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# Decision Making in Children's Speech-In-Noise Perception, in partnership with the University of Pittsburgh

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University of Pittsburgh

# Ashley Parker, PhD

Ashley Parker joined the Department of Communication Science and Disorders in 2022 as a Postdoctoral Associate, and in 2024, she transitioned to a faculty role. Parker is a trained teacher and has brought that passion for education to the university classroom with experience leading courses in hearing sciences at both Pitt and UConn, where she earned her PhD.

# Disclosures

- **Presenter Disclosure**: Financial: Ashley Parker is an employee of The University of Pittsburgh. Non-financial: Ashley Parker has no relevant non-financial relationships to disclose. AudiologyOnline is making a donation to the audiology program at the University of Pittsburgh for this presentation.
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- As healthcare is rapidly evolving, new findings may change the validity of the information presented in this course. Providers should always consult the latest research and guidelines from professional associations.
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- Healthcare providers should apply cultural competence and sensitivity to ensure effective and respectful care based on their patients' diverse needs.
- Providers should always evaluate the limitations of diagnostic and screening tools, considering their potential for false results as well as any ethical implications.
- It is the responsibility of course participants to critically evaluate the evidence from multiple sources to guide professional practice.

# Learning Outcomes

After this course, participants will be able to:

- Explain how drift-diffusion models (DDMs) provide insights into the cognitive mechanisms, such as evidence accumulation and decision thresholds, involved in children's auditory decision-making.
- Identify the impact of age and signal-to-noise ratio (SNR) on children's accuracy, response time, and decision strategies during phoneme categorization tasks.
- Discuss the role of phonological awareness as a potential protective factor against performance declines in adverse listening conditions.

*Why do some people struggle more than others when it comes to speech perception in noise?*

*The Brain Behind the Behavior*

# Accurate perception of auditory signals is complex

- Engages peripheral and central auditory processing of sound, as well as memory, attention, cognition, and language processes
- (most) adult brains handle this challenge efficiently, but listening in complex environments is still developing in children
  - Even just within typically developing kids, there is individual variability in speech perception

# Speech perception in noise (SPIN) is more difficult for children than adults. Why?

- Auditory system maturation: central auditory pathways continue developing through childhood.
- Cognitive development: attention, working memory, and executive control improve with age, supporting SPIN.
- But even within typical development, we see a lot of variability in SPIN skills (Corbin et al., 2011).

**This impacts real-world tasks like following instructions in classrooms, communicating with peers, or understanding caregivers at home.**

# SPIN Deficits in Clinical Populations

**Cochlear Implants**
Caldwell & Nittrouer, 2013
Gifford et al., 2011

**Auditory Neuropathy**
Rance et al., 2007
Hassan, 2011

**Dyslexia**
Li et al., 2023

**Learning Difficulties**
Ferenczy et al., 2022

**Importantly, each of these pediatric clinical populations often present with poorer phonological processing skills than their typically developing peers.**

# Why look at Phonological Awareness (PA) and SPIN

- **PA is a foundational metalinguistic skill**
  - It involves recognizing and manipulating the sound structure of language (e.g., rhyming, blending, segmenting sounds).
- **PA is critical for decoding degraded or masked speech**
  - Helps listeners extract and interpret linguistic features from noisy input.
- **PA and SPIN rely on shared representations**
  - Both require accessing acoustic–phonetic and phonological representations of sounds and words.
- **PA has been shown to predict speech perception in quiet**
  - But its role in noisy, complex listening conditions has shown mixed findings — *motivating this study* (Foy & Mann, 2001; Mayo et al., 2003; Nittrouer, 1996; Rvachew & Grawburg, 2006)

# Previous findings have been mixed…

- Some studies found that stronger phonological processing skills are associated with better SPIN performance.
  - Brady et al., 1983 reported that children with stronger PA showed better speech perception in noise.
- Other studies did not find a clear connection between phonological processing and SPIN outcomes.
  - Example: Lewis et al., 2010 found no significant relationship between PA and SPIN performance.

