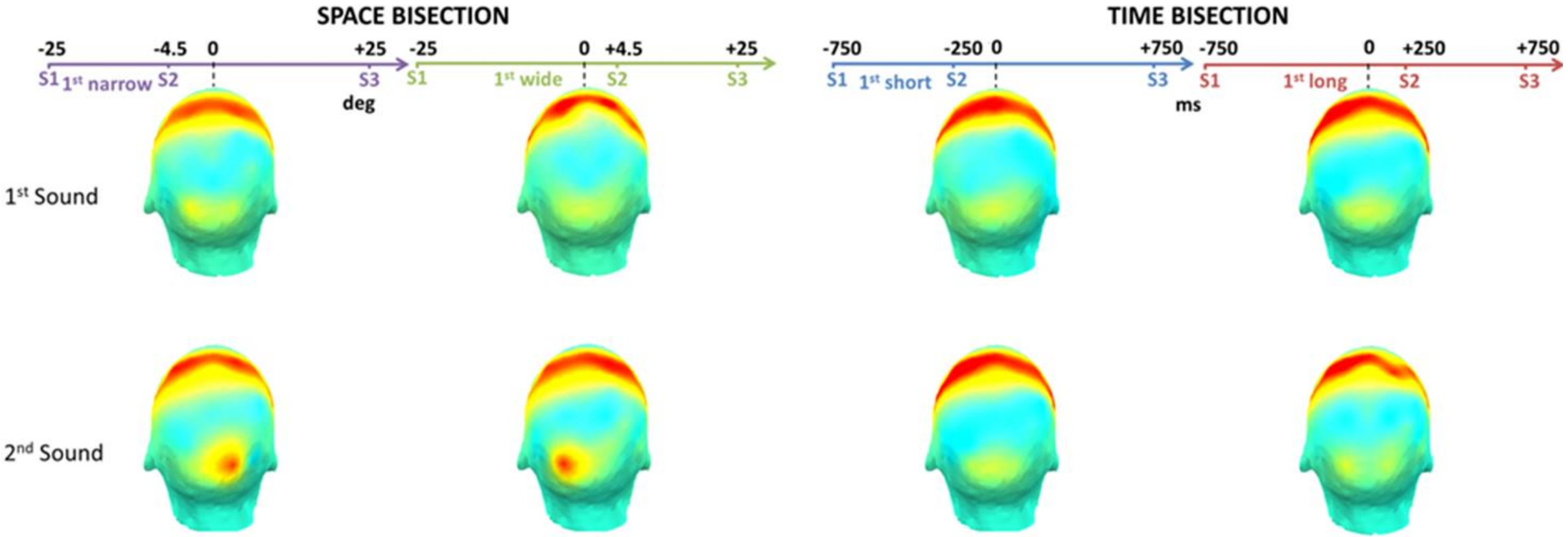


Occipital activation for audio space processing, mimicking the C1 ERP reseponse for visual stimuli

