Spatial processing in adults with hearing loss

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Spatial processing facilitates speech understanding in noise for normal-hearers.

Hearing-impaired people struggle in noise despite amplification.

Do hearing-impaired people experience spatial processing deficits?
What is Spatial Processing?

- Spatial Processing is the ability to selectively attend to sounds arriving from one direction while suppressing sounds arriving from other directions.

- It can be assessed by measuring speech understanding in spatially-separated and co-located noise.
What is SPD?

Noise

Noise

Speech

Noise
Study 1 - Aims

- To investigate the effect of hearing impairment and aging on spatial processing ability.
- To examine the relationship between spatial processing and self-report measures of difficulty.
Method

- Participants: 80 participants aged between 7 & 89 years
  - English as a first language
  - Normal middle ear function on day of testing
  - No history of learning or attention disorders
  - Up to a moderate-severe sensorineural hearing loss
Age and hearing loss

![Graph showing the relationship between age and hearing loss in dB HL.](image)
• The Listening in Spatialized Noise - Sentences Test (LiSN-S)
  – Adaptive speech in noise test using spatialized stimuli. (Target adaptive, distractors at 55 dB SPL)
  – Assesses how well normal-hearing people use spatial cues and pitch cues to understand speech in noise
  – Includes amplification
Four LiSN-S Conditions

Same Voice - 0° Condition

Different Voices - 0° Condition

Same Voice - ±90° Condition

Different Voices - ±90° Condition

Talker Advantage

Total Advantage

Spatial Advantage

Low cue

High cue
Adaptation of LiSN-S for hearing-impaired

Enter the participant’s hearing thresholds

Software applies required gain according to a NAL-RP to the speech files.
Changes in LiSN-S scores with hearing loss

Speech reception threshold (dB SNR)

Better

4FAHL in worse ear (dB HL)
### Results: Multiple regression

<table>
<thead>
<tr>
<th></th>
<th>p-value</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>4FAHL (worse)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Cue SRT</td>
<td>&lt;0.001 *</td>
<td>0.075</td>
</tr>
<tr>
<td>High Cue SRT</td>
<td>&lt;0.001 *</td>
<td>0.001 *</td>
</tr>
<tr>
<td>Spatial Advantage</td>
<td>&lt;0.001 *</td>
<td>0.104</td>
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<tr>
<td>Talker Advantage</td>
<td>&lt;0.001 *</td>
<td>0.523</td>
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<tr>
<td>Total Advantage</td>
<td>&lt;0.001 *</td>
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</table>
Results: The effect of hearing impairment

Low Cue SRT vs 4FAHL
p <0.001 *

High Cue SRT vs 4FAHL
p <0.001 *
Results: The effect of hearing impairment

Spatial Advantage vs 4FAHL

$p <0.001$ *

1.6dB decrease in SRT
A Quick Summary

• Spatial processing ability declines as hearing loss increases.

• The non-spatially separated measures of the LiSN-S are less affected by hearing loss than the spatialized measures.
Effect of mild loss

High cue SRT = -19.101 + 0.2377 * x

![Graph showing the relationship between 4FAHL worse ear and high cue SRT in decibels.]
Results: The effect of aging

Low Cue SRT vs Age
p = 0.075

High Cue SRT vs Age
p = 0.001 *
Results: The effect of aging

Spatial Advantage vs Age

$p = 0.104$
• All hearing-impaired people will have a spatial processing disorder of some degree.

• Spatial processing ability declines only mildly (insignificantly) with age.

• Use of non-spatialized speech in noise tests will underestimate difficulty.

• Even slight hearing loss results in loss of SRT in noise.
Spatial processing facilitates speech understanding in noise for normal-hearers.

Hearing-impaired people struggle in noise despite amplification.

All hearing-impaired people have a spatial processing deficit of some degree.

Can spatial processing deficits in hearing-impaired people be remediated?
Study 2 - Aims

- Can spatial processing deficits in hearing-impaired people be remediated (with LiSN & Learn)?

- (LiSN & Learn already shown to be effective for children with spatial processing disorder and normal hearing thresholds)
What is LiSN & Learn?

- Computer based auditory training software
- Originally designed for children
- Five games presented over headphones
- Target sentences at 0° azimuth; competing stories at ±90° azimuth.
- Weighted up-down adaptive procedure used to adjust the signal level of the target
- SRT calculated over 40 sentences
LISN & Learn Game

Target at 0°:

Distracters at + and -90°:
Target: The horse kicked six wet shoes
Method

- 10 participants (5 children & 5 older adults) with symmetrical sensorineural hearing loss
- Assessed pre- and post-training on LiSN-S, questionnaire of listening difficulty & BKBs in noise
- LiSN & Learn speech files shaped with NAL-RP gain for each participant.
- Train with LiSN & Learn 15 min/day, 5 days/week, 12 weeks.
Preliminary Results: LiSN & Learn (n = 6)

Better
Preliminary Results: LiSN-S (n = 6)

- **High Cue SRT (dB)**
  - Pre-training: -10 dB
  - Post-training: -11 dB
  - **p = 0.83**

- **Low Cue SRT (dB)**
  - Pre-training: -1.0 dB
  - Post-training: -0.1 dB
  - **p = 0.10**
Preliminary Results: LiSN-S (n = 6)

Spatial Advantage (dB)

pre-training  post-training

p = 0.51
Spatial processing deficits cannot be remediated in hearing-impaired children or adults.

Spatial processing facilitates speech understanding in noise for normal-hearers.