**Recruitment methods:** Differences in how participants were selected (e.g., community vs. clinic samples).

**WHY?**

**Experimental design:** Differences in task type, noise type (e.g., noise, multitalker babble), or masker level.

**Participant eligibility:** Variation in inclusion criteria (e.g., age ranges, cognitive or hearing status).

**Analysis approaches:** Variability in statistical methods or outcome measures across studies.

Or maybe accuracy doesn't tell us everything…

# How do we usually test SPIN?

- Speech perception integrates sensory, cognitive, and decision-making processes.
- Listening to speech requires categorizing phonemes as they are heard.
- Categorization tasks assess how well children extract and use auditory information.

Commonly used tests to evaluate SPIN skills, such as QuickSIN, HINT, and WiN are simple and quick to administer; however, scores are primarily based on ***accuracy alone*** in repeating key, whole-words □ *limited insights*

| List 1 | | Score |
|---|---|---|
| 1. A white silk jacket goes with any shoes. | S/N 25 | 5 |
| 2. The child crawled into the dense grass. | S/N 20 | 5 |
| 3. Footprints showed the path he took up the beach. | S/N 15 | 4 |
| 4. A tent near the edge brought in fresh air. | S/N 10 | 3 |
| 5. It is a band of steel three inches wide. | S/N 5 | 2 |
| 6. The weight of the package was seen on the high scale. | S/N 0 | 0 |
| 25.5 - TOTAL = 6.5 SNR Loss | TOTAL | 19 |

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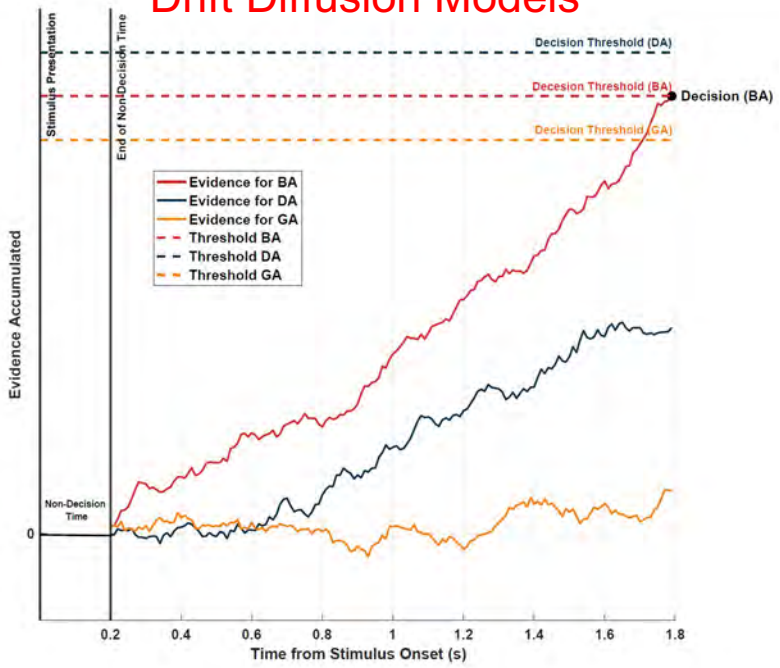
How can we “test” for SPIN difficulties when we don’t really know the underlying cognitive and neural processes driving individual differences in speech perception skills?

# How can we target the true deficit?

**Our work starts by investigating some of the under-studied top-down processes involved in SPIN across development.**

Drift Diffusion Models



# CURRENT STUDY

# METHODS

# Participants

**44 children**
7-12 Years Old

**Younger Group:**
7-9 Years Old

**Older Group:**
10-12 Years Old

## Speech/Language Battery

- CELF-5
- BBTOP-2
- GFTA-3
- KLPA-3
- OASES
- WASI-IVQ
- BBTOP-2
- TONI-4
- CTOPP-2

## Audiology+ Battery

- Pure tone audiogram
- Otoacoustic emissions
- Words-in-Noise (WiN)
- The Speech, Spatial and Qualities of Hearing Scale (SSQ)
- Temporal Response Functions
- Frequency Following Response (FFR)

# Phonological Awareness Measure


**Comprehensive Test of Phonological Processing, Second Edition (Wagner et al., 2013)**

The CTOPP-2 is a standardized test widely used to assess phonological processing abilities in children and adults.

