Spatial Processing Disorder in Normal-Hearing Children and Hearing-Impaired Adults

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Spatial processing disorder:

- In “normal hearing”
- Impact of task (cognitive load)
- Remediation
- Hearing impairment
- Inter-aural mechanisms
- Non-speech sounds
- Neural locus
- Implications for hearing aids
Disclosure

The National Acoustic Laboratories is a division of Australian Hearing, a Statutory Authority of the Australian Government.

- NAL licences the LiSN-S test to Phonak, and is paid a royalty on sales.
- NAL directly sells the LiSN & Learn training package through its web site.
SPATIAL PROCESSING DISORDER IN "NORMAL" HEARING
Spatial Processing Disorder

Lack of spatial release from masking

Noise

Speech

Noise

Noise

Noise
Listening in Spatialized Noise - Sentences test (LiSN-S)

1. Adaptive speech-in-noise-test
2. Virtual auditory environment under headphones
3. Target sentences - 0º azimuth
4. Competing speech - 0º or ±90º azimuth at 55 dB SPL
5. Runs on a PC with specified headphones
6. Four LiSN-S conditions
LiSN-S Diagnostic Screen

Diagnostic Session

Test date: 20/08/2009

Different voices ±90°

Seq Phrase
22 They are moving the boxes

% Completed

Number of reversals: 12
Standard Error of Mean (dB): 0.8
SRT (dB): -9.5
### Results profile: spatial processing disorder

<table>
<thead>
<tr>
<th>Measure</th>
<th>Average Score for Age</th>
<th>Client's Score (dB)</th>
<th>Normal Limits</th>
<th>Variance from Average in StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Cue SRT</td>
<td>-1.4</td>
<td>-1.0</td>
<td>Within</td>
<td>-0.4</td>
</tr>
<tr>
<td>High-Cue SRT</td>
<td>-15.3</td>
<td>-9.5</td>
<td>Outside</td>
<td>-3.9</td>
</tr>
<tr>
<td>Talker Advantage</td>
<td>4.1</td>
<td>3.8</td>
<td>Within</td>
<td>-0.2</td>
</tr>
<tr>
<td>Spatial Advantage</td>
<td>12.4</td>
<td>7.6</td>
<td>Outside</td>
<td>-2.7</td>
</tr>
<tr>
<td>Total Advantage</td>
<td>14.0</td>
<td>8.5</td>
<td>Outside</td>
<td>-3.8</td>
</tr>
</tbody>
</table>

**Variance from mean**

- **Low Cue SRT**
- **High Cue SRT**
- **Talker Advantage**
- **Spatial Advantage**
- **Total Advantage**
202 participants:

- 106 children - 6 yrs, 2 mths to 17 yrs, 7 mths
- 60 young adults - 18 yrs, 1 mth to 29 yrs, 10 mths
- 36 older adults – 31 yrs, 8 mths to 60 yrs, 7 mths

- English as a first language;
- no history of hearing disorders;
- no learning or attention disorders;
- normal pure tone audiogram and middle ear function.
Low Cue SRT

$p < 0.000001$
High Cue SRT

p < 0.000001
Talker Advantage

Talker Advantage (dB)

Age Group

Better

$p < 0.000001$
Spatial Advantage (≡ Spatial Release from Masking)

Age Group

Spatial Advantage (dB)

Better

Australia

Nth America
Children with Spatial Processing Disorder

- Nine children aged 6 to 11 years experiencing listening difficulties in class relative to peers who had no learning or attention disorder (SusAPD group).

- Eleven children with confirmed learning or attention disorders (LD group).

- Assessed on LISN-S and results compared to 70 age-matched controls.

- Assessed with a traditional (C)APD test battery
LiSN-S vs. Traditional Battery (LD Group)

Deviation from Mean Normal Performance

-12 -10 -8 -6 -4 -2 0 2 4 6

Cameron & Dillon (2008)

Median
25%-75%
Min-Max

PPS (RE)  PPS (LE)  DD (RE)  DD (LE)  RGDT  MLD  LC SNR  HC SNR  Talker Adv  Spatial Adv  Total Adv
LiSN-S vs. Traditional Battery (sus CAPD Group)

