Auditory experience and development: implications for sound localization and language processing in preschool children with hearing loss

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Infant development

Language

Walking

Spatial hearing (sound localization)

Eye-hand coordination

Facial motor control

Experience promotes development

Sound (Hearing) → Sound (Hearing)

Hearing = experience with sound

Frequency discrimination
Intensity discrimination
Spoken language
Spatial hearing
Speech perception in noise
I. Spoken language processing
   - Development
   - Impact of hearing loss

II. Spatial hearing
   - Development
   - Impact of hearing loss

III. Considerations for aural rehabilitation and education
I. Spoken language development, Year 1

Infants learn about their native language during the first year of their life

Infants
- become sensitive to the sounds of their native language
- engage in joint attention
- can find patterns in sounds
- use gestures to communicate
- begin to acquire word meaning

I. Spoken language development, Year 2

Toddlers become proficient (i.e., faster) at processing spoken language in real-time by 2 years of age.

Experience with language promotes processing speed and vocabulary development.

Early speech processing skills correlate with cognitive and linguistic skills in later childhood

Experience $\rightarrow$ Processing speed $\rightarrow$ Language & Cognitive growth

Fernald et al. (1998); Fernald, Perfors & Marchman (2006); Weisleder & Fernald (2013); Marchman & Fernald (2008)
I. Hearing loss

Children who with hearing loss
*Experience auditory deprivation
*Learn language through a degraded auditory signal

Early intervention:

More mature auditory system
e.g.,
Sharma et al., 2005
Gordan et al., 2007

Better speech and language outcomes on standardized tests
e.g.,
Yoshinaga-Itano, 1998
Miyamoto et al., 1999
Kirk et al., 2002
Nicholas & Geers, 2006
Niparko et al., 2010
Tomblin et al., 2014

Hearing loss in children

Development of other auditory skills that might support spoken language acquisition?
I. Real-time spoken word recognition

“ball” Recognizing spoken words
Auditory label ➔ Visual object

“cat”

How well can toddlers with hearing loss recognize spoken words?

I. Looking while Listening

“Look at the doggie”

Pictures On
Reaction time (RT): Time between the label onset and first eye shift

Accuracy: Proportion of looking at the target

I. Looking while Listening

I. Looking while Listening: Accuracy

*Grieco-Calub, Saffran & Litovsky, 2009
I. Looking while Listening: Processing speed

*NH group

*CI group

HL group

Time to target object after label onset (sec)

*I. Audiovisual speech perception

Auditory-only

Audiovisual

*Grieco-Calub, Safirin & Litovsky, 2009
I. Processing speed

![Graph showing processing speed comparison between NH and HL groups.](Grieco-Calub, Olson & Ward, in prep)

I. Spoken language development: summary

1. Toddlers with hearing loss can quickly recognize a known object when hearing is spoken label.
   a. They are less accurate than their normal hearing peers.
   b. They are slower than their normal hearing peers.

2. Congruent visual information had variable effects in toddlers.
   a. In normal hearing children, in optimal listening conditions, the addition of visual cues slows processing
   b. In children with hearing loss, the addition of visual cues, on average, doesn’t change processing speed.
I. Spatial Hearing

Role of spatial hearing

II. Spatial Hearing

**Spatial hearing**: being able to locate sound sources in one’s environment

*Interaural Timing Differences (ITDs)*
*Sounds arrive at each ear at different times*

*Interaural Level Differences (ILDs)*
*Head shadow effect: the head acts as an acoustic shield*
II. Spatial Hearing

How does our brain encode interaural cues?

II. Development of spatial hearing

The ability of infants to discriminate the location of two sound sources develops over the first few years of life.

Morrongiello and Rocca, 1990, Child Dev
Children who use hearing loss

- Children with mild to severe hearing loss
  - Can be unilateral or bilateral

- Children with cochlear implants
  - Severe-profound BILATERAL sensorineural hearing loss
  - Little or no benefit from the use of hearing aids

I. Spatial Hearing

- Bilateral CIs improve performance in *postlingually deafened* adults

- Sound localization skills are emerging in older children with *prelingual deafness* who have bilateral cochlear implants.

- On average, children perform better when using both of their implants versus their 1st implant alone. Most performed worse than their normal hearing peers.

  e.g., Van Hoessel & Tyler, 2003; Litovsky et al., 2004; Grieco-Calub & Litovsky, 2010
Observer-based psychophysical method

Minimum Audible Angle

Minimum Audible Angle (MAA)

Grieco-Calub & Litovsky, 2012
Does spatial hearing support language development?