**Phonological Awareness Composite Score (PACS)**

A composite index combining performance across three subtests:

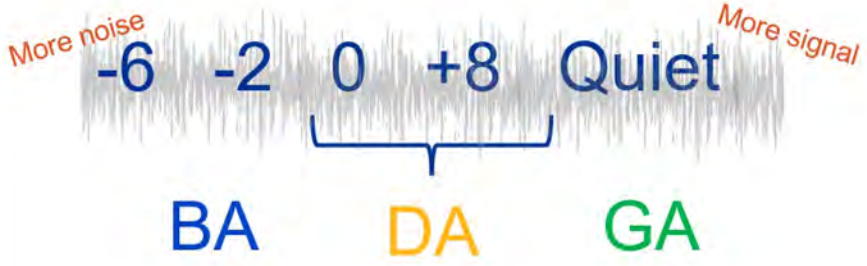
1. **Elision:** ability to remove sounds from words (e.g., say "bold" without the /b/)
2. **Blending Words:** ability to combine sounds to form words (e.g., /c/ /a/ /t/ → cat)
3. **Phoneme Isolation:** ability to identify individual sounds in words (e.g., first sound in "dog")

# Phoneme Categorization Task

In this task, you will hear a sound and you will categorize it into 1 of 3 categories.

If you think the sound is BA, press 1 (Blue).
If you think the sound is DA, press 2 (Yellow).
If you think the sound is GA, press 3 (Green).

Please try to respond as **quickly** and **accurately** as possible.




75 trials presented at each SNR, split across speech sounds

~12 minutes total

**Outcomes Collected:**

- Accuracy
- Response Time
- Evidence Accumulation
- Decision Thresholds

# Drift Diffusion Models (DDMs)

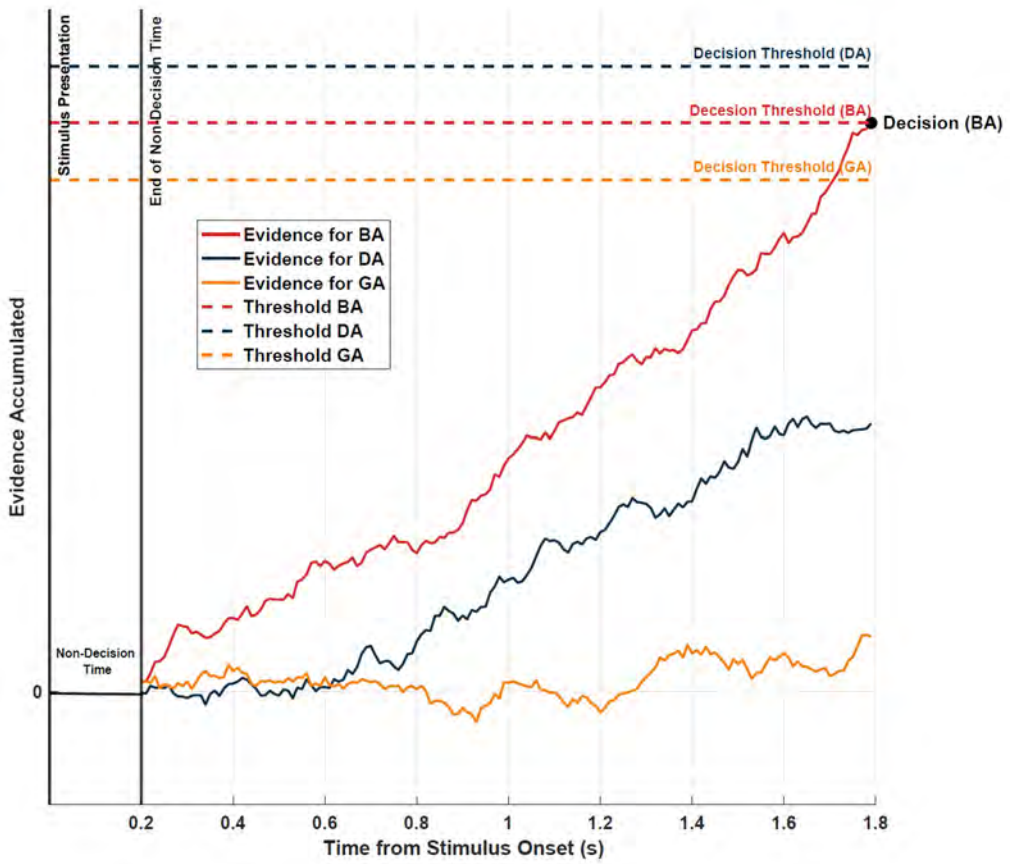
The process of mapping phonemes from an incoming speech stream onto neural representations requires **categorization decisions**.

