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Auditory attention and source segregation in children with cochlear implants or normal hearing

Sara M. Misurelli[1], Alan Kan[1], Matthew J. Goupell[2] & Ruth Y. Litovsky[1]
University of Wisconsin-Madison, USA[1], University of Maryland, College Park, MD, USA[2]
Email: smisurelli@wisc.edu

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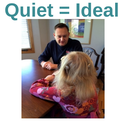
Introduction

The ability to attend to target speech while simultaneously ignoring irrelevant information is an extremely important skill, especially for children, who spend much of their day in noisy educational environments.

Quiet = Ideal



however…

Noisy = Realistic!

Some factors that may impact the ability to hear speech in noise

Spatial Unmasking

In *free-field* environments, intelligibility of target speech improves when the interfering speech and noise are spatially separated from the target for children with normal hearing (NH). This is known as *spatial unmasking*. Children who use bilateral cochlear implants (BiCIs) to access sound show less spatial unmasking compared to their NH peers[3,4], especially in conditions in which interferers are on both the right and left sides.

Auditory Attention

Auditory attention is a non-spatial phenomenon that contributes to successful segregation of multiple auditory streams. Previous research has shown that children with NH perform worse than adults with NH on tasks of auditory attention[7]. *It is unknown how auditory attention contributes to the ability to function in noisy environments for children with BiCIs.*

Executive Function

Executive function (EF) is a term used to describe an array of cognitive abilities that facilitate the organization of information for purposeful and goal-directed behavior—specific to this study are working memory, inhibition, and shifting[5]. These components are thought to be necessary in order to function in multi-source auditory environments. *Little is known about the relationship between EF and ability to hear speech in noise.*

Goals of the current study

1. *Examine auditory attention in children with BiCIs and NH.*
   - Compare the ability to attend to target speech in various target-interferer conditions: (1) no interferer (2) interferer in the ear opposite the target (contralateral), (3) interferer and target in the same ear (ipsilateral), and (4) interferer in both ears (ipsilateral+contralateral).
   - Compare performance between NH and BiCI groups.
2. *Investigate the relationship between EF and performance on the auditory attention task.*

Table 1. Participants

Bilateral Cochlear Implants (BiCI) (n=10)

Participant	Age (yr;mo)	CI use (yr;mo) Right	Left
CIEU (F)	17;2	*12;11	6;9
**CIAP (F)	16;0	*12;6	10;10
**CIBO (F)	16;0	*13;2	12;1
**CIAY (M)	15;11	*10;9	9;11
CIAW (M)	15;2	*14;0	9;9
CIAG (M)	14;10	*13;2	11;9
CIEV (F)	14;2	*11;6	3;2
CIDJ (F)	14;0	*12;5	9;0
CIBI (F)	13;8	*12;7	10;10
CIEH (M)	10	9;0	9;0

**some early acoustic experience *1st CI

Normal Hearing (NH) (n=10)

Participant	Age (yr;mo)
CSM (M)	17;2
CLG (F)	16;5
CVP (M)	15;3
CRK (F)	14;1
CLC (M)	12;8
CNI (F)	12;6
CQY (F)	10;10
CUN (F)	10;2
COU (F)	9;6
CVQ (M)	7;10

1. Measures of Auditory Attention

Task:

- Identify target speech in the presence of interfering speech at various **target-to-masker ratios (TMRs)** and conditions.

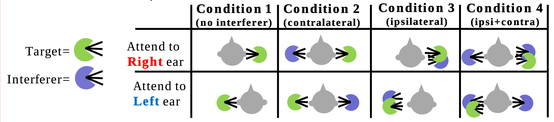
Stimuli:

- 5-word closed-set sentences (name, verb, number, adjective, and object)[2]
  - Target: female talker; Interferer: male talker
  - Reference level= 70 dB SPL
    - **Positive TMR:** *Interferer* level *decreased* ; **Negative TMR:** *Target* level *decreased*
  - BiCI: presented stimuli via direct audio input to their clinical processors
  - NH: presented with stimuli via headphones

Procedure:

