

**Canadian Academy of Audiology** Academie Canadienne d'audiologie

# Successful Pathways to Outcomes in Bilateral Cochlear Implantation

Speaker: Ruth Litovsky, PhD, Oros Bascom Chair & Professor, Waisman Centre

Department of Communication Sciences & Disorders, University of Wisconsin

Moderator: Dr. Karen Gordon, PhD, Professor, Department of Otolaryngology, Hospital for Sick Children

March 19, 2025

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Canadian Academy of Audiology is a professional association dedicated to enhancing the role of audiologists as primary hearing health care providers through advocacy, education and research.



## Moderator: Dr. Karen Gordon, PhD, Professor, Department of Otolaryngology, University of Toronto, Hospital for Sick Children

Dr. Karen Gordon is a professor in the Department of Otolaryngology-Head & Neck Surgery and a graduate faculty member in the Institute of Medical Science at the University of Toronto. She works at SickKids as a Senior Scientist in the Research Institute and as Director of Research of Archie's Cochlear Implant Laboratory.

She is a member of the Cochlear Implant team, which is responsible for determining candidacy for cochlear implantation of children applying to the program and monitoring children who are using either a single cochlear implant or bilateral cochlear implants.





Speaker: Ruth Litovsky, PhD, Oros Bascom Chair & Professor, Waisman Centre, Department of Communication Sciences & Disorders, University of Wisconsin

Ruth Litovsky has a been a Professor in the Department of Communicative Sciences and Disorders at the University of Wisconsin – Madison for the past 24 years. She has a joint appointment in the Division of Otolaryngology in the Department of Surgery and serves as the Academic Associate Dean.



Her research has funded by grants from NIH since 1995. She has published over 150 papers and book chapters based. Ruth has received many awards during her career, including the first woman to receive the Silver Medal from the Acoustical Society of America, and the Fulbright Senior Fellow award.











Successful Pathways to Outcomes in Bilateral Cochlear Implantation Ruth Litovsky, Ph.D.

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Canadian Academy of Audiology March 19, 2025



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R01-DC003083 (completed) R01-DC008365 (completed) Bilateral hearing provide benefits relative to unilateral hearing

#### Sound Localization



Over 2 decades of research has shown that Bilateral hearing outperforms unilateral

#### Separating Speech from Noise







Cognitive Load, listening effort





But.... Bilateral CI users do not typically achieve same level of performance as NH



## **Modes of Bilateral / Binaural Hearing**



## Binaural cues on the horizontal plane

# Sound reaches the near ear first



→ Interaural time difference (ITD)
 @ low frequencies - temporal fine structure of signal



## Binaural cues on the horizontal plane

### Sound reaches the near ear first & with greater intensity

- → Interaural time difference (ITD)
  @ low frequencies temporal fine structure of signal
- → Interaural level difference (ILD)
  @ high frequencies

ITDs and ILDs vary with location → *Map of acoustic space* 



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## Successful Pathways to Outcomes in Individuals with Bilateral Cochlear Implants

#### Engineering

- Coordination of Cl's in the two ears
- Signal processing to capture binaural cues, and delivery to pairs of electrodes in the two ears with precision

#### Early access

• Minimize Auditory Deprivation

#### Top-down processes

• Minimize cognitive load and listening effort

Bilateral hearing provide benefits relative to unilateral hearing



#### Sound Localization



## Sound Localization in CHILDREN: Better with 2 Cls, but worse than NH



1. Children with BiCIs <u>5-12 years</u> old: show benefits with 2 vs. 1 CI

- 2. Worse than normal hearing children
- 3. Longitudinal data show improvement over 3-4 years





Tina Grieco-Calub

Yi Zheng

Grieco-Calub &Litovsky (2010) Zheng, Godar & Litovsky (2015)

## Sound Localization in **ADULTS**: Better with 2 **Cls, but worse than NH**





- 1. Patient outcomes vary in how good they are at localizing
- 2. Good news: Most patients gain benefits with 2 vs. 1 Cl
- 3. Challenges: Generally worse than normal hearing listeners



Localization in free field: 37 locations (every 5 degrees) Task: where is the sound coming from? Stimuli: broadband noise or speech