**Accuracies and response times alone don't really capture these.**

**Drift Diffusion Models:** Computational models that go beyond observed behavior to extract descriptions of latent cognitive processes that have been linked to different brain substrates.

## Two Key Metrics from DDMs

- **Evidence Accumulation:** how efficient the listener is at extracting information from the stimulus to make a decision—think of it as the *slope*
- **Decision Threshold:** how cautious is the responder in making their decision




Theoretically, DDMs assume that, when a stimulus is presented, evidence is noisily accumulated from the stimulus towards each decision alternative, and a decision is made when a particular "evidence threshold" has been reached.

*lddmm package R (Paulon & Sarkar, 2021)*

# GOALS AND HYPOTHESES

# Current Study Goals

- To examine how **age, noise level** (SNR), and **phonological awareness** jointly influence children's phoneme categorization in noise

- To use **Drift Diffusion Modeling** to uncover the cognitive and decision-making mechanisms underlying their performance.

# Current Study Hypotheses

- **H1**: Phonological awareness will help **compensate for developmental immaturity**, playing a stronger protective role in younger children
- **H2**: Stronger phonological awareness will predict **better categorization performance** (higher accuracy, steeper evidence accumulation), especially under noisy conditions.
- **H3**: Younger children will show **slower, more cautious decision-making** in phoneme categorization compared to older children.

# RESULTS

(and a disclaimer about quiz question order)

# Statistical Analyses

**Modeling Approach:**
Linear mixed-effects models (LMEMs)

**Fixed Effects Included:**

- Age group (younger vs. older)
- Signal-to-noise ratio (SNR)
- Phonological awareness (PACS, continuous)
- Interaction terms (e.g., SNR × PACS)