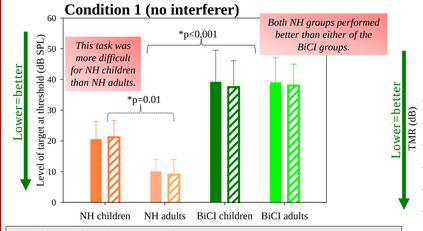
- Order of conditions, ear to attend to, and TMRs were randomized
  - Trials/condition: 5 words/sentence x 10 sentences/block x 2 blocks/TMR = 100 trials/condition
- Percent correct (PC) for each condition calculated by creating a psychometric function[6]
  - **Speech Reception Threshold (SRT) defined as PC=50%**

Conditions (described based on the location of the interferer relative to the target)



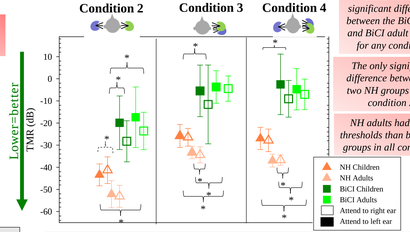
Condition 4 was intended to create a perceptually centered image of the interferer (bilaterally presented) and the target off to the side (unilaterally presented).

Results: Comparison between all child groups and previous adult data[1]



This task was more difficult for NH children than NH adults.

Both NH groups performed better than either of the BiCI groups.



There were no significant differences between the BiCI child and BiCI adult groups for any condition.

The only significant difference between the two NH groups was in condition 2.

NH adults had lower thresholds than both BiCI groups in all conditions.

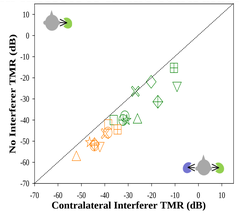
Fig 1. Mean (±SD) thresholds with no interferer (condition 1) are shown for each group. Filled bars =thresholds when the target was played in the *right* ear. Dashed bars=thresholds when the target was played in the *left* ear. A oneway between subjects ANOVA was conducted to compare threshold between groups. A Bonferroni correction for multiple comparisons was applied (*p<0.0125).

Fig 2. Mean (±SD) thresholds are shown for conditions with interferers for each group. Filled symbols=thresholds when the target was played in the *right* ear. Open symbols = thresholds when the target was played in the *left* ear. A oneway between subjects ANOVA for each condition was conducted to compare threshold between groups. A Bonferroni correction for multiple comparisons was applied (*p<0.0125).

Results: Comparison between listening conditions for children

Are children able to attend to a target with an interferer in the contralateral ear?

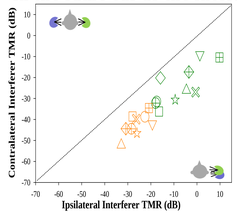
A.



On average, children need the level of the target to be only slightly more intense (2 dB) when an interferer is contralateral to the target, compared to when there is no interferer.

Are children able to attend to a target when it is in the same ear as the interferer?

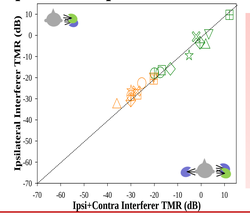
B.



Children with BiCIs and NH show, on average, a 17 dB increase in threshold when the target and interferer are in the same vs. opposite ears.

Are children able to center a bilaterally presented interferer to perceive separation from the unilateral target?

C.



Children with BiCIs and NH show, on average, less than a 2 dB difference in threshold between conditions with the target and interferer in the same ear (ipsilateral) vs. in the condition designed to create a perceptually centered interferer separated from the unilaterally presented target.

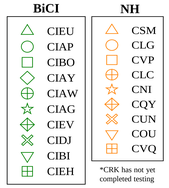
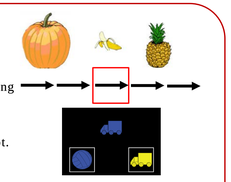


Fig 3. Thresholds between conditions are compared for each listener in the BiCI (green) and NH (orange) groups. Individual participants are represented with different symbols. The diagonal line represents equal performance in each condition. Panels A-C show the following comparisons: A: no interferer vs. contralateral interferer, B: contralateral vs. ipsilateral interferer, C: ipsilateral vs. ipsilateral+contralateral interferer.