1. Children with unilateral hearing loss
   - Poor spatial hearing
   - At risk for language and academic delay
   - Increased listening effort

2. Children with bilateral cochlear implants
   - Better language outcomes (Sarant et al., 2014)
   - Have more mature brainstem function

Abnormal perception of binaural input increases with asymmetries in auditory brainstem function

Courtesy of Karen Gordon
Steel, et al., PLOS One, 2015
Clinical consideration: Microphone placement

**Body-level microphone**

**Ear-level microphone**

Clinical consideration: Hearing Assistive Devices

**Directional microphones**

**FM systems**
## II. Spatial Hearing: Summary

1. Toddlers with bilateral cochlear implants can develop spatial hearing skills
   a. More complex conditions?
   b. Better performance than their peers with unilateral devices

2. Having two devices is sometimes not sufficient to promote spatial hearing
   a. Device limitations
   b. Anatomical limitations
   c. Untested influence of assistive devices

### Considerations for aural rehabilitation and education
Spatial awareness

Development of spatial hearing
1. Provides sound localization awareness

2. Allows children to better hear a target talker, like a teacher, especially if he/she is walking around the classroom

3. Better able to understand speech when there is background noise (spatial release from masking)

Unilateral vs. bilateral hearing

Benefit of bilateral hearing
1) Second look at the input

2) Always including the best ear

3) Subjective reports
   * Children are more attentive
   * Children seem less tired
Thank you for your attention!
I.a. Right/Left Discrimination

Age-matched children with normal acoustic hearing

I.a. Spatial hearing in older children

Sound Source Localization → Root-Mean-Square (RMS) error
I. Spatial Hearing

**Spatial hearing**: being able to locate sound sources in one’s environment

Binaural cues

Bilateral CIs improve performance in postlingually-deafened adults and older children

Van Hoesel & Tyler, 2003
Litovsky et al., 2004
Litovsky et al., 2006

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On average, performance with bilateral CIs is better than with 1st CI alone
Cochlear implants (CIs)

Surgically implantable devices which provide individuals who are deaf with access to auditory information

External:
- microphone
- processor
- transmitting coil

Internal:
- receiver
- stimulator
- electrode array

Acoustic vs Electric Hearing

**Acoustic Hearing**
- Sound is converted to a *mechanochemical* signal
- Thousands of frequency channels
- Good frequency resolution (ability to discriminate pitch)

**Electric Hearing**
- Sound is converted from an acoustic signal to an *electrical* signal which is delivered directly to the auditory nerve
- 12-24 physical electrodes
- Poor frequency resolution
Reaction time to target object

How long does it take to shift gaze to the target object?

“Look at the DOGGIE”

Time course of spoken word recognition

“Look at the DOGGIE”

Analysis window

Grieco-Calub, Saffran & Litovsky, 2009
Summary, Part II

Young implant users recognize target objects at above chance performance, but there was large individual variability.

- The CI group was less accurate than their peers with normal hearing.
- The CI group was slower to recognize the visual target after the label onset.

Acoustic competition reduced spoken word recognition in both groups of toddlers.

Variability observed in this study may relate to the variability in language outcomes observed in older children who use CIs.
Auditory experience in children who use cochlear implants

**Scientific issues:**
- Effects of auditory deprivation on development
- How does a degraded signal drive auditory and language development
- Differences in development, if any, between having *unilateral* versus *bilateral* input

**Clinical issues:**
- When should children be implanted?
- Should we be providing all children with *Bilateral* CIs?
- What are other sources of variability in performance and can they be managed?
Performance at fixed angle: 50°

Bilateral group  
Both devices  
Bilateral group  
Single device-1st CI  
Unilateral group  
Single device

*p < 0.01  
p = 0.6

Grieco-Calub & Litovsky, in press

Right/Left Discrimination Task

FIXED ANGLE: Measure percent correct at 50°

Target: Speech at 60 dB SPL
I. Audiovisual speech perception

<table>
<thead>
<tr>
<th>Quiet</th>
<th>Competitor</th>
<th>A+V Quiet</th>
<th>A+V Competitor</th>
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Pictures On
Video On
(Video trials only)
“Look at the doggie”

Silence or Competitor

Analysis window

Time (sec)

-3 -2 -1 0 1 2

Right/Left Discrimination Task

**ADAPTIVE METHOD:** Quickly targets the range of angles near their threshold for this task

**Target:** speech, 60 ± 4 dB SPL