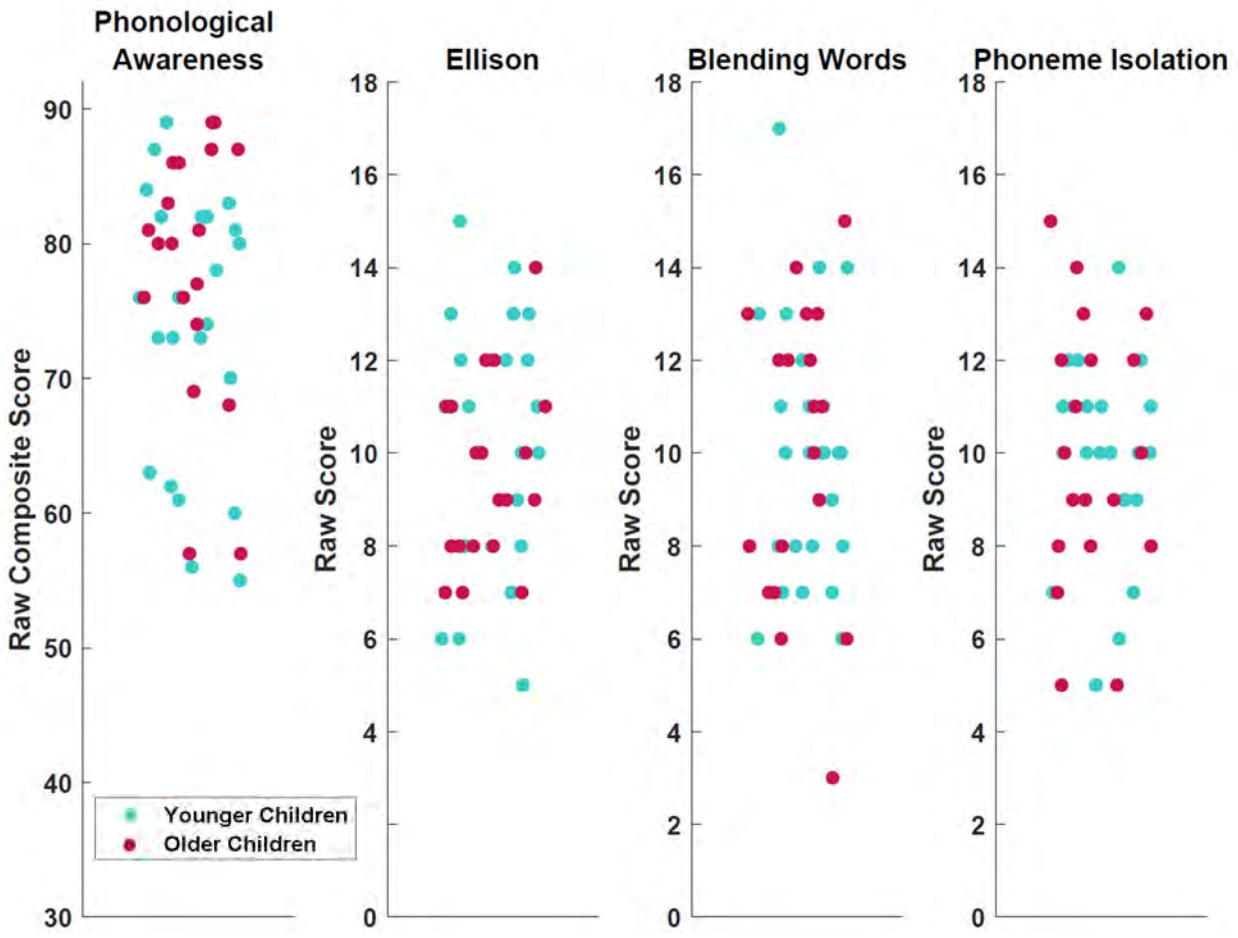
**Random Effects:**
Random intercepts for participants

