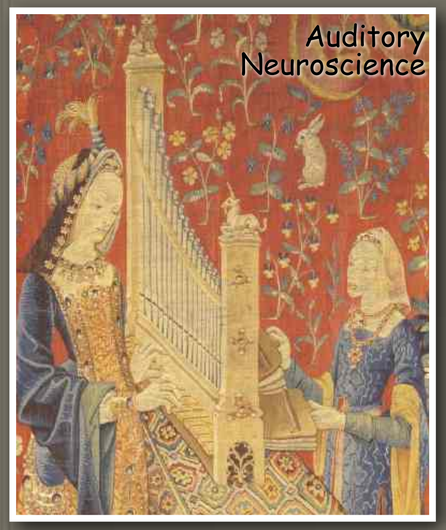
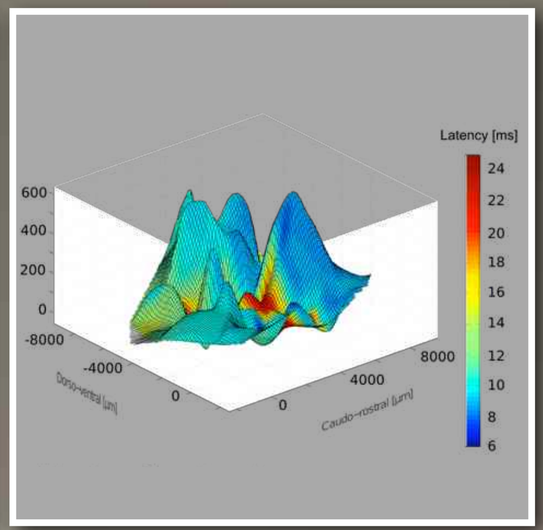
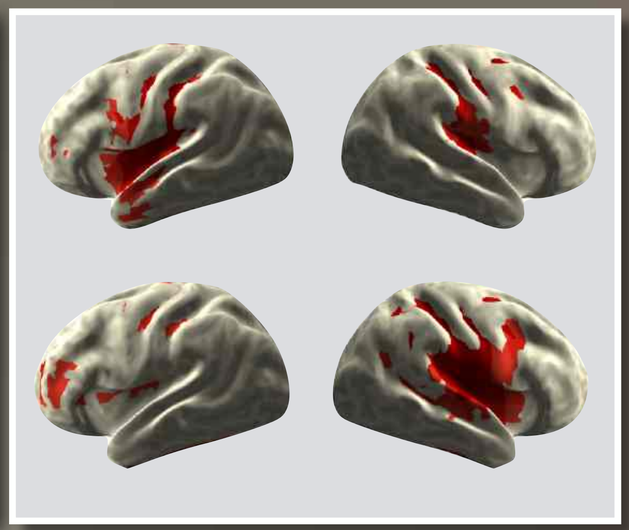