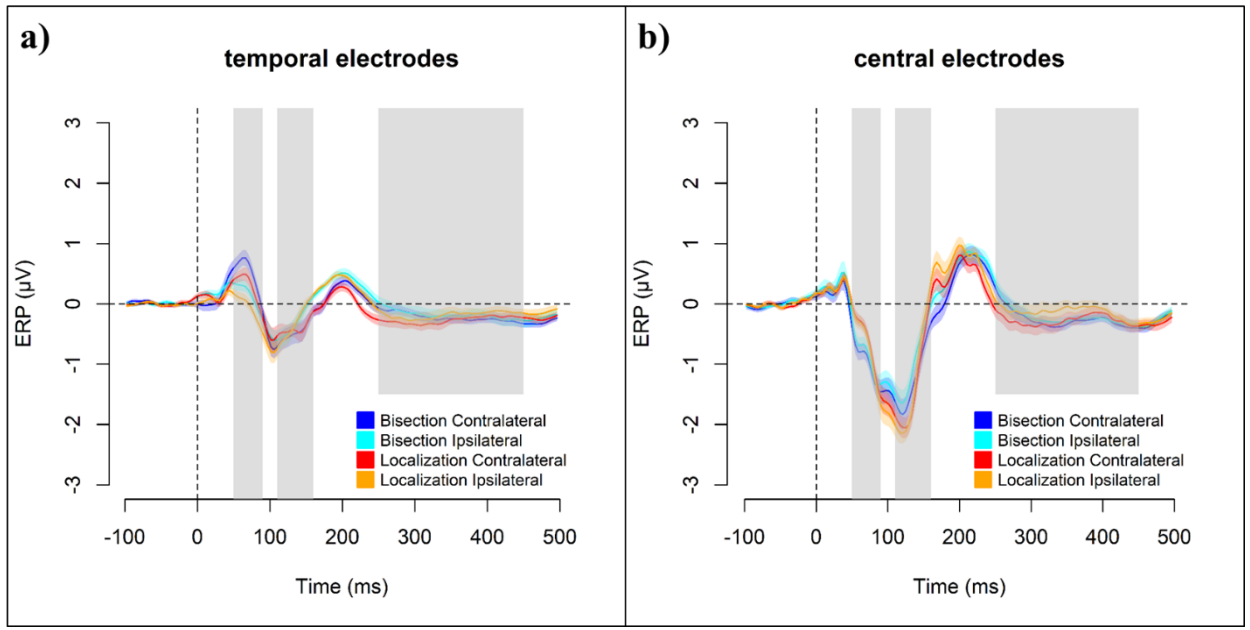
50-90ms time window

Campus, Sandini, Morrone, Gori SREP (2017)

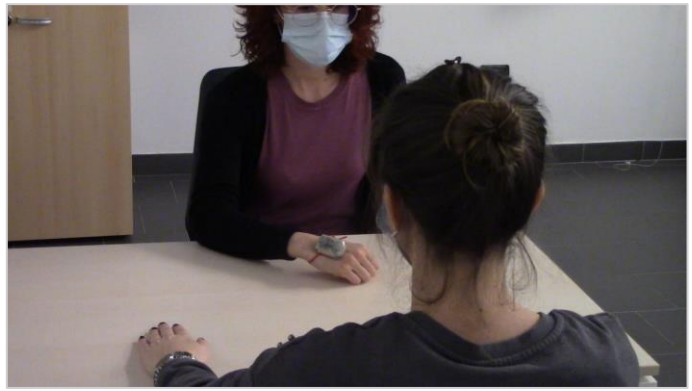
No evident for time

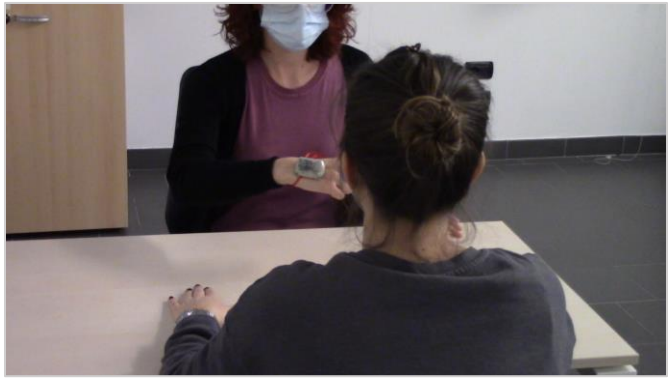


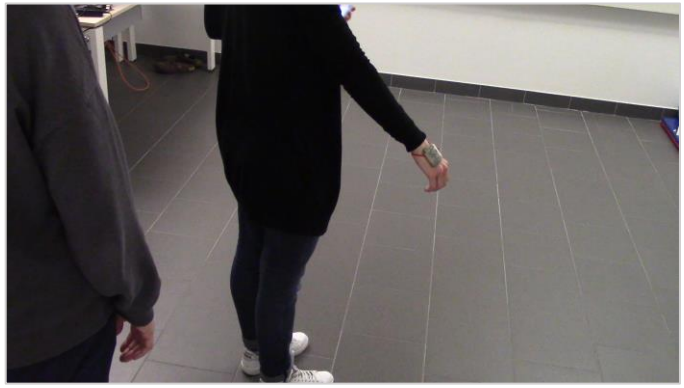
50-90ms time window


a)
temporal electrodes
ERP (μV)
3
2
1
0
-1
-2
-3
-100
0
100
200
300
400
500
Time (ms)
Bisection Contralateral
Bisection Ipsilateral
Localization Contralateral
Localization Ipsilateral
b)
central electrodes
ERP (μV)
3
2
1
0
-1
-2
-3
-100
0
100
200
300
400
500
Time (ms)
Bisection Contralateral
Bisection Ipsilateral
Localization Contralateral
Localization Ipsilateral

Training: total of 10 activities various difficulty levels







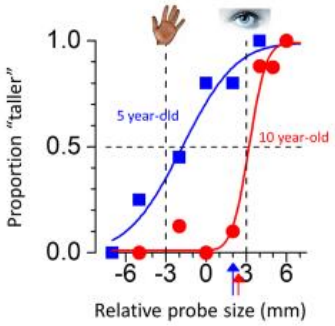
	PRE	POST
Localization sound	✗	✓
Depth	✗	✗
Path reproduction linear (hand)	✗	✓
Cortical reorganization (EEG)	✗	✓