**Outcome Measures Analyzed:**

- Accuracy
- Response Times
- Evidence Accumulation Rate
- Decision Thresholds

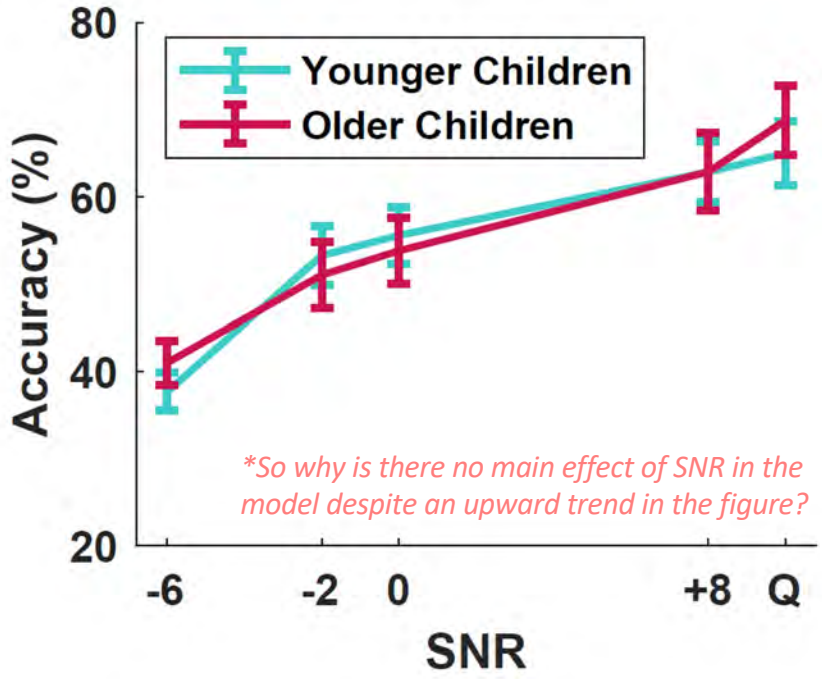
**Significance Threshold:**
$p < .05$

# Phonological Awareness




*Significant variability within both younger and older groups.*

# Accuracy




No main effects of age or SNR on accuracy* → Age group and noise level alone did not significantly predict accuracy.

**SNR × Phonological Awareness (PACS) interaction was significant.**

As SNR improves, children with stronger phonological awareness show a greater increase in accuracy than those with weaker phonological awareness.

***Linear Mixed Effects Model with Multiple Comparisons for Accuracy***

| Fixed Effect | Estimate | SE | t-value | p-value |
|---|---|---|---|---|
| Intercept | 24.932 | 19.177 | 1.3 | .195 |
| SNR | -.52 | 3.308 | -.157 | .875 |
| PACS | .147 | .26 | .565 | .573 |
| Group | .605 | 1.314 | .461 | .821 |
| SNR*PACS | .095 | 0.045 | 2.125 | .035* |
| SNR*Group | -.586 | 6.101 | -.1 | .924 |
| PACS*Group | .096 | .459 | .21 | .834 |
| SNR*PACS*Group | .005 | .079 | .065 | .948 |