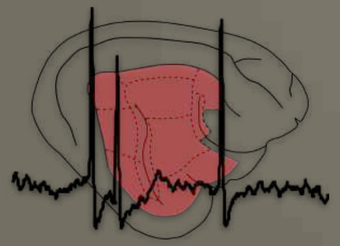



# The time is running: how the brain learns to hear

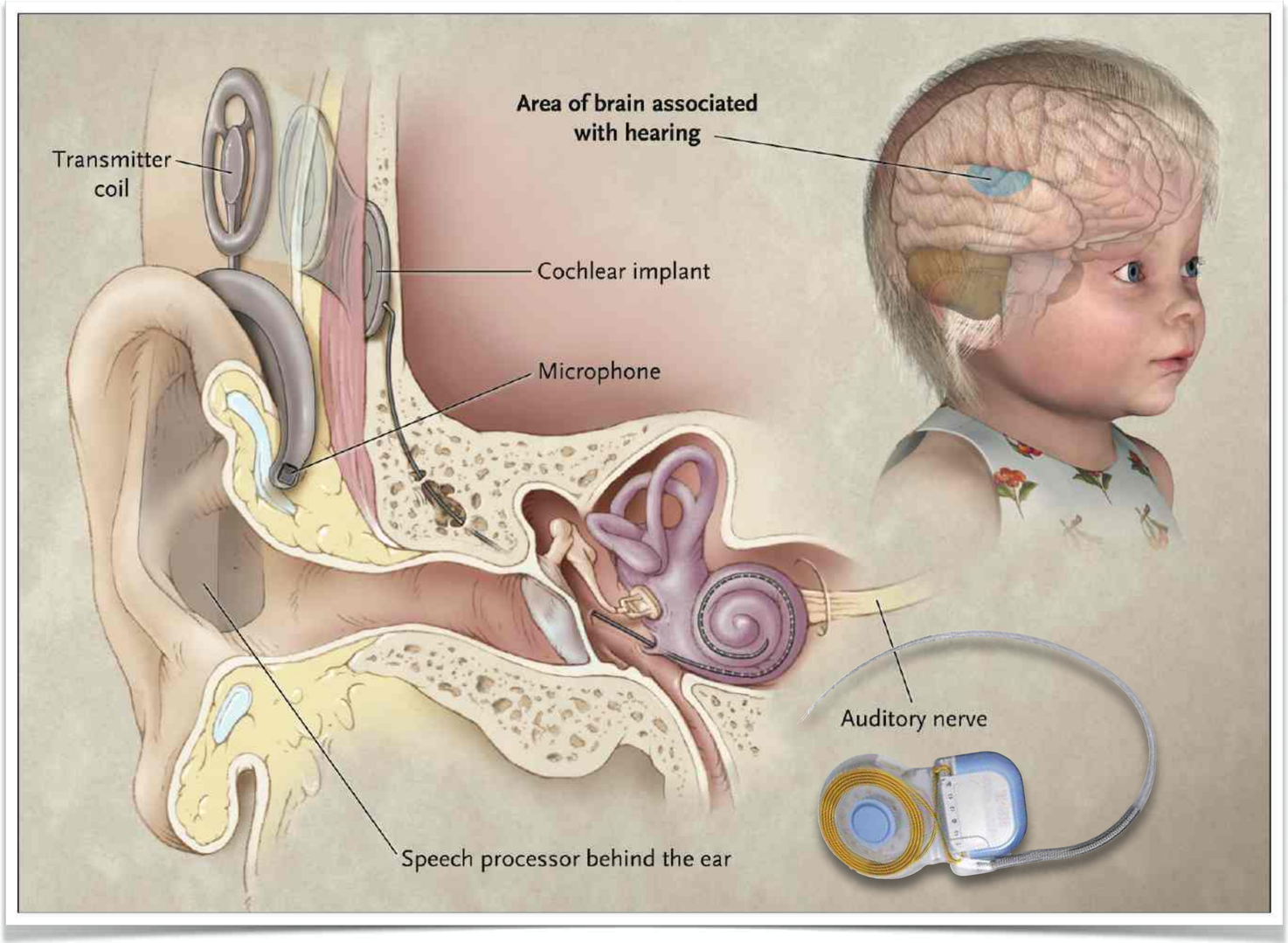
*Andrej Kral*

*www.neuroprostheses.com*

Institute of AudioNeuroTechnology (VIANNA) &
Dept. of Experimental Otology, ENT Clinics
Cluster of Excellence Hearing4All, Hannover, Germany
&
School of Medicine & Health Sciences
Macquarie University, Sydney, Australia

