English language and language-free detection of spatial processing disorders in Aboriginal and Torres Strait Islander children

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Acronyms:

CVCV: consonant-vowel-consonant-vowel

DV0: different voices 0°

DV90: different voices ±90°

LiSN-S: Listening in Spatialized Noise – Sentences test

LiSN-U: Listening in Spatialized Noise – Universal test

SV0: same voice 0° condition

SV90: same voice ±90°

SA: spatial advantage

SPD: Spatial processing disorder

SRT: speech reception threshold

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Objective: The aim of this study was to compare speech reception thresholds in noise measured with the Listening in Spatialized Noise – Universal test (LiSN-U; which requires no English knowledge) with those measured from the relevant conditions of the LiSN – Sentences test (LiSN-S; a test requiring knowledge of English) in Aboriginal and Torres Strait Islander children. A second aim was to compare the ability of the two tests to detect spatial processing disorder.

Design: Participants completed audiometry, the LiSN-S, and the LiSN-U.

Study Sample: 90 Aboriginal and Torres Strait Islander children aged six to 14 years tested in a school setting.

Results: Strong correlations were found between speech reception thresholds in noise for the two tests. A moderate correlation was found between the difference scores that each test uses to detect spatial processing disorder. Consistent diagnoses of whether a child had spatial processing disorder or not on both tests were found for 72% of children.

Conclusions: The moderate-to-strong relationships and agreement between diagnoses found for the LiSN-S and LiSN-U show promise for the LiSN-U being used as a tool to investigate spatial processing disorder in children, without requiring the test to use a language familiar to the children being tested.

Introduction

The ability to understand speech in noise relies on the brain's skill at combining a sound's timing and level cues from both left and right auditory pathways. This is known as spatial processing. Children's spatial processing abilities improve with age (Cameron & Dillon, 2007a). Spatial processing disorder (SPD) results when a person has reduced ability to use these time and intensity differences between the ears to segregate a target signal coming from one direction from competing signals coming from other directions (Cameron & Dillon, 2007a, 2008, 2011, Cameron, Dillon, & Newall, 2005, 2006; Cameron, Glyde, & Dillon, 2012; Glyde, Cameron, Dillon, Hickson, & Seeto, 2013; Glyde, Hickson, Cameron, & Dillon, 2011). People with SPD have abnormal difficulty understanding speech in noise despite having normal hearing thresholds (Cameron et al, 2014).

SPD is diagnosed using the Listening in Spatialized Noise – Sentences test (LiSN-S) (Cameron & Dillon, 2009). The LiSN-S measures the SNR at which a listener can segregate 50% of the words for the target sentence from simultaneously presented competing