The Role of Executive Functioning in Deaf/Hard of Hearing Children's Number Learning

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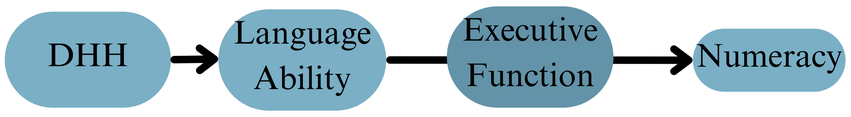
Introduction

- Deaf and hard-of-hearing (DHH) children without early access to a native language show numeracy delays and low STEM attainment (Pagliaro & Kritzer, 2013).
- We don't know the pathway between deafness and numeracy.
  - DHH children with native sign input show no delays in executive function (EF; Goodwin et al. 2022) or numeracy (Hrastinski et al., 2016). Thus, deafness itself cannot explain developmental delays seen in DHH children.
  - Initial pathways indicated language ability impacts numeracy (Shusterman et al. 2022):
    - Deafness → Shortened Access to Language → Lower Language Ability → Lower Numeracy.
  - However, in a different study (Santos et al. 2023), rather than language ability, it found hearing access to drive numeracy, suggesting a complicated relationship between these variables.
- Recent evidence points towards strong relationships between EF and both language and numeracy (Ribner et al., 2017).
- Emerging evidence of EF deficits in DHH children raises the possibility that EF mediates the relationship between language delays and numeracy.

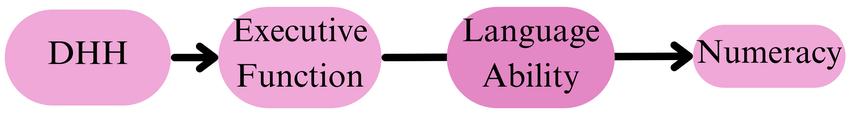
Research Questions

- What is the pathway from deafness to numeracy deficits?
- Is EF involved in this relationship?
  - Does EF mediate the relationship between deafness and numeracy?
  - Does EF mediate a specific language and numeracy relationship, or does it reflect more general cognitive effects of early language input?

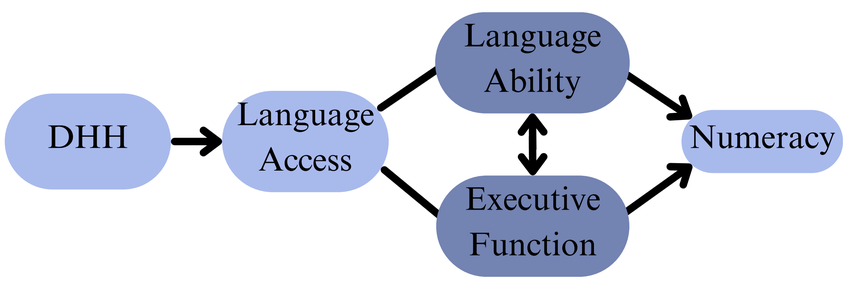
Hypothesized Pathways:



Execute Function as a mediator between Language Ability and Numeracy.



Language Ability as a mediator between Executive Function and Numeracy.



Both Language Ability and Executive Function as mediators between Language Access and Numeracy.

Methods

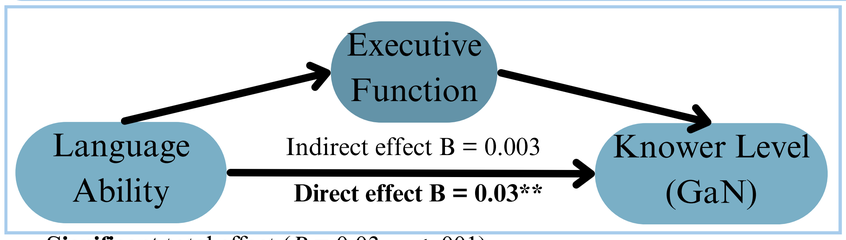
Participants: 123 children made up of two groups;
- DHH children (n = 44; 21F; range = 40.3–74.5 mos; m = 57.5 mos)
- TH children (n=79; 51F; range = 36.0–79.0 mos; m = 49.2 mos).