2. Measures of Executive Function

NIH Toolbox Cognition Battery (www.nihtoolbox.org)

- **Working Memory,** *List Sort Task:* Participants presented with a series of items (food, or food & animals) and instructed to verbally repeat the items in size order from smallest to largest.
- **Inhibitory Control,** *Flanker:* Participants indicate the direction of the middle arrow while simultaneously inhibiting the other arrows.
- **Attention Shifting,** *Dimensional Change Card Sort:* Target pictures that vary along two dimensions (color, shape) are presented. Participants match the target picture to test pictures for either color or shape, depending on the prompt.



Other Cognitive Assessments

- **Expressive Vocabulary** *Expressive Vocabulary Test (EVT)*
- **Intelligence Quotient** *Kaufman Brief Intelligence Test (nonverbal) (Kbit)*

Results: Standardized scores for all EF and cognitive measures

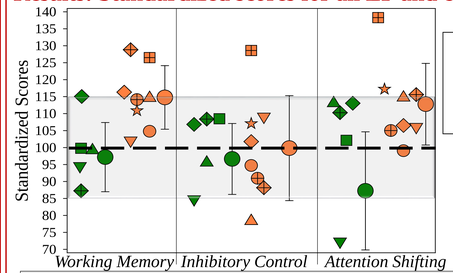


Fig 4. Standardized scores for EF measures. The dashed line represents average performance. The shaded region represents performance within normal range. Individual participants are represented by different symbols (green=BiCI, orange=NH). Group mean (±SD) are shown to the right of the individual symbols.

Mean (±SD) for *Other Assessments*

	Non-verbal IQ	Vocabulary
BiCI	105 (10.7)	104.6 (13.2)
NH	114.7 (19.9)	114.6 (17.2)

On average, children with BiCIs score lower than children with NH on only the measure of working memory.

It is interesting to note that the one child with BiCIs (CIAY) who had 42mo. of early acoustic experience prior to getting CIs performs similarly to his NH age-matched comparison (CRK).

Results: Relationship between measures of *EF* and performance on *Auditory Attention* task

r^2 values	No interferer (1)		Contralateral Interferer (2)		Ipsilateral Interferer (3)		Ipsi.+Contra. Interferer (4)	
	BiCI	NH	BiCI	NH	BiCI	NH	BiCI	NH
Working Memory	0.20	0.07	0.003	0.01	0.30	0.16	0.24	0.02
Inhibitory Control	0.06	0.52	0.35	***0.58** (p=0.46)	0.55	***0.66** (p=0.03)	0.50	***0.69** (p=0.02)
Attention Shifting	0.13	0.09	0.27	0.09	0.28	0.01	0.13	0.04

Inhibitory control is significantly correlated with performance on the auditory measures that contain an interferer for only the NH group.

More work is needed before any conclusions can be made regarding EF and performance on auditory tasks for children with BiCIs.

Table 2. Individual simple linear regressions between each measure of EF and performance in each condition of the auditory task. Within each condition, the first column (green) displays correlations for the BiCI group (n=5) and the second column (orange) displays correlations for the NH group (n=8). Significant correlations are bolded and labeled with an asterisk (*).

Discussion

- These data show that in extreme cases of separation (i.e. interferer contralateral to the target) both children with NH and BiCIs are able to successfully ignore an interferer, suggesting no difficulty attending to a target (i.e. similar performance with no interferer and with a contralateral interferer) (Fig. 3A).
  - When the interferer is contralateral to the target, children are significantly better at inhibiting the interferer compared to when the interferer is ipsilateral to the target, and only voice pitch cues are available (Fig. 3B).
- When the interferer is played bilaterally and the target unilaterally, intended to create unmasking of the target speech, neither the NH or BiCI groups showed benefit (Fig. 3C).
  - It may be that for NH children, the difference in sex of the target (female) and interferer (male) (i.e. fundamental frequency of voices) may provide cues that aid in separation of the two sources even when they are played ipsilaterally. Therefore, there may not be a significant added benefit of contralateral unmasking (i.e., ipsi+contra interferer).
- For the NH group (n=8), attention inhibition significantly correlates with ability to ignore an interferer. Results thus far suggest that for the BiCI group none of the measures of EF correlate with performance on the auditory task (n=5) (Table 2).
- Gaps in working memory between the NH and BiCI groups exist (Fig. 4), similar results have been shown by others. More work is needed to further investigate *why* these gaps occur and how it may effect performance in other domains.

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