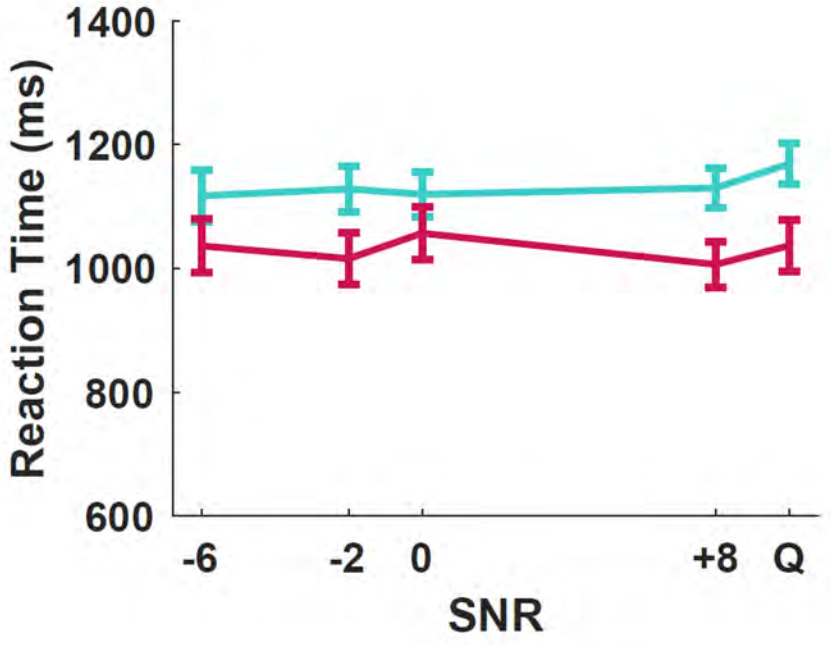
# Response Times

Q3

**Main effect of SNR → Children responded more slowly at better (higher) SNRs — an *unexpected* pattern.**

**SNR x PACS→ Kids with higher phonological awareness show a smaller increase in response time as SNR improves.**

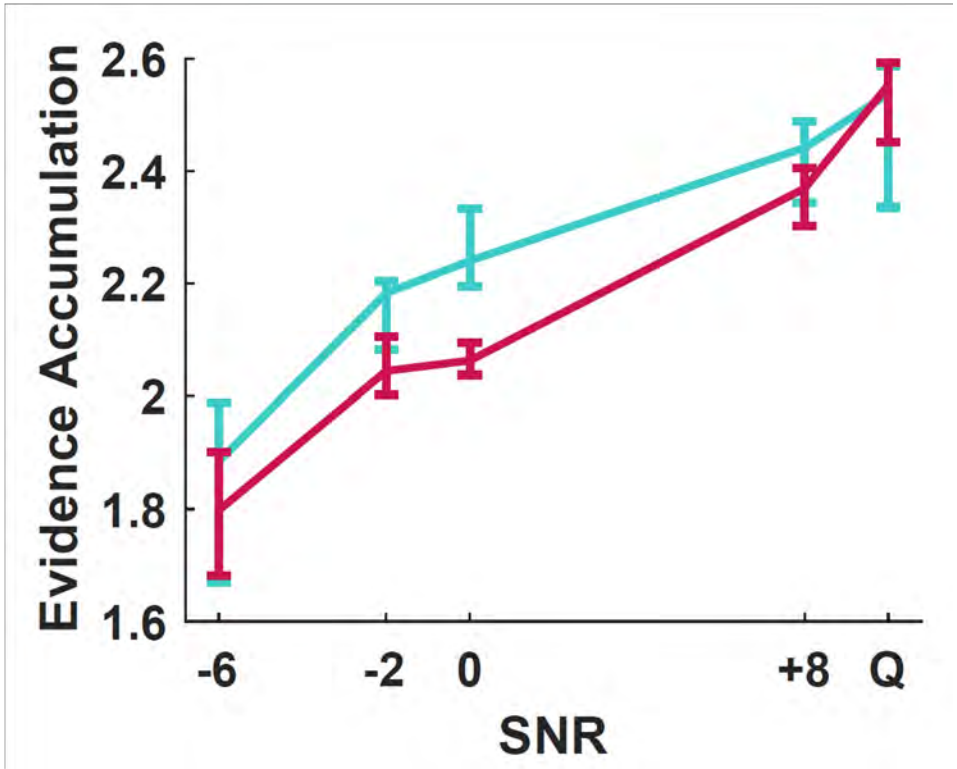
No main effect of age group on response time.




***Linear Mixed Effects Model with Multiple Comparisons for Response Time***

| Fixed Effect | Estimate | SE | t-value | p-value |
|---|---|---|---|---|
| Intercept | 706.59 | 216.51 | 3.264 | .001** |
| SNR | 90.595 | 27.203 | 3.318 | .001** |
| PACS | 5.401 | 2.935 | 1.847 | .066 |
| Group | 429.61 | 399.36 | 1.076 | .283 |
| SNR*PACS | -1.1 | .37 | -2.97 | .003* |
| SNR*Group | -59.455 | 50.358 | -1.181 | .239 |
| PACS*Group | -6.798 | 5.18 | -1.312 | .191 |
| SNR*PACS*Group | .673 | .653 | 1.03 | .304 |

# Evidence Accumulation Q4




**Main effect of phonological awareness → Children with stronger phonological awareness showed steeper evidence accumulation rates.**

No main effect of age group on evidence accumulation.

**SNR × PACS interaction → At better SNRs, children with stronger phonological awareness showed enhanced gains in evidence accumulation.**

***Linear Mixed Effects Model with Multiple Comparisons for Evidence Accumulation Rates***

| Fixed Effect | Estimate | SE | t-value | p-value |
|---|---|---|---|---|
| Intercept | .364 | .712 | .511 | .61 |
| SNR | -.01 | .044 | -.227 | .821 |
| PACS | .02 | .01 | 2.027 | .044* |
| Group | .605 | 1.314 | .461 | .646 |
| SNR*PACS | .002 | .001 | 3.84 | <.001** |
| SNR*Group | .143 | .081 | 1.766 | .079 |
| PACS*Group | -.01 | .017 | -.613 | .54 |
| SNR*PACS*Group | -.002 | .001 | -1.815 | .071 |