Heath Sean Anderson Jones

Litovsky et al., 2009; Jones et al., 2014

### Auditory Cortical Activity with Increase Bilateral CI use



FIGURE 3 Changes in amplitude of auditory cortical activity with increased bilateral Cl use. Amplitude of cortical activation (omnibus-corrected pseudo-Z) plotted for each child, with estimated marginal means from the linear mixed-effect regression model (white-filled points) and bars representing ±1 SE



- 1. EEG cortical responses to newly implanted ear are abnormally large compared with first implanted ear.
- 2. Reduction in activation with time

*Work from Karen Gordon and Colleagues: Anderson, Cushing, Papsin, Gordon (2022)* 

# Bilateral hearing provide benefits relative to unilateral hearing



# Separating Speech from Noise

# Bilateral hearing provide benefits relative to unilateral hearing

The "cocktail party" and classroom environments

#### **Involvement of:**

- Bottom-up processing at monaural and brainstem levels
- Top-down attentional and cognitive networks



## **Benefits of Bilateral / Binaural Hearing**



### **Benefits of Bilateral / Binaural Hearing**



Benefits of spatial separation are mainly due to <u>"monaural</u> <u>head shadow"</u> (one ear being farther from the masker)

### **Benefits of Bilateral / Binaural Hearing**



Benefits of spatial separation are mainly due to <u>"binaural</u> <u>integration"</u> (information from the two ears combined and activated binaural mechanisms

## Separating Speech from Maskers

- Bilateral CI users benefit from Monaural cues (Asymmetrical); little evidence for use of binaural cues
- Sex of talker/masker: similarity induces informational masking & more release from masking with spatial cues





Sara Misurelli

Misurelli & Litovsky (2012; 2015)



Peng & Litovsky (2023)

Misurelli & Litovsky (2012; 2015)

## **Maximizing Benefit of Spatial Separation**

- 180 deg separation
- Targets = sentences (Misurelli used single words in a 4-afc task)
- Informational masking (samesex target and masker)
- Masker speech = short excerpts (e.g., continuous discourses) of science stories written for children on various topics, such as climate change, space travel and animal psychology





Ellen Peng

# Why are benefits smaller in children with Cl's than NH?

- Experiment was done using Virtual Space (Head Related Transfer Functions).
- Measured responses of microphone: In the Canal& Behind the Ear
- Interaural Level Differences are smaller in BTE (circles) than in the canal KEMAR (manikin)

#### In the canal.



#### **Behind the ear**





#### Peng & Litovsky (2023)

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## Engineering – Related Limitations in Bilateral CIs

- CI speech processors function on independent time clocks
- Programming: No deliberate matching of inputs by frequency across electrode array (which the binaural system depends on)
- Mis-match in insertion depth (surgical) not accounted for
- Spread of current due to monopolar stimulation creates excitation patterns that interfere with selective stimulation



Litovsky et al. 2012; Kan & Litovsky (2015) Experimental approaches to bypassing engineering Limitations in bilateral cochlear implants (BiCls):

The 2 cochlear implant processors are independent (not synchronized) → binaural cues are irregular or absent





Stephen Dennison

Fig. 4. Examples of pulsatile outputs recorded from a matched pair of left and right electrodes from various cochlear implant processors. Each example was recorded from electrode number 12. Recordings show the output from a National Instruments (Austin, TC) data acquisition card (NI USB-6343).





#### Dennison, et al. (2021)

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### Patient-based / Biological Factors Auditory Deprivation→ Negative impact on binaural processing



Litovsky et al. (2010) Thakkar et al. (2020)

## Patient-based / Biological Factors Age at Onset of Deafness

#### Interaural time difference (ITD) 11 adult patients



Litovsky et al. (2010)

#### Patient-based / Biological Factors Age at Onset of Deafness Interaural time difference (ITD) 46 adult patients

![](_page_30_Figure_1.jpeg)

Interaural level difference(ILD) is different!All bilateral CI users show ILDsensitivity regardless of ageat onset of deafness

Stimuli: 100 pulses/sec (slow)