All hearing-impaired people will have a spatial processing deficit of some degree.

Hearing-impaired people struggle in noise despite amplification.

Spatial processing deficits cannot be remediated in hearing-impaired children or adults.

What causes spatial processing deficits in hearing-impaired people?

How do people with normal-hearing achieve spatial processing?
Interaural cues

- Interaural Time Differences (ITDs) dominant for low frequency sounds.
- Interaural Level Differences (ILDs) dominant for high frequency sounds.
Previous Research

- Theories about use of ITDs and ILDs largely generalised from localization research.
- ITDs dominant for localising speech
- Very little evidence to show a link between speech understanding in spatially separated noise and localization.
• To investigate the relative importance of ITDs and ILDs to spatial processing.
  • Using Listening in Spatialized Noise – Sentences test (LISN-S) paradigm
  • Special version with altered cues
- 12 normal-hearing participants aged 24 – 53 years

<table>
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<th>ITD cues</th>
<th>ILD cues</th>
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<td>✓</td>
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<td>X</td>
</tr>
<tr>
<td>ILD only</td>
<td>X</td>
<td>✓</td>
</tr>
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</table>
Results

- No sig. difference between spatial advantage in ILD only and reference condition (p = 0.938).

- Spatial advantage is significantly reduced in ITD only condition (p < 0.001).
Conclusion

• Interaural Level Differences are the dominant cue used in this spatial processing task.

• Interaural Time Differences alone do result in some spatial release from masking.

• The benefits from ITD and ILD not additive.

• Suggests that hearing-impaired people are unable to take advantage of ILD cues.
ILDs are the dominant interaural cue used by normal-hearers. Spatial processing facilitates speech understanding in noise for normal-hearers. All hearing-impaired people will have a spatial processing deficit of some degree. Hearing-impaired people struggle in noise despite amplification. Spatial processing deficits cannot be remediated in hearing-impaired children or adults. What causes spatial processing deficits in hearing-impaired people?
• ILD use may be impaired if hearing thresholds limit audibility of speech.

• Study 1 provided amplification to improve audibility but did not match audibility to normal-hearers.

• Does reduced audibility cause of spatial processing deficits in hearing-impaired people.
Method

- 12 normal hearing adults (25 – 47 years)

- Frequency specific filtering (attenuation) applied to LiSN-S to match audibility experienced by average hearing-impaired listener in Study 1.

- Results compared normative data for normal-hearers and subset of 16 hearing-impaired participants
Results

Reduced audibility different from:
- Normal hearers
- Hearing impaired
Conclusions

- Reduced audibility explains a large portion of the observed spatial processing deficits.

- Approximately 2 dB of spatial advantage remains unexplained.
ILDs are the dominant interaural cue used by normal-hearers.

Spatial processing facilitates speech understanding in noise for normal-hearers.

All hearing-impaired people will have a spatial processing deficit.

Hearing-impaired people struggle in noise despite amplification.

What causes the remaining spatial processing deficits that aren’t explained by audibility?

How do people with normal-hearing use ILDs achieve spatial processing?

Audibility + ???? causes spatial processing deficits in hearing-impaired people.
Study 5 - Aims

• One way that ILDs may be used to achieve spatial processing is through cross-ear dip listening.

• Is cross-ear dip listening used by normal-hearers?

• Do widened auditory bands could reduce hearing-impaired people’s spatial processing ability.
• Tested Cross-ear normal hearing (CENH) and Cross-ear hearing impaired (CEHI)

• CEHI used widened auditory bands.

• 22 normal-hearing adults (18 – 29 years)
Results
• Cross-ear dip listening explains some, but not all, of the benefit gained from spatial processing.

• Widened auditory bands may explain the spatial processing deficits not attributable to audibility.
Overall Interpretation

• Normal hearers use level differences between the ears → combine bands across ears that have the better SNR

• Normal hearers supplement this with spatial cues available from either ITDs or ILDs

• Hearing impaired people lose lower level information in the gaps, even with (linear) amplification

• Widened auditory bands further limits spatial processing ability
ILDs are the dominant interaural cue used by normal-hearers. But the puzzle isn’t complete.

Spatial processing facilitates speech understanding in noise for normal-hearers.

All hearing-impaired people will have a spatial processing deficit of some degree.

Hearing-impaired people struggle in noise despite amplification.

Spatial processing deficits cannot be remediated in hearing-impaired children or adults.

ILDs are the dominant interaural cue used by normal-hearers.

Audibility + widened auditory bands in the cochlear cause spatial processing deficits in hearing-impaired people.

How do these findings apply to situations where the target isn’t coming from 0 degrees?

How do we compensate for spatial deficits?
So what for the clinician?

- Hearing impaired people *will* need better SNR than normal hearers
- Deficit in SNR *will* be underestimated if speech and noise are co-located.
- Deficit in SNR *cannot* be trained
- Deficit in SNR can *easily* be measured using LiSN-S
- Implications for directional microphones, wireless remote hearing aids are clear
Clinical Implications

High-cue condition:
If the deficit re normal hearing is:

• < 3 dB ........ Should do well with hearing aids, even in noisy places.

• 3 to 6 dB ........ Should do well with directional hearing aids, even in noisy places, provided the target or the dominant noise is close.

• > 6 dB ........ Will often need more than any hearing aid can offer to enable effective communication in noise places – remote microphone hearing aids.
SNR deficit

Cameron, Glyde & Dillon (in press)
Acknowledgements

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