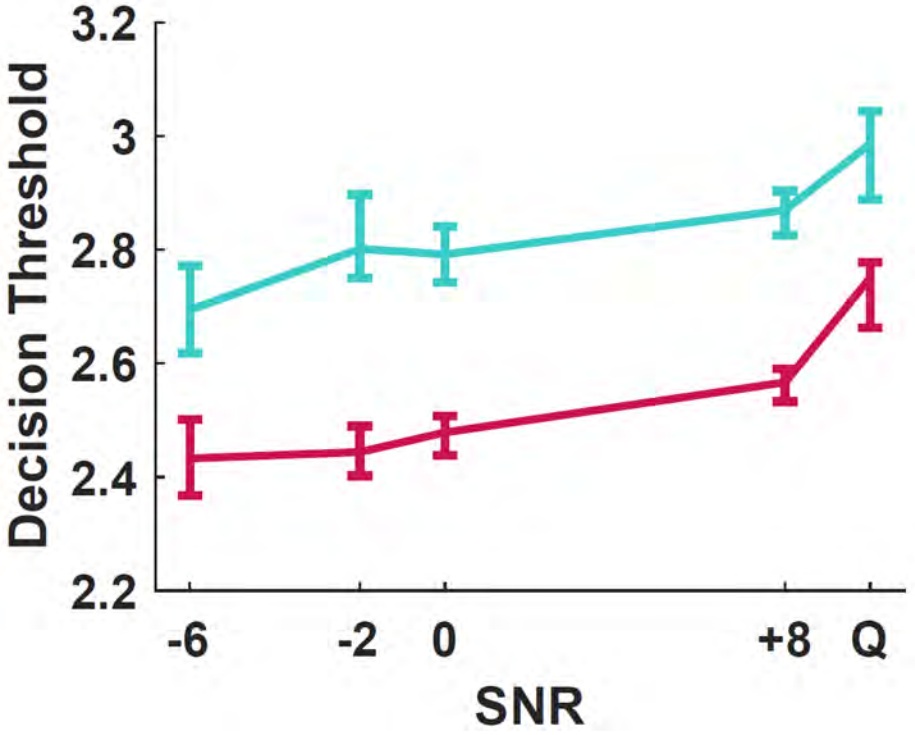
# Decision Thresholds

Q5

**Main effect of SNR → Children set higher decision thresholds (more cautious responses) at better SNRs.**

**Main effect of PACS→ Children with stronger phonological awareness showed more cautious decision-making overall (higher thresholds).**

No main effect of age group on decision threshold, nor any interactions.




***Linear Mixed Effects Model with Multiple Comparisons for Decision Thresholds***

| Fixed Effect | Estimate | SE | t-value | p-value |
|---|---|---|---|---|
| Intercept | .422 | .775 | .544 | .587 |
| SNR | .19 | .061 | 3.121 | .002* |
| PACS | .029 | .011 | 2.726 | .007* |
| Group | 1.332 | 1.43 | .931 | .253 |
| SNR*PACS | -.001 | .001 | -1.557 | .121 |
| SNR*Group | -.058 | .113 | -.515 | .607 |
| PACS*Group | -.02 | .019 | -1.097 | .274 |
| SNR*PACS*Group | <.001 | .001 | .226 | .822 |

# SUMMARY AND TAKE HOMES

# Summary of Findings

- Phonological awareness predicted performance across outcomes  Higher PA linked to better accuracy, faster evidence accumulation, and more cautious decisions.
- No main effect of age group  Age (7–12 years) did not significantly predict accuracy, response time, or DDM parameters.
  - Younger children performed at levels comparable to their older peers  phonological awareness skills may be able to mitigate developmental disparities in challenging auditory tasks.
- Significant interaction between SNR and phonological awareness for accuracy  Children with stronger PA showed greater accuracy improvements as noise decreased.
- Children became more cautious at better SNRs  Stronger PA associated with greater caution across SNRs.

# Take Home Messages

- Phonological awareness plays a key role in children's speech perception in noise, beyond age alone.
- Children with stronger PA benefit more from clearer listening conditions.
- Strengthening phonological awareness may enhance listening abilities in noisy educational environments.
- Cognitive modeling (DDMs) reveals insights beyond accuracy and reaction time — showing how children approach auditory decisions.



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