Martolini, Amadeo, Cappagli, Campus & Gori Neuropsychologia 2022

Cross modal calibration theory

Started in 2002

Optimal integration development: haptic dominance for size



Gori et al., Current Biology (2008)

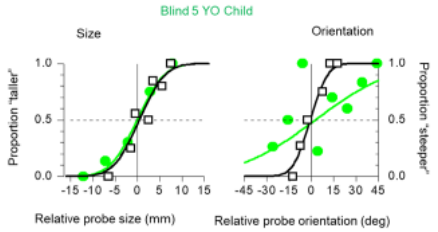
Gori et al 2008

F1000 FACULTY of 1000

Current Biology

Vision important for orientation: haptic orientation impaired in blind

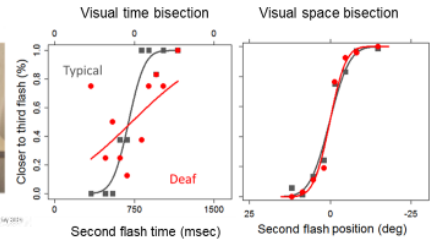
Current Biology



Gori, Martinoli, Sandini & Burr Current Biology 2010
Cuturi &Gori FNINS 2017

Audition is important for temporal bisection: visually time impaired in deaf

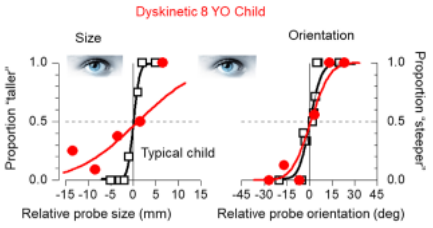
NEUROPSYCHOLOGIA



Gori, Chilosi, Forli and Burr Neuropsychologia (2017)
Amadeo, Campus, Pavani, Gori, iScience 2020

Haptic is important for size: visually size impaired in dyskinetic

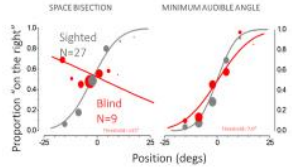
NEUROPSYCHOLOGIA



Gori, Tinelli, Sandini, Cioni & Burr Neuropsychologia 2012

Vision is important for spatial bisection: auditory space impaired in blind

BRAIN

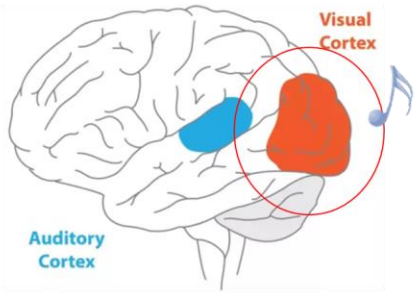


Gori, Martolini, Sandini and Burr Brain 2014
Vercillo, Burr and Gori Dev sci 2016

SPACE:
More visual responses modality independent

Audio Space

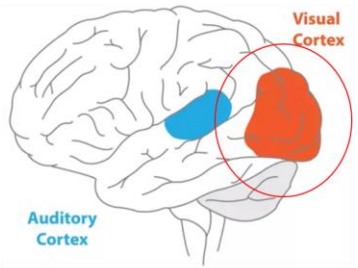
Early processing of visual areas task specific for audio space bisection



Campus et al. (2019)

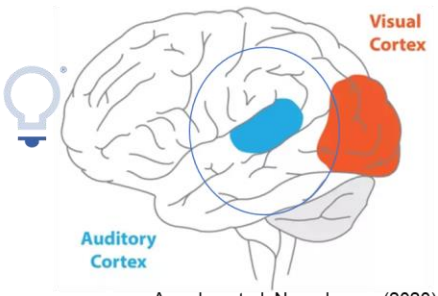
Audio-Visual Space

Early processing of visual areas for audio-visual space: more dominance on vision for space



Visual Time

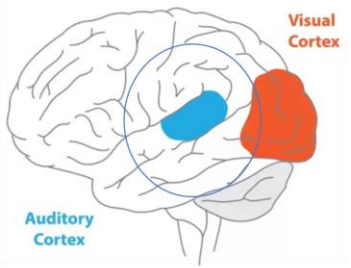
Early processing of audio areas task specific for visual time bisection



Amadeo et al. NeuroImage (2020)

Audio-Visual Time

Early processing of audio areas for audio-visual time: more dominance on audio for time



Gori, Bertonati, Campus & Amadeo, Submitted

TIME:
More temporal responses modality independent