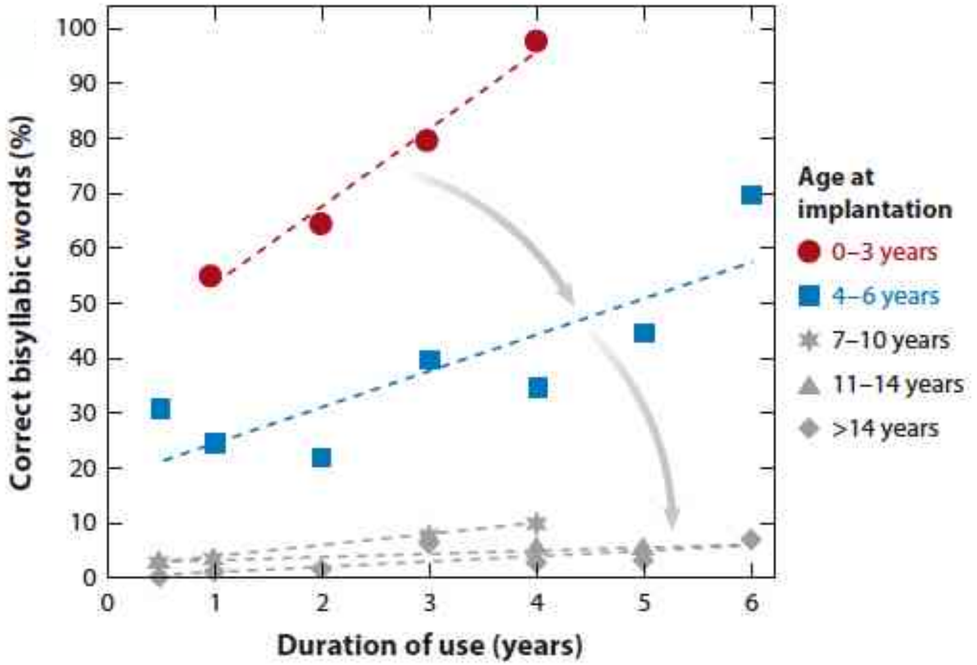


# Critical period of 3 years for therapy of congenital deafness in children




Kral & O'Donoghue, 2010, New Engl J Med
Kral and Sharma, 2012, Trends Neurosci

## Why is the period critical?

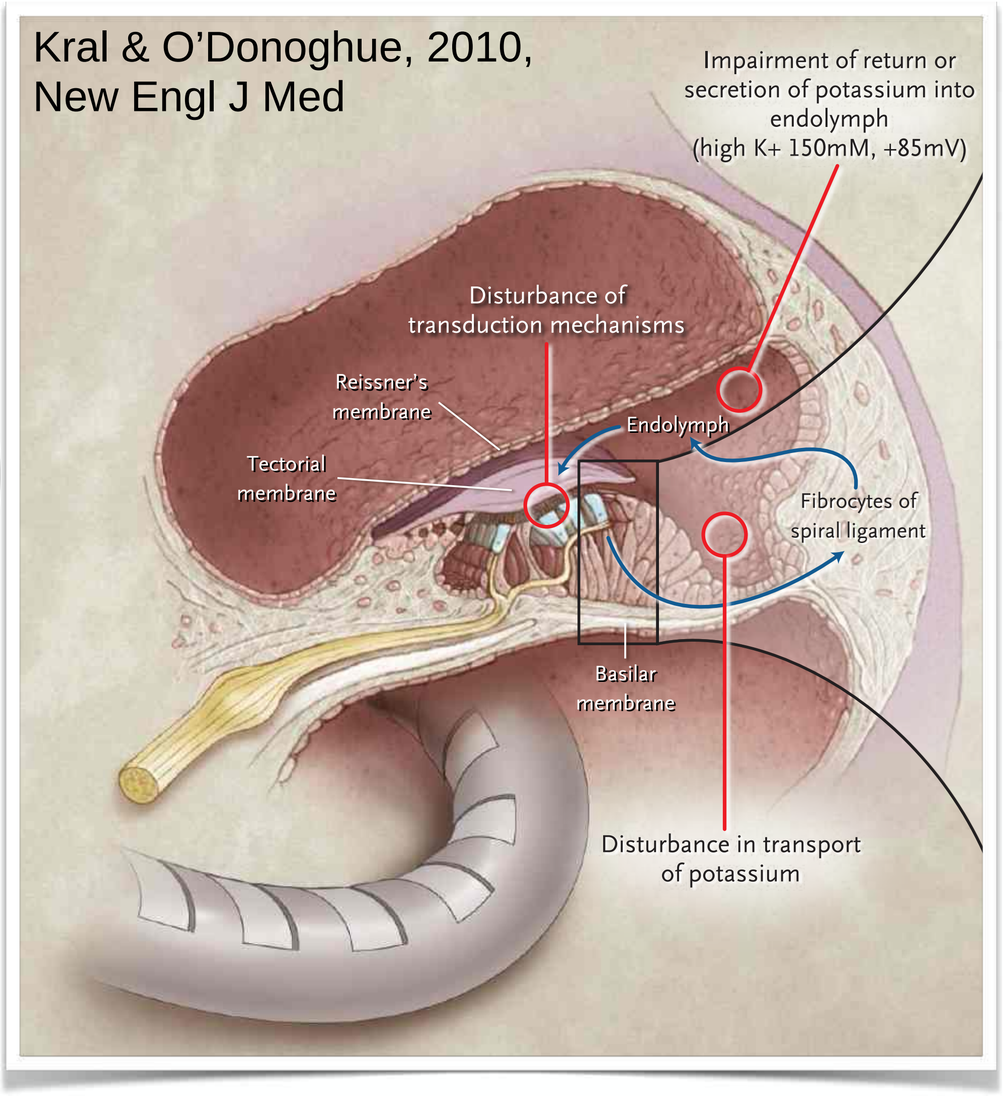



Manrique et al., 1999 Int J Ped ORL

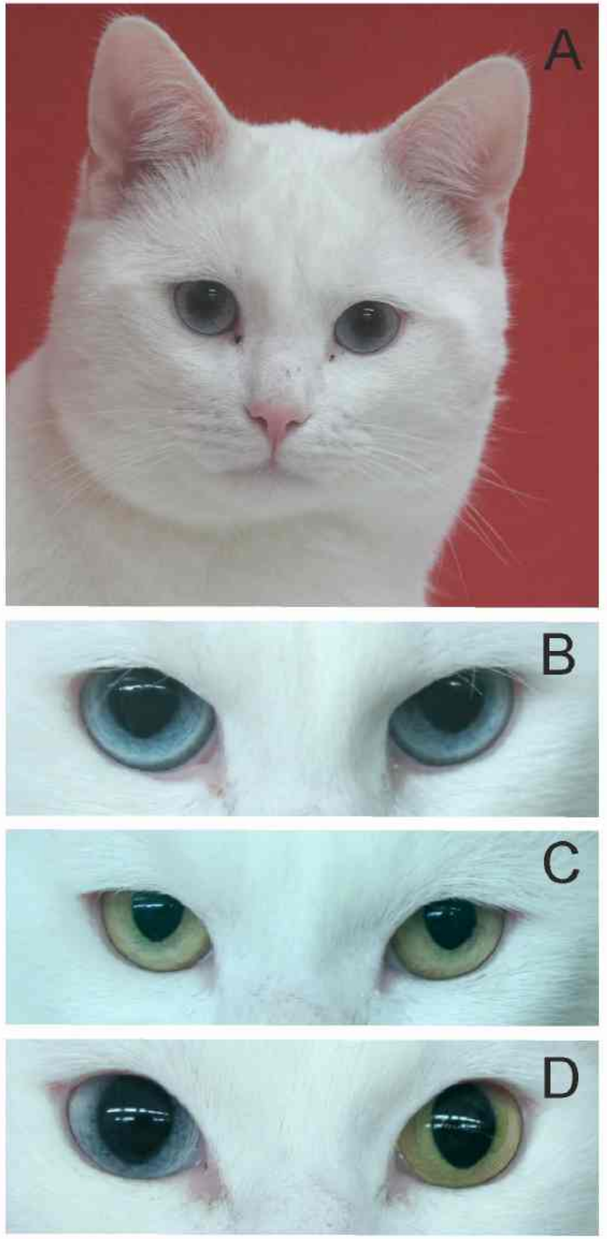
Figure from
Kral et al., 2019, Ann Rev Neurosci

# Congenitally deaf white cats





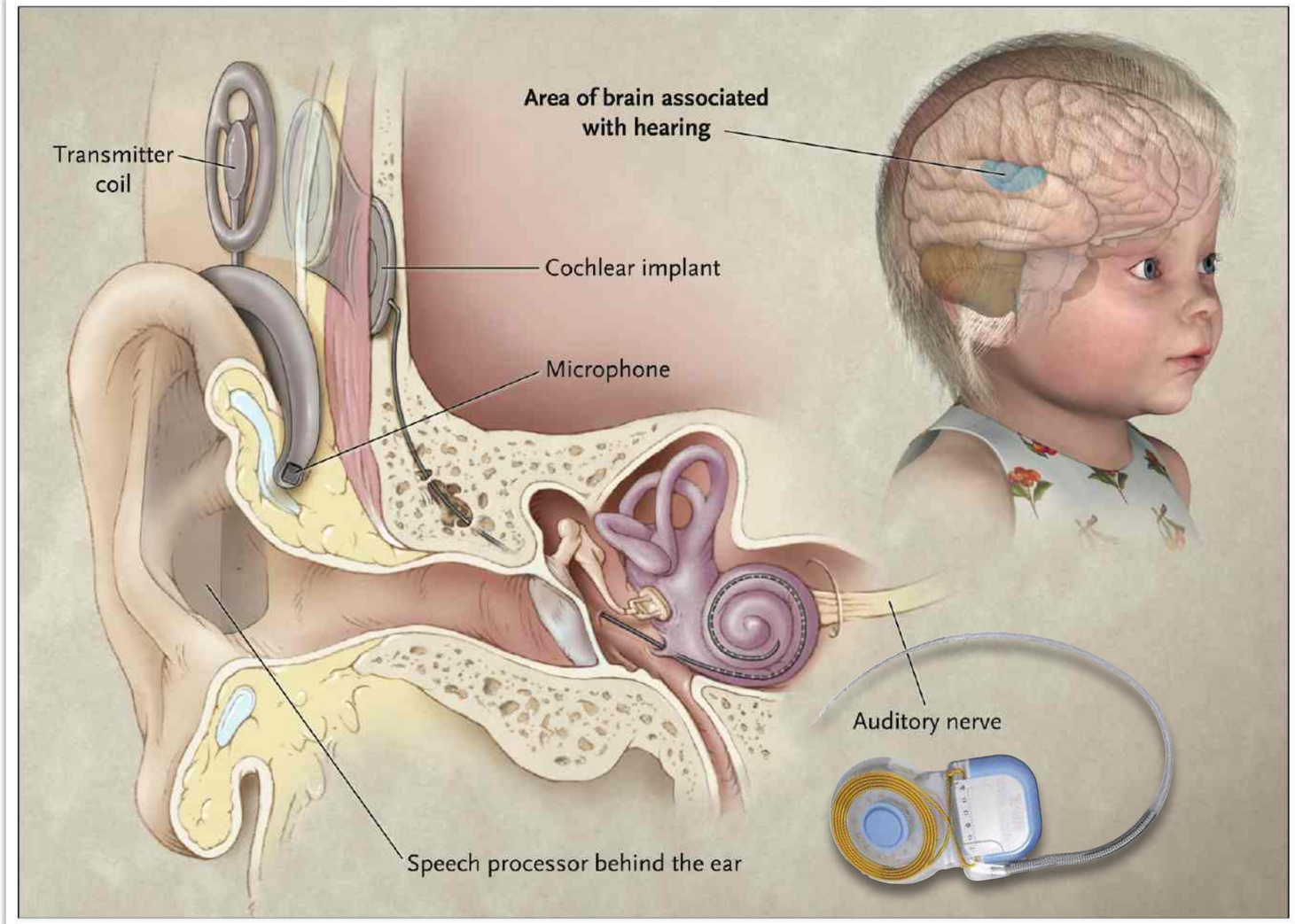

Phenotypes:



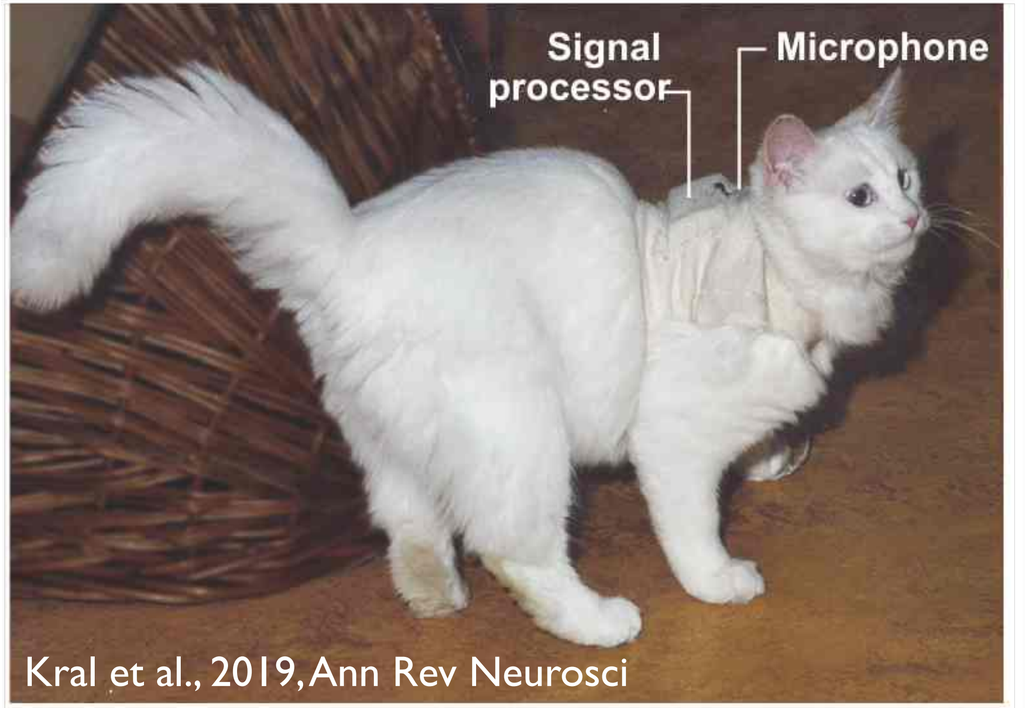

Heid et al., 1998, Hear Res
Kral et al., 2006, Prog Brain Res
Kral & Lomber, 2015, Curr Biol

# Critical period for therapy of deafness in kittens

## The auditory cortex is the bottleneck




Kral & O'Donoghue, 2010, New Engl J Med
Kral and Sharma, 2012, Trends Neurosci



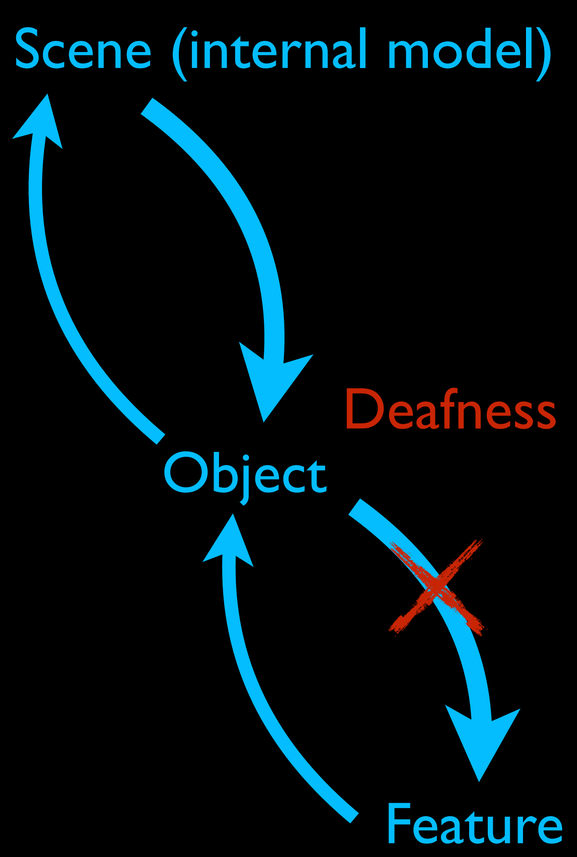

Sharma et al., 2002, Ear Hear
Sharma et al., 2005, Hear Res

Klinke et al., 1999, Science
Kral et al., 2002, Cereb Cortex
Kral et al., 2006, Prog Brain Res
Kral et al., 2009, J Neurosci
Kral et al., 2013, Brain
Tillein et al., 2016, Cereb Cortex
Hubka et al., 2024, J Neurosci