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300 ms duration

Right

Thakkar et al. Brain Sci. (2020)

Depriving young children of binaural cues early in life is likely to limit potential for binaural development

![](_page_31_Picture_1.jpeg)

Compelling reasons to see if we can design new binaural strategies that children can receive (clinically) early in life

## Cochlear Implant Processing: Speech signal divided into multiple channels

![](_page_32_Figure_1.jpeg)

Slide courtesy of Tanvi Thakkar

**Novel signal processing: Mixed Rates of stimulation** *Proof of concept that delivery of ITDs to select pairs of electrodes yields improved binaural hearing* 

![](_page_33_Figure_1.jpeg)

*Thakkar et al., 2018; 2023* 

Novel signal processing: Mixed Rates of stimulation Proof of concept that delivery of ITDs to select pairs of electrodes yields improved binaural hearing

![](_page_34_Figure_1.jpeg)

![](_page_34_Picture_2.jpeg)

![](_page_34_Picture_3.jpeg)

Tanvi Thakkar

Summary: Inserting low-rate ITDs at even one electrode pair restores binaural ITD sensitivity to all-low rates Need to study role of health of the cochlea

Thakkar et al., 2018; 2023

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## **Beyond Percent Correct**

![](_page_36_Figure_1.jpeg)

![](_page_37_Picture_0.jpeg)

## Beyond percent correct Pupillometry – Proxy for listening effort

#### Pupil dilation varies with:

- Activity in the autonomic system that regulates attention (Aston-Jones & Cohen, 2005)
- Related to arousal state (attend to environment; flight/fright; controlled by norepinephrine)
- Individual differences; hearing loss, age

![](_page_37_Picture_6.jpeg)

![](_page_37_Picture_7.jpeg)

![](_page_37_Picture_8.jpeg)

Lukas Suveg

Matt Winn

![](_page_37_Picture_11.jpeg)

![](_page_37_Picture_12.jpeg)

Emily Burg

Xin Zhou

![](_page_37_Picture_15.jpeg)

![](_page_37_Picture_16.jpeg)

Tanvi Thakkar

Shelly Godar

![](_page_38_Picture_0.jpeg)

## Beyond percent correct Pupillometry – Proxy for listening effort

![](_page_38_Picture_2.jpeg)

![](_page_38_Picture_3.jpeg)

![](_page_38_Picture_4.jpeg)

Lukas Suveg

Matt Winn

![](_page_38_Picture_7.jpeg)

![](_page_38_Picture_8.jpeg)

Emily Burg

Xin Zhou

![](_page_38_Picture_11.jpeg)

![](_page_38_Picture_12.jpeg)

Tanvi Thakkar

Shelly Godar

Association between Spatial Release from Masking and Release from Effort (SSD-CI patients) Maskers at 0 dB SNR (co-located vs. separated)

![](_page_39_Figure_1.jpeg)

![](_page_39_Picture_2.jpeg)

Lukas Suveg

![](_page_39_Picture_4.jpeg)

Emily Burg

![](_page_39_Picture_6.jpeg)

Tanvi Thakkar

Suveg et. al., (2025)

Successful Pathways to Outcomes in Individuals with Cochlear Implants

## Ideal Outcomes with Intervention:

![](_page_40_Figure_2.jpeg)

## **Non-Ideal Possible Outcome:**

![](_page_40_Figure_4.jpeg)

Successful Pathways to Outcomes in Individuals with Cochlear Implants

## Ideal Outcomes with Intervention:

![](_page_41_Figure_2.jpeg)

## **Other Possible Outcome:**

![](_page_41_Figure_4.jpeg)

#### Association between Spatial Release from Masking and Release from Effort (SSD-CI patients) Maskers at 0 dB SNR (co-located vs. separated)

![](_page_42_Figure_1.jpeg)

![](_page_42_Picture_2.jpeg)

Lukas Suveg

![](_page_42_Picture_4.jpeg)

Emily Burg

![](_page_42_Picture_6.jpeg)

Tanvi Thakkar

Suveg et. al., (in press)

## **Bilateral Cochlear Implant Users**

![](_page_43_Figure_1.jpeg)

#### FIGURE 3

Grand average pupil tracks (n = 12) for each listening condition. Maximum proportional change in pupil dilation was extracted from the silent period, indicated by the vertical dashed lines (0-2,000 ms). Shaded regions represent  $\pm$  1.96 SE (95% confidence interval). Asymmetries: Pupil dilation shows cost associated with integrating sounds from "poor" and "better" ears.

