Listening difficulties can be caused by deficits in auditory processing, speech processing, cognition and language

Harvey Dillon
Macquarie University
National Acoustic Laboratories,
University of Manchester
Hearing CRC

CHSCOM
Linkoping
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Thanks to my collaborators …….
What you might remember

- Listening difficulties have multiple causes, which need to be allowed for, and quantified.

- Diagnosing the type(s) and extent of auditory processing disorder present requires quantitative control of the effects of:
  - Memory,
  - Attention,
  - Intelligence, and
  - Language,
Deficits (various) in auditory processing

Deficits (various) in cognition

Deficits (various) in language

Listening difficulties

Performance on tests of APD
Deficits (的各种) in auditory processing

Deficits (的各种) in cognition

Deficits (的各种) in language

Performance on tests of APD
Example of a test that tests multiple abilities

- Dichotic digits test – Musiek (1983) - 333 citations
- Easy to administer and score
- Often failed by children seeking APD assessment
Dichotic Free Recall Paradigm
Diotic Paradigm

Dichotic Digits difference Test

DDdT - diotic
Dichotic versus diotic (%)

Clinic
School

$r = 0.82$
Correlations with cognition

Attention (prudence)

Attention (vigilence)

Forward digit span

Reverse digit span

Non-verbal IQ

Free recall dichotic

Correlations:
- Attention (prudence): 0.31
- Attention (vigilence): 0.21
- Forward digit span: 0.53
- Reverse digit span: 0.36
- Non-verbal IQ: 0.27
Attention (prudence)
Attention (vigilence)
Forward digit span
Reverse digit span
Non-verbal IQ

Correlations with cognition

Diotic
Dichotic scores and memory

The normal range! R=0.60
Accounting for variance

- Memory: 64%
- Other non-dichotic factors: 64%
- Random measurement error: 27%
- Dichotic factors: 9%

Dichotic test scores

Total variance: 91%

64% + 27% = 91%
.. and then there’s attention!

Fig 1 from Stavrinos (2018)
Dichotic tests

Testing cognitive ability

- Selective attention
- Working memory
- Executive function
- Aging
- Mental Retardation

Application to brain-lesion patients

Information about hemisphere differences

Application to auditory processing disorder patients

Inferences about auditory processing
Brain “lesions” in Central Auditory Nervous System

Cognitive deficits

Cause

Indicate

Low dichotic test scores
What *not* to do in “sensitising” a test

**Problem:** A test gives ceiling performance for too many people

**Usual solution:** Make the test harder by demanding additional skills:
- dichotic digits – make it two pairs, or three pairs $\rightarrow$ memory $\uparrow$
- speech tests – low-pass filter it $\rightarrow$ vocabulary $\uparrow$, phonetic awareness $\uparrow$

**Result:** Scores decrease below ceiling, but cause become uncertain

**An alternative:** Adaptively change inter-aural level
Disentangling the disorders

Cognitive disorder

Auditory processing disorder

Language disorder
Speech understanding – what could go wrong?

Auditory processing
- Auditory filtering
- Envelope analysis
- Temporal fine structure
- Spatial analysis

Complex signals analysed

Speech processing
- Phonemic awareness
- Comparison to stored templates (phonemes, syllables or words)
- Categorical perception

Phonemes, syllables or words identified

Language processing
- Morphology knowledge
- Syntactic knowledge
- Semantic knowledge
- Prosody knowledge
- (World knowledge)

Degrade the input
- Noise
- Spatial cues
- Reverb
- Rate

Phonemic and lexical neighbourhood density

These enable auditory closure

SNR

Percent understanding

Attention, Memory

Understanding

Message length

Semantic cues

Prosodic cues

Syntactic cues

Morphology knowledge

Syntactic knowledge

Semantic knowledge

Prosody knowledge

(World knowledge)
Speech recognition – where is the problem?