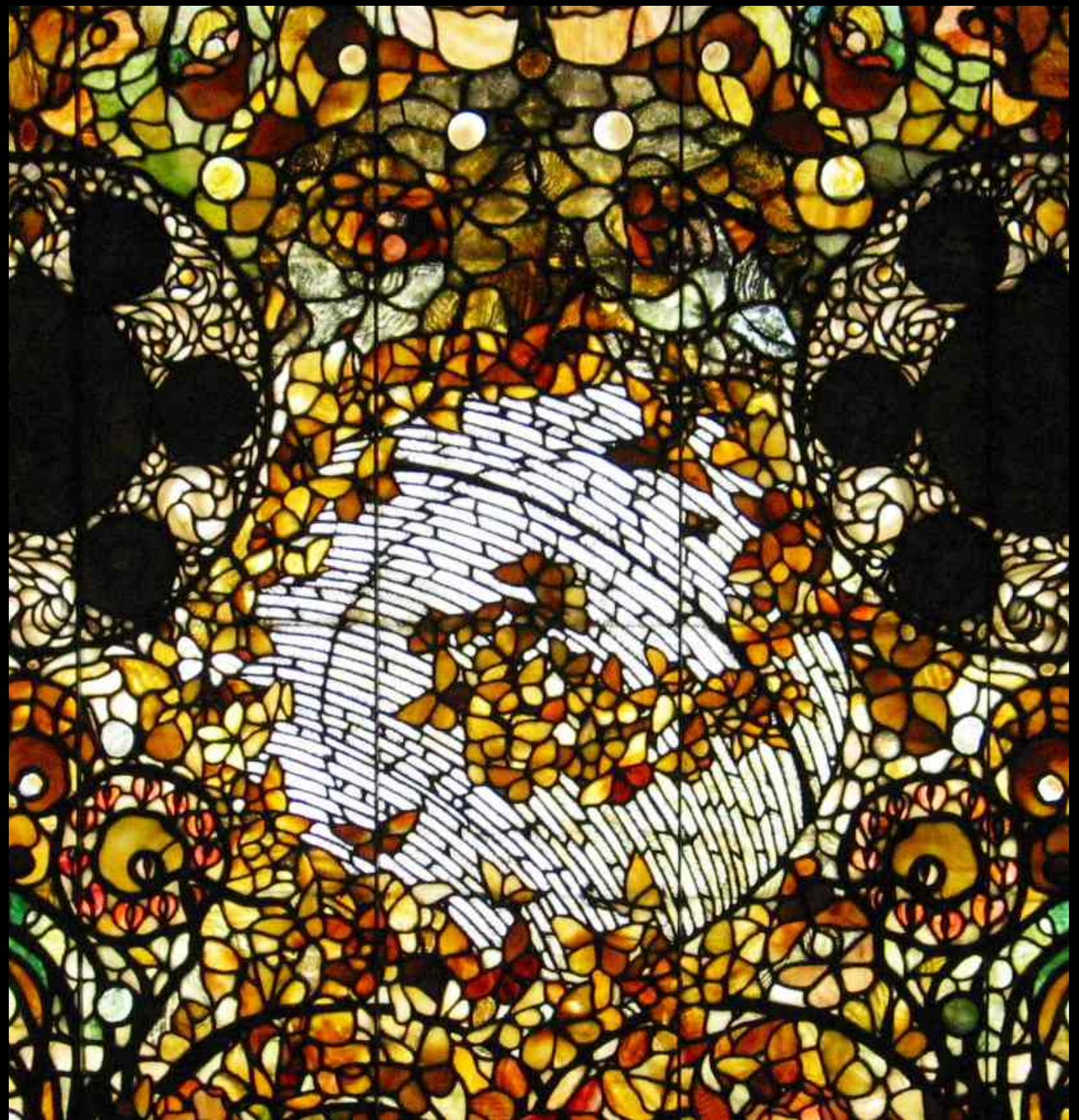
# From features to objects and internal model

Kral Lab

How is the internal model established?




Yusuf et al., 2017, Brain
Berger et al., 2017, J Comp Neurol
Yusuf et al., 2021, Front Neurosci
Yusuf et al., 2022, Front Syst Neurosci
Yusuf et al., 2024, Hear Res