Tasks: a battery of tasks were administered, including Give-N (GaN; Wynn, 1990), Which-Has-X (WHX; Wynn, 1990), Panamath (Halberda & Feigenson, 2008; adapted in Shusterman et al. 2022), Opposites Task (Leonard et al. 2014), and the PPVT-4 (Dunn et al. 2007).

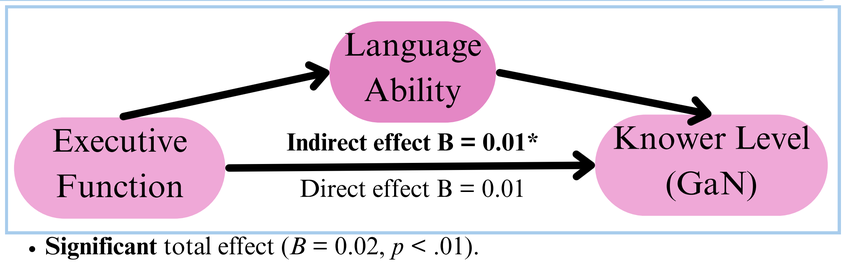
- Structural equation modeling (SEM) served as the framework for mediation analysis.
- Indirect effects were identified through bootstrapping over 1,000 samples.
- Measures were selected to maximize available data and reduce loss.
- All mediation analyses controlled for age and were conducted in R using the lavaan package.

Knower Level (Numeracy)	Give-N (GaN); ask children to give N number of fish to see up to what number they know.
ANS Acuity	Panamath; rapidly show children two quantities of dots, they must decide which one is of the higher quantity.
Executive Function (EF)	Opposites Task; children learn and remember two opposing rules, they are tested in implementing both in a game.
Language Ability	PPVT-4 (TH), test of children's vocabulary (varied for DHH children).
Language Access	Time from first device (DHH) / Age (TH)

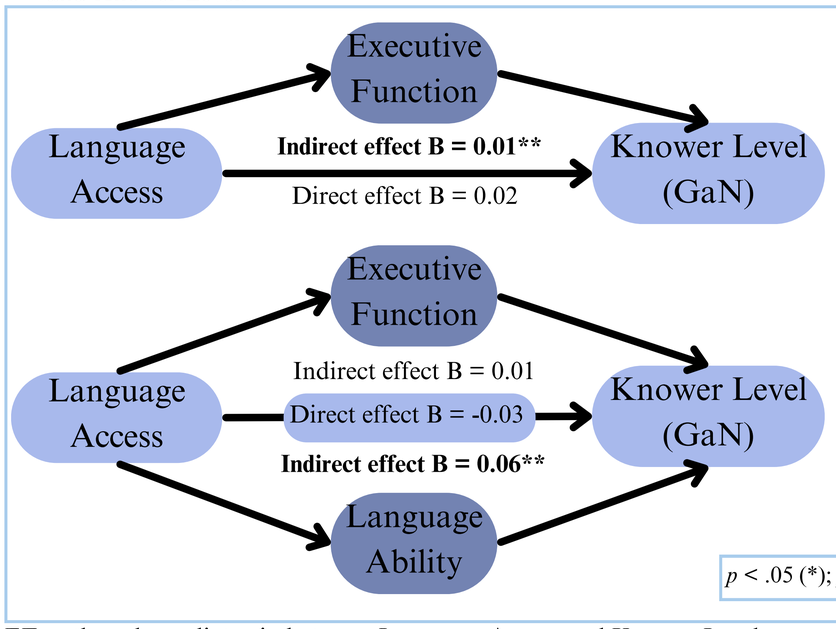
Results



- **Significant** total effect ($B = 0.03$, $p < .001$).
- **Significant** direct effect ($B = 0.03$, $p < .01$).
- **Insignificant** indirect effect ($B = 0.003$, $p > .05$).
- **No evidence** for that EF mediates the relationship between Language Ability and Knower Level.



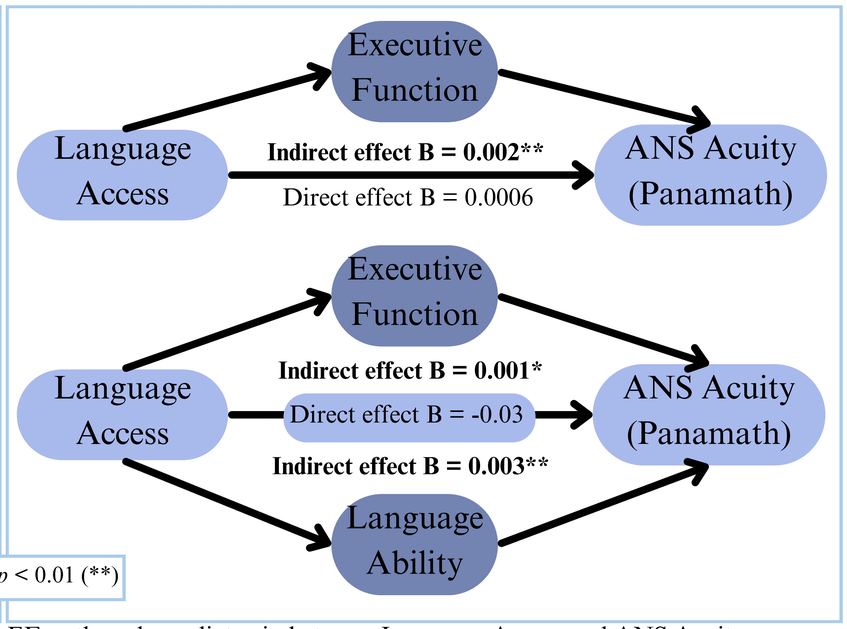
- **Significant** total effect ($B = 0.02$, $p < .01$).
- **Insignificant** direct effect ($B = 0.01$, $p > .05$).
- **Significant** indirect effect ($B = 0.01$, $p < .05$).
- Evidence for Language Ability **fully mediating** the relationship between EF and Knower Level.



EF as the sole mediator in between Language Access and Knower Level:
- **Insignificant** direct effect ($B = 0.02$, $p > .05$).
- **Significant** indirect effect ($B = 0.03$, $p < .01$).
- **Evidence for full mediation** by EF.

When we add Language Ability as a mediator:
- Language Ability has a **significant** indirect effect ($B = 0.06$, $p < .01$).
- EF has an **insignificant** indirect effect ($B = 0.01$, $p > .05$).
- **Insignificant** direct effect ($B = -0.03$, $p > .05$).

Language Ability, not EF, **fully mediates** the relationship between language access and Knower Level.



$p < .05$ (*); $p < 0.01$ (**)

EF as the sole mediator in between Language Access and ANS Acuity:
- **Insignificant** direct effect ($B = .001$, $p > .05$).
- **Significant** indirect effect ($B = 0.002$, $p < .01$).
- **Evidence for full mediation** by EF.

When we add Language Ability as a mediator:
- Language Ability has a significant indirect effect ($B = 0.003$, $p < .01$).
- EF has a significant indirect effect ($B = 0.001$, $p < .05$).
- Insignificant direct effect ($B = -0.001$, $p > .05$).

Evidence for **EF and Language ability both fully explaining** the relationship between Language Access and ANS Acuity.

Discussion

- Language ability overall offers **a better pathway to explain** access to language's impact onto ANS acuity and numeracy than executive functioning.
  - Executive functioning **cannot** explain the relationship between language ability and numeracy.
  - EF **no longer explains the relationship** between Language Access and Knower Level after Language Ability is added.
  - EF and Language Ability **both explain** the relationship of language access onto ANS Acuity.
    - ANS Acuity is influenced by language, even though it is a non-verbal system.
- The known relationship between EF and Numeracy could be acting through a pathway of Language Ability.
  - Language ability **fully mediates** the relationship between EF and Knower Level.

Limitations

- Low sample size of DHH children.
- Low completion rates and lack of standardization for language tests.
- Below 85% completion of certain tasks limited possible analyses.
- Hearing age assumes that initial hearing intervention is effective.
- Language access is likely highly correlated with socio-economic status.

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