#### Burg et al. (2022)

![](_page_44_Picture_0.jpeg)

Successful Pathways to Outcomes in Individuals with Cochlear Implants

## **Conclusions, Future Directions**

#### **Benefits observed to date:**

 (1) sound localization and (2) speech understanding in noise; however, improvements sometimes small and we need to close the gap re: NH listeners

Clinical Intervention: Early access helps but Engineering needs to be improved

• Early access to acoustic binaural hearing & minimizing auditory deprivation maximizes success

## Top-down processes – helping with spatial hearing?

 In addition to clinical and typical research tools, need to assess cognitive load and listening effort

![](_page_44_Picture_9.jpeg)

Future Engineering: CCi-Mobile - Portable Real Time Speech Processing Platform (UTDallas & NYU)

![](_page_44_Picture_11.jpeg)

![](_page_45_Picture_0.jpeg)

#### Past students and postdocs

Tina Grieco-Calub Yi Zheng Antje Ihlefeld Gary Jones Matthew Goupell Patti Johnstone Matthew Winn Yu Gongquiang Tyler Churchill Smita Agrawal Michael Kiewe **Brittany Jaeckel** Christi Hess **Cindy Zettler** Ann Todd **Corey Stoelb** Frica Fhlers Heath Jones **Taylor Fields** Xin Zhou Keng Moua Thibaud Leclere Ellen Peng Tanvi Thakkar **Emily Burg** Sean Anderson Jasenia Hartman Stephen Dennison

## Binaural Hearing and Speech Lab

#### **Current Lab Members & Collaborators**

Shelly Godar; Sara Misurelli; Lukas Suveg; Agudemu Borjigin; Aditi Gargeshwari; Roya Abdi; Didulani Dantanarayana; Mohammad Maarefvand; Jarett Kanoepker; Kayla Kristensen; Stephanie Sellner; Margaret Koeritzer; Molly Sheridan; Rachael Jocewicz John Hansen; Mario Svirsky; Carlos Benitez-Barrera; Audra Sterling Andrew Alexander; Rene Gifford; Karen Gordon; Sigan Hartley; Nike Gnanatheja; Erik Jorgensen; Bobby Gibbs

![](_page_45_Picture_6.jpeg)

#### Past Collaborators

Richard van Hoesel; Alan Kan Christopher Long; Zachary Smith Andrew Brown; Robert Carlyon Philippos Loizou (RIP) Jenny Saffran; Jan Edwards Andy King; Susan Ellis-Weismer Sam Gubbles; Melanie Buhr-Lawler Joseph Roche; Daniel J. Lee Christina Runge; Robert Peters Colette McKay; Ozioma Okonkwo Carrie Niziolek

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R01-DC019511	(2021-2016
R01-R01DC016839	(2018-2024
R01-DC003083	(1998-2024
R01-DC008365	(2007-2021
<u>NIH-NICHD</u>	
P01HD076892	
U54HD090256	

Partial Support from MED-EL Advanced Bionics Cochlear

![](_page_46_Picture_0.jpeg)

## Question?

## Questions?

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![](_page_47_Picture_4.jpeg)

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ARCHIVED WEBINAR: OPPORTUNITIES AND CHALLENGES FOR ASSISTIVE LISTENING WITH BLUETOOTH LE AUDIO AND AURACAST AIRED WEDNESDAY, OCT 16, 2024 AT 1PM ET

ARCHIVED WEBINAR: STRATEGIC PRACTICE MANAGEMENT PLANNING FOR AUDIOLOGY PRIVATE PRACTICE AIRED ON WEDNESDAY, NOV. 20, 2024 AT 1PM ET

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![](_page_48_Picture_8.jpeg)

![](_page_49_Picture_0.jpeg)

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## Thank You