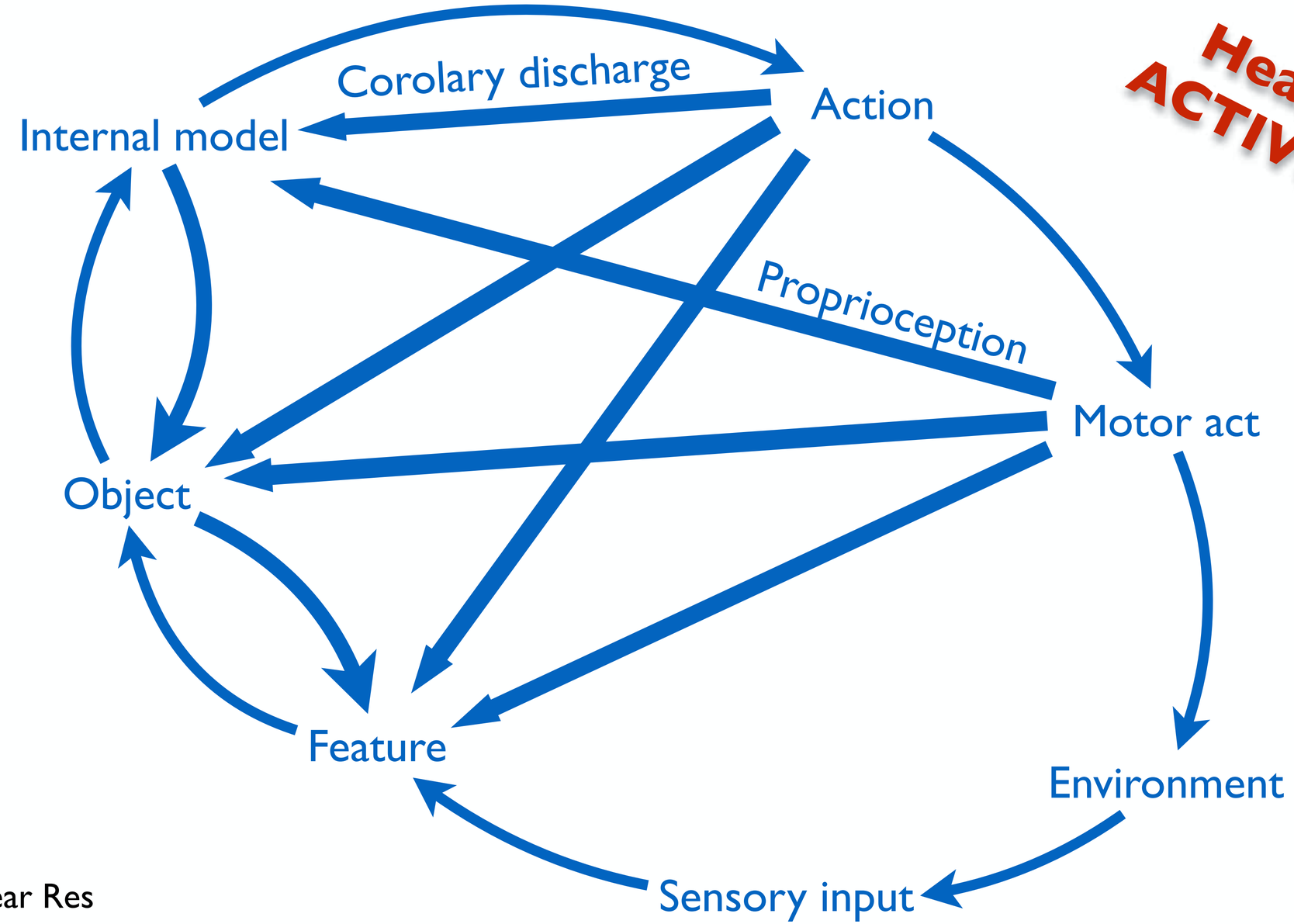


Predictive processing:
Kral et al., 2017, Hear Res

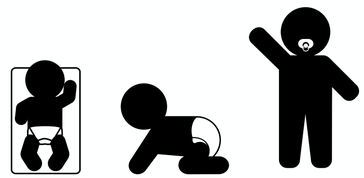
Projections supporting bottom-up interactions mature before those supporting top-down interactions (Batardiere et al., 2002, Cereb Cortex)

# Role of sensorimotor contingencies for internal model

Sensorimotor contingencies are repeated consistencies between motor act and sensory input resulting from it.



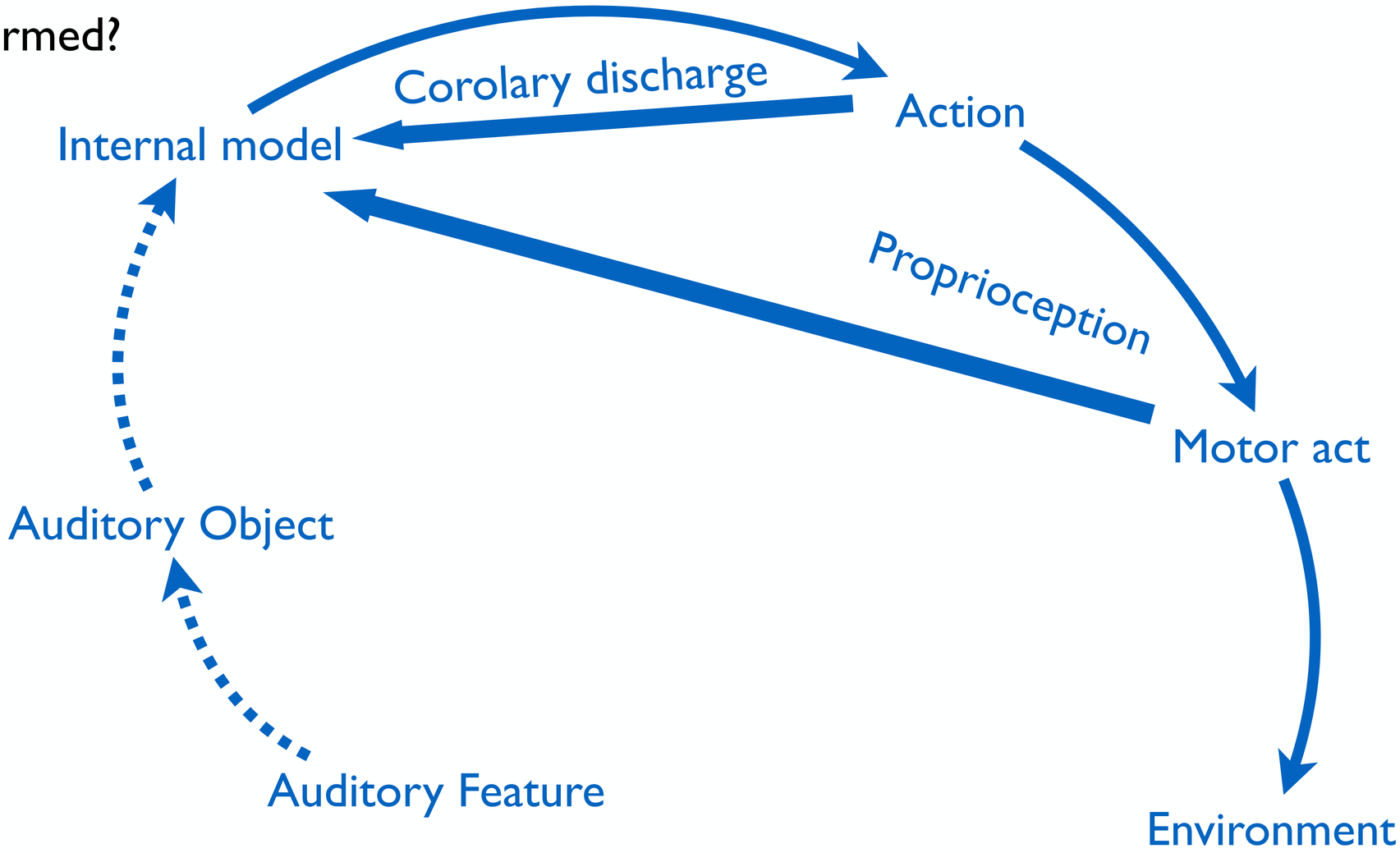

**Hearing requires ACTIVE interaction!**



Kral et al., 2025, Hear Res

# Deafness breaks up the closed loop at many places in auditory cortex

When are these circuits formed?




Kral et al., 2025, Hear Res

# Milestones of speech & language development



Effect of deafness sets is before 6 months of age!

| | |
|---|---|
| Birth: | ***Preference for mother language and mother's voice*** |
| 3rd-4th month: | ***Cooing (first phonemes)*** |
| | ***Imitation of the Mother: Motherese / Parenthese*** |
| 4th-6th month: | ***Categorization of sensory features into sensory objects*** |
| 6th month: | ***Top-down interactions*** |
| 6th-8th month: | ***Canonical babbling*** |
| 7th-8th month: | ***Loss of discrimination of „foreign" phonemes*** |

*Yusuf et al., 2017, Brain*
*Berger et al., 2017, J Comp Neurol*
*Yusuf et al., 2021, Front Neurosci*
*Yusuf et al., 2022, Front Syst Neurosci*
*Yusuf et al., 2024, Hear Res*

Kral et al., 2025, Hear Res

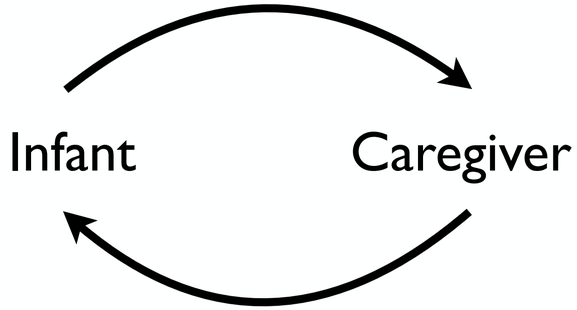
# Developmental stages in communication: turn-taking

**Turn-taking**: simplest active conversation with changing roles: sender and receiver.



**Affected in hearing loss**

## Dyadic communication

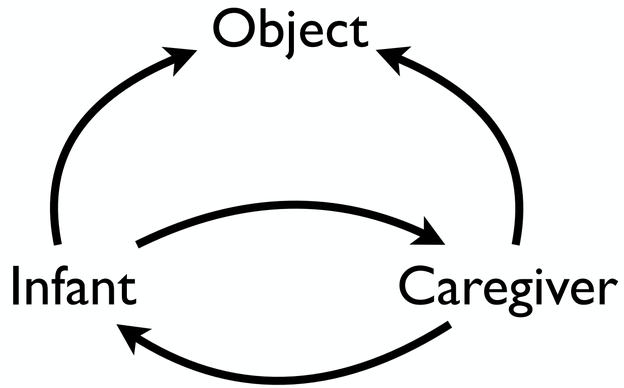



**3rd month; communication circle**

face-face interaction, exchange of sender and receiver role; infant **active exploratory efforts**

(still face experiments: broken circle)

## Triadic communication




**9th months „revolution“**

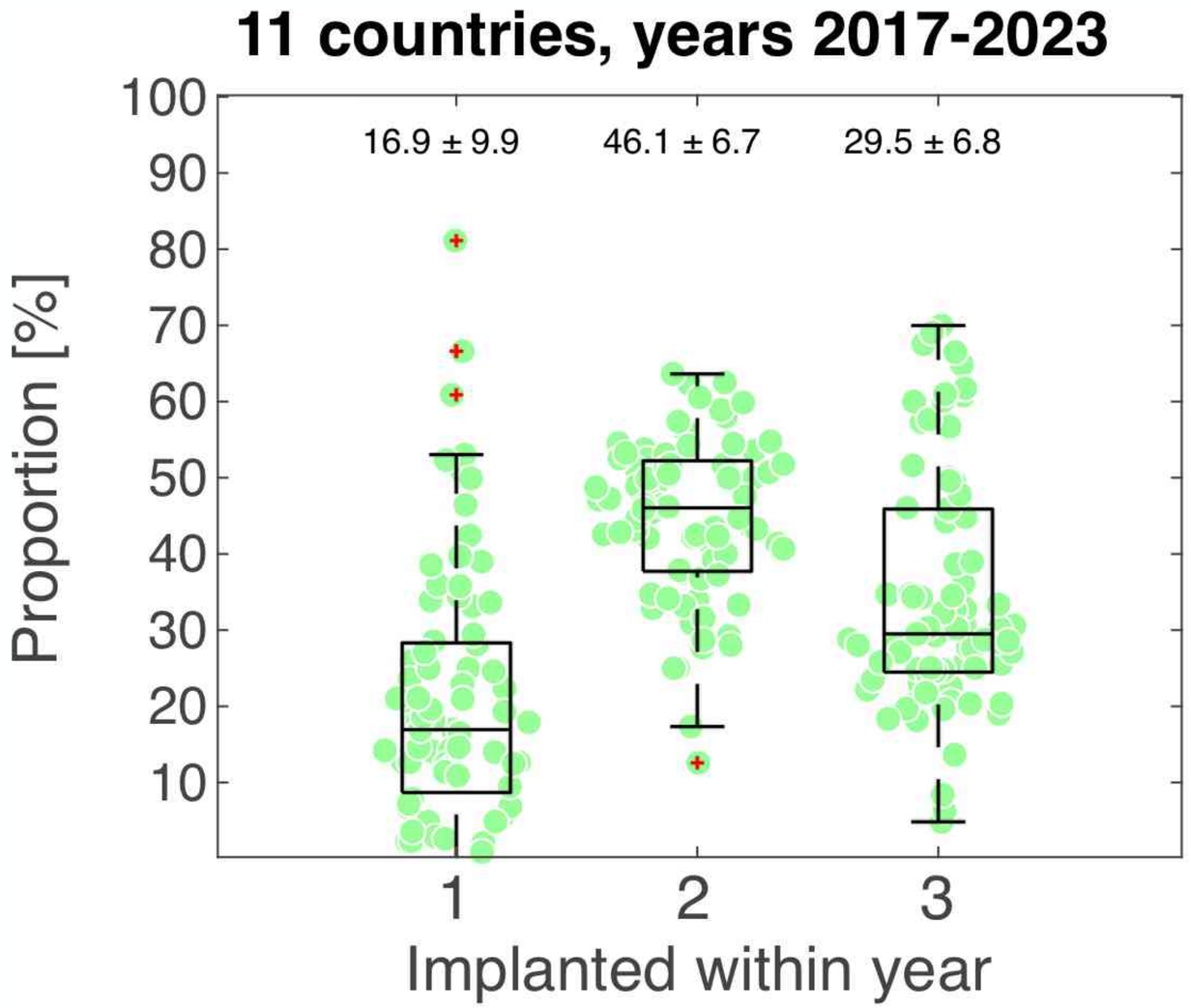
Common reference & object tracing; pointing to objects; sharing goals

(disambiguation by caregivers emotional display)

Kral et al., 2025, Hear Res

Gibson, 1988; Tronick, 1989; Zaidman-Zait & Dromi, 2007; Romeo et al., 2018; 2019

# Do we implant early enough?






**Better outcomes with intervention before 9 months:**

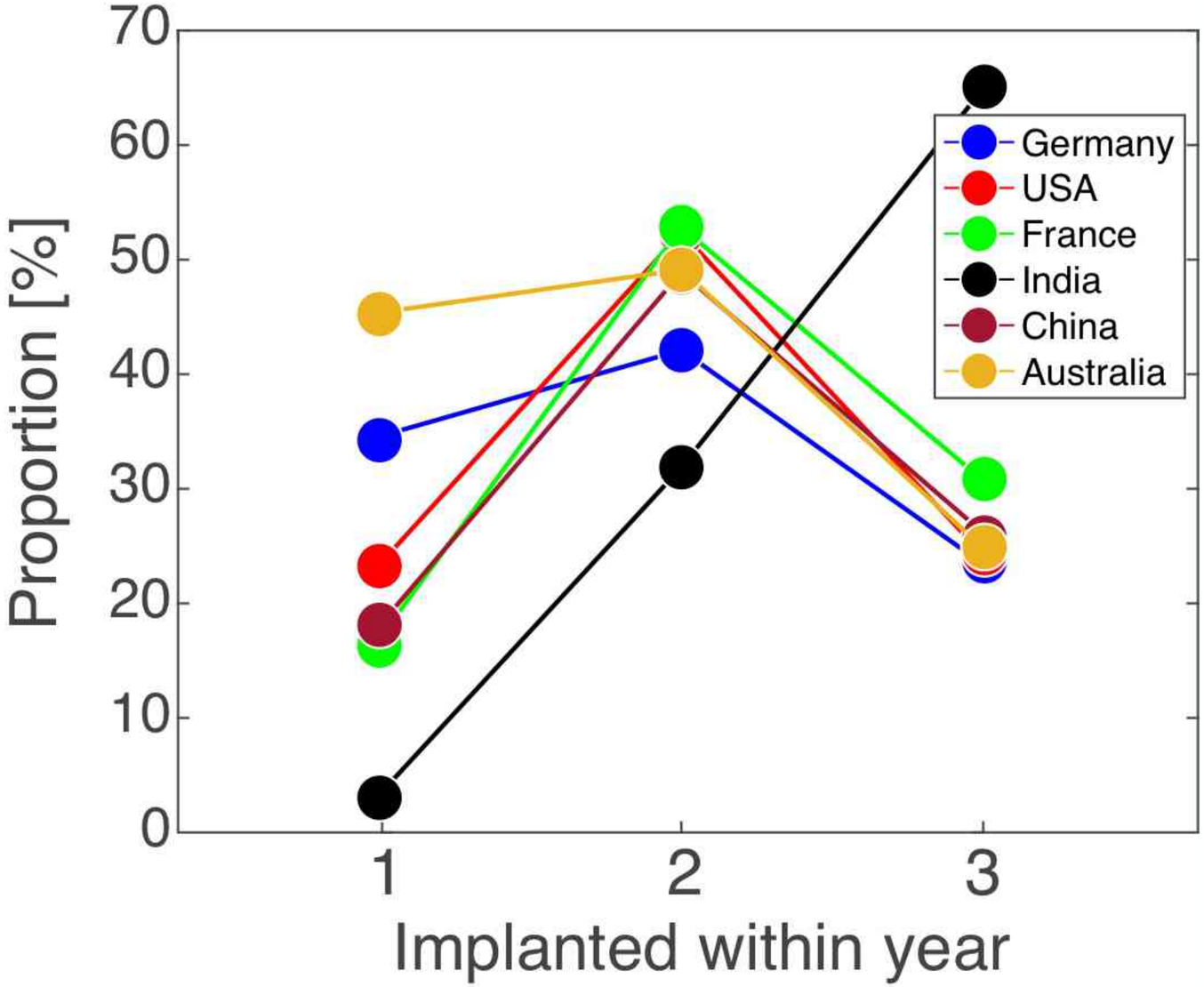
Davis et al., 2026, JSLHR (in press)
Illg et al., 2024, J Speech Lang Hear Res
Chweya et al., 2021, Otol Neurotol
Ching & Leigh, 2020, Hear Bal Comm
Karltorp et al., 2020, Acta Pediatrica
Hoff et al., 2019, Otol Neurotol
Nicholas & Geert, 2013, Otol Neurotol

Courtesy of
Cochlear Ltd., Sydney, Australia
MedEl Co., Innsbruck, Austria
Advanced Bionics, Valencia, USA

*Hearing misses key developmental milestones if implantation is in the 2nd year of life*

Kral et al., 2025, Hear Res

# Distribution for individual countries, mean of 2017-2023






Courtesy of Cochlear Ltd. Headquarters Sydney, Australia
MedEl Co., Innsbruck, Austria
Advanced Bionics, Valencia, USA

Kral et al., 2025, Hear Res

# Main messages

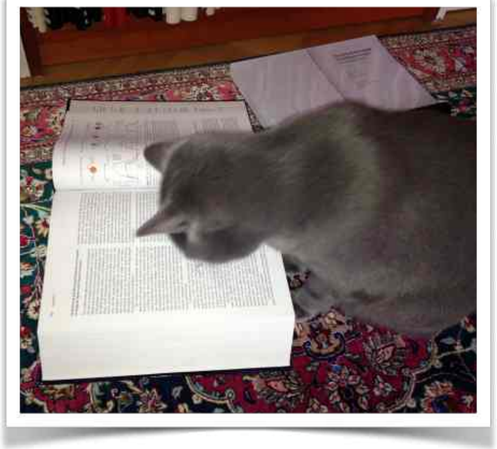
1. The critical period for CI therapy is related to transformation of acoustic features to auditory and phonological objects.

2. Intervention within the first 9 months better aligns to the corresponding developmental milestones

3. **1-3-6-9 strategy**

4. Early intervention is not enough. Most hearing happens in the family: Parents have a cardinal role and can extensively contribute to the outcomes

5. Clinical pathways sometimes do not allow following optimal timelines. But the brain potential within the critical period remains high and a lot of compensation remains possible





Thanks to cats…

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*Supported by Martin Lee Center for Innovation in Hearing Health, Sydney, Australia.*