-12 -10 -8 -6 -4 -2 0 2 4 6
Deviation from Mean Normal Performance

-12 -10 -8 -6 -4 -2 0 2 4 6

Cameron & Dillon (2008)
IMPACT OF TASK (COGNITIVE LOAD) ON SPATIAL PROCESSING DISORDER
LiSN – continuous discourse test

1. Listen and seek to understand
2. Make judgement about difficulty
3. Recount story after 3 minutes

Extract meaning, memorise and recall

Easy to understand

Just understand

Too hard to understand
Impact of task on spatial processing deficit

LiSN - S

LiSN - CD
REMEDIATION OF SPATIAL PROCESSING DISORDER
Managing Spatial Hearing Deficits

1. Teacher-directed strategies
2. Child-directed strategies
3. Language training
4. Classroom acoustic modification
5. Classroom amplification
6. FM systems
7. Training in spatial selectivity
LISN & Learn game

- Four games presented on PC over headphones
- Target sentences at 0° azimuth (initially 62 dB SPL)
- Competing stories at ±90° azimuth (55 dB SPL)
- Weighted up-down adaptive procedure used to adjust the signal level of the target
- SRT calculated over 40 sentences
- 131,220 unique sentences can be generated
LISN & Learn Game

Target at 0°:

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

- 9 children (6 to 11 years) - LISN-S SA >2SD
- CAPD Pediatric SSQ
- *LISN & Learn* - 15 minutes per day; 5 days per week; over 12 weeks (120 games)
- Re-evaluate post-training; 3 months post-training
LiSN & Learn - Performance Over Time (n=9)

The graph shows the performance improvement of LiSN & Learn over time. The performance is measured in SRT (dBA) and is plotted against the game number. The blue line represents the Group SRT - Per Game, while the red line represents the Group SRT - 5 Day Running Average. The graph indicates a steady improvement in performance over time, with a significant drop at game number 101 indicating a better performance at 10 dB.
Effect of training on LiSN-S scores

<table>
<thead>
<tr>
<th>LiSN-S Scale</th>
<th>Pre</th>
<th>Post</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2.5</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>-1.5</td>
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<td></td>
<td></td>
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<tr>
<td>-1.0</td>
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<td></td>
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<tr>
<td>1.0</td>
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</tbody>
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LiSN-S scores (popn SD)
Additional Results – Pre- vs. Post Training

- CAPD SSQ:
  - Listening in Quiet – $p = 0.103$
  - Listening in Noise – $p = 0.0002$

- TOVA-A
  - Omissions – $p = 0.168$
  - Commissions – $p = 0.0004$

- TAPS-3
  - Memory Index – $p = 0.003$
Effect of training on Speech Spatial Quality Scores

TIME

Pre-training  Post-training  Follow-up

SSQ scale score

Noise  Quiet
Phase II Clinical Study

1. 16 children - LISN-S spatial advantage >2SD from mean
   a) 8 x *LiSN & Learn* (experimental group)
   b) 8 x *Earobics* (control group)

2. Questionnaire
   a) Participant (LIFE)
   b) Parent (Fishers)
   c) Teacher (LIFE)

3. *LiSN & Learn or Earobics* training – 15 minutes per day

4. Re-evaluate LiSN-S and questionnaires post-training

5. Offer *LiSN & Learn* to control group.
Randomized Control Trial

**LiSN & Learn**

- N = 5

<table>
<thead>
<tr>
<th>Group</th>
<th>Low Cue</th>
<th>Talker Adv</th>
<th>Spatial Adv</th>
<th>Total Adv</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-6</td>
<td>-5</td>
<td>-4</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>-2</td>
<td>0</td>
<td>1</td>
<td>2</td>
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**Earobics**

- N = 5

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<tbody>
<tr>
<td></td>
<td>Pre-training</td>
<td>Post-training</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High Cue</td>
<td>Spatial Adv</td>
<td>Total Adv</td>
<td></td>
</tr>
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*Graphs showing LiSN-S Score (Population Stan)*
Questionnaire results

Parents

Current effect: $F(1, 8) = 1.7524, p = .22215$
Vertical bars denote 0.95 confidence intervals

Children

Current effect: $F(1, 8) = .78788, p = .40064$
Vertical bars denote 0.95 confidence intervals

Teachers

Current effect: $F(1, 8) = 4.9181, p = .05739$
Vertical bars denote 0.95 confidence intervals
Conclusion

- *LiSN & Learn* training has the potential to strengthen or reorganize connections dedicated to binaural processing.

- Training results in enhanced ability to process speech in background noise.
SPATIAL PROCESSING DISORDER IN HEARING IMPAIRMENT
LiSN-S Prescribed Gain Amplifier
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 sensorineural hearing loss
Age and hearing loss
Changes in LiSN-S scores with hearing loss

4FAHL in worse ear (dB HL)

Better

Speech reception thre

Different voices 90
Same voices 90
Different voices 0
Same voice 0

Better
Multi non-linear regression

Measure = a + spline(4FAHL) + spline(age)
Results: The effect of hearing impairment

High Cue SRT vs 4FAHL

- Low Cue SRT: 0.8 dB decrease in SRT
- High Cue SRT: 2.4 dB decrease in SRT

High Cue SRT vs 4FAHL

p <0.001 *
Results: The effect of hearing impairment

Spatial Advantage: 1.6 dB decrease in SRT

Talker Advantage: 1.2 dB decrease in SRT
Results: The effect of hearing impairment
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.

Results: The effect of hearing impairment
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

Talker Advantage vs Age
p = 0.523
Results: The effect of aging

![Graph showing the relationship between total advantage and age. The x-axis represents age in years, ranging from 0 to 80, and the y-axis represents total advantage in dB, ranging from -2 to 20. The graph includes a shaded area indicating a trend line with a p-value of 0.059.](image-url)
Results: The effect of aging

A Quick Summary

• Spatial processing ability is not significantly affected by age.

• High Cue SRT is correlated with age. This could be due to issues such as cognitive load.
Effect of mild loss

High cue SRT = -19.101 + 0.2377*x

With age allowed for, SRT increases by 1.8 dB per 10 dB of hearing loss.
Spatial processing disorder may be a major reason why hearing-impaired people have trouble listening in noise, despite wearing hearing aids.

→ Directional microphones
→ FM systems
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 – the FM system.

Other three LiSN-S conditions:
May provide insights into reasons for SNR deficit.
Spatial deficit

Cameron, Glyde & Dillon, unpublished data)
MECHANISMS IN SPATIAL PROCESSING AND ITS DISORDERS
Binaural processing mechanisms

SO / IC / A1

Sensorineural hearing loss

CAPD

Executive control

ILD ITD

CN

CN

L R
Origins

Of 49 children with spatial processing disorder seen in research studies at NAL, 25 had three or more episodes of ear infections when younger.
Spatial SNR improvement – dynamic best-ear model

SNR difference between:

0° target
±90° distractors
Dynamic best ear

And

0° target
0° distractors
Left | right ear

Source: Jorg Bucholz
Relative importance of ILD and ITD cues?

Current effect: $F(6, 48) = 5.3639$, $p = 0.00026$

Vertical bars denote 0.95 confidence intervals

Inter-aural cues available

-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22

SRT (dB)

Better
SPATIAL PROCESSING FOR NON-SPEECH SOUNDS
Spectro-temporal properties

Tone duration

- 10ms
- 30ms

Max jitter

- 0ms
- 30ms
Results – spatial advantage

- Spatial advantage increases with increasing amount of jitter → dip-listening improves spatial advantage…?

- Spatial advantage increases with increasing tone-burst duration → pitch strength influences spatial advantage…?

- Temporal integration and jitter benefit are ~additive

Preliminary data from 3 listeners
LOCUS OF SPATIAL PROCESSING
Cortical Auditory Evoked Potential Study
Adult Control Group – Active P300 Task
N1 and P2 to Standard Stimulus at Cz

Background Noise

0°
±90°

-200.0  50.0  300.0  550.0  800.0
-10.0 -7.5 -5.0 -2.5  0.0  2.5  5.0  7.5  10.0
µV

-2.1 µV
-4.6 µV
-6.4 µV
2.9 µV
2.1 µV
Age Matched Control - Passive P300 Task
N1 and P2 to Standard Stimulus at Cz

Background Noise

- 0°
- ±90°

ms

µV

-200.0 50.0 300.0 550.0 800.0

-10.0 -7.5 -5.0 -2.5 0.0 2.5 5.0 7.5 10.0

-9.1µV
-7.8µV
1.7µV
5.9µV
Frequency following response

Krishnan et al 2012
Thanks for listening

www.NAL.gov.au