Auditory processing
- Auditory filtering
- Envelope analysis
- Temporal fine structure
- Spatial analysis
- Pitch contour analysis
- Object formation

Speech processing
- Phonemic awareness
- Comparison to stored templates (phonemes, syllables or words)
- Categorical perception

Language processing
- Morphology knowledge
- Syntactic knowledge
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Complex Signals analysed
- Phonemes, syllables or words identified

Spatial cues
- Noise
- Reverb
- Rate

Attention, Memory
- Phonemic and lexical neighbourhood density

Under-standing
- Syntactic cues
- Semantic cues
- Prosodic cues
- Message length

Test(s) of auditory processing
- Test of auditory and speech processing
- Test of auditory and speech and language processing

Test of auditory and speech and language processing
Listening in Spatialized Noise – Universal (LiSN-U) Test

Adaptive Procedure:
0 correct = +3 dB
1 correct = +2 dB
2 correct = +1 dB
3 correct = no change
4 correct = -2 dB
LiSN-U performance versus age

![Graph showing speech reception threshold (dB SNR) versus age group. The graph compares targets and distractors co-located and separated.](image-url)
So,

top-level testing
to find the strength of deficit in each area,
but ....

How do we find the specific deficit(s)?
How do we find the specific deficit(s) causing listening difficulties?

1. **Differential testing**
   - DDdT (Dichotic digits difference test, Cameron et al, 2016)
   - SPIN (Speech in noise test; Kalikow, Stevens & Elliott, 1977)
   - LiSN-S (Listening in spatialized noise sentences test, Cameron & Dillon, 2007)

2. **Allow for other abilities** that affect test scores (just like we allow for age)

3. **Use tests that rely only minimally on other abilities**
Differential testing (e.g. SPIN – Kalikow, Stevens & Elliot, 1977) Sheldon, Pichora-Fuller & Schneider (2008)

Test of auditory and speech and language processing (with semantic cues)

Test of auditory and speech and language processing (with no semantic cues)

\[ \Delta \text{SRT} = \text{SRT}_2 - \text{SRT}_1 \]

**Auditory processing**
- Auditory filtering
- Envelope analysis
- Temporal fine structure
- Spatial analysis
- Pitch contour analysis

**Speech processing**
- Phonemic awareness
- Comparison to stored templates (phonemes, syllables or words)
- Categorical perception

**Language processing**
- Morphology knowledge
- Syntactic knowledge
- Semantic knowledge
- Prosody knowledge
- (World knowledge)

**Auditory (speech) input**
- Complex Signals analysed
- Phonemes, syllables or words identified
- Attention, Memory

**Understanding**
- Message length
- Syntactic cues
- Semantic cues
- Prosodic cues

**Test of auditory and speech and language processing**
- SRT

- **Factors**
  - Noise
  - Spatial cues
  - Rate
  - Reverb
Diagnosing spatial processing disorder with the Listening in Spatialized Noise - Sentences (LiSN-S) test

Disclosure
Licensed to Phonak
Listening in Spatialized Noise – Sentences test:
To diagnose **Spatial Processing Disorder**

**LiSN-S test**
Spatial Advantage (≡ Spatial Release from Masking)

Better

Australia

Spatial Advantage (dB)

Nth America
How do we find the specific deficit(s) causing listening difficulties?

1. Differential testing
   - DDDT
   - SPIN
   - LiSN-S

2. Allow for other abilities that affect test scores (just like we allow for age)

3. Use tests that rely only minimally on other abilities
Allowing for related abilities

APD test z-score = \( AP \text{ ability} + c. \text{(memory)} + d. \text{(attention)} \)

Therefore:

\[ \textbf{AP ability} = \text{APD test z-score} - c. \text{(memory)} - d. \text{(attention)} \]
Dichotic scores and memory

Dichotic free recall (z score)

Clinic
School

Number memory forward (z score)
Dichotic scores and memory

Clinic
School
But how do we allow for attention?

.... and is it:

How motivating is the attention task?
The attention that matters in diagnosing APD is .....
Allowing for attention

Sound Scouts game/tests

- Speech in quiet
- Speech in noise
- Tone in noise
Adaptive track with good attention and average speech in noise ability
Good attention, great performance

Good attention, poor performance
Adaptive track with poor attention
Loss and regain of attention, poor performance

Loss of attention, poor performance
Speech SNR = -16.4 + 1.3*SD
Allowing for related abilities

\[ \text{AP ability} = \text{APD test z-score} - c.(\text{memory}) - d.(\text{attention}) \]

![Diagram showing the relationship between AP ability and other cognitive abilities such as memory, language, attention, and age, with a 1.3*SD threshold.](image-url)
How do we find the specific deficit(s) causing listening difficulties?

1. Differential testing
   • DDDt
   • SPIN
   • LiSN-S

2. Allow for other abilities that affect test scores (just like we allow for age)

3. Use tests that rely only minimally on other abilities
But which cognitive or language abilities affect which auditory processing tests?
<table>
<thead>
<tr>
<th>Cognitive (NVIQ, memory, attention)</th>
<th>APD (dichotic, non-speech)</th>
<th>APD (speech tests)</th>
<th>Outcomes (reading, questionnaires, language)</th>
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A model

- Language ability
- Reported Listening ability
- Academic or reading ability

Speech in noise

- AFG
- LiSN_{HC}
- VCV

Mem_{avg} → NVIQ → Atten_{avg}

Prudence
Vigilance
Divided aud attention
Visual attention

NMR
NMF
MLD
SSW
DDT-L
DDT_{avg}
DDT-R
CW
CS
FPT
GIN
FW
LiSN_{SA}
Are listening difficulties *mostly*: Language, Auditory processing, or Cognition?

University of Melbourne
Spatial processing disorder: 3 / 105
3%  

Australian Hearing
Spatial processing disorder 130 / 666
20%  
P=0.000 000 000 000 1  
Cameron et al (2015)
Next steps

• Top level tests
  • Language specific
  • Language independent

• High-level auditory processing tests

• More specific auditory processing tests
  • Tests administered depend on high level results
  • Tests scores
    • Independent of memory, attention, and language, by design; or
    • Corrected for memory, attention, and language
Thanks for listening
Traditional approach to APD testing

**History**

Is there a problem that APD might explain?

- No: Exclude APD; Refer elsewhere
- Yes: Detailed test battery

**Test result interpretation & diagnosis**

- 2 or more tests ≥ 2 SDs below the mean: “APD”

**Non-specific remediation and management:**
- Classroom placement
- FM use
- Instruction style
- Soundfield amplification
- Auditory training

**Caveats:**

1. Diagnosis may be needed to get the funding needed for management
2. Diagnosis may help teachers and/or parents “understand” reason for problems

Detailed remediation:

- Deficit-specific remediation
Early management, cognitive abilities, speech perception, language, and psychosocial.
Impact of early ...
Relation between APD and Attention Disorder

101 children with listening difficulties

Gyldenkaerne, Dillon, Sharma and Purdy (2014); JAAA.
Instead of “What disorder(s) does this person have” ....

How strongly do deficits in each of: cognition, auditory processing, and language impede speech understanding

With a common unit of measure!
Reported Listening difficulties

Suspected Language Disorder
Suspected Auditory Processing Disorder
Suspected Cognitive Disorder

- Bornstein & Musiek (1992)
- Dawes, Bishop, Sirimanna, Bamiou (2008)
- Sharma, Purdy & Kelly (2009)
- Rosen, Cohen, Vanniasegaram (2010)
- Umat, Mukari, Ezan & Din (2011)
- Gyldenkaerne, Dillon, Sharma, Purdy (2014)
- Boothalingam, Allan, Allen & Purcell (2015)
- Saxena, Allan & Allen (2015)
- Neijenhuis, de Wit, Luinge (2017)
Dawes, Bishop, Sirimanna, Bamiou (2008):

“Children diagnosed with APD reported similar symptoms and similarly had high rates of co-morbid learning problems [as those not diagnosed with APD]."
CHAPS questionnaire results – Great Ormond Street APD Clinic, London

Parents

Teachers

CHildren’s Auditory Performance Scale

CHAPS scores (parents)
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0

CHAPS scores (teachers)
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0

No APD
APD issues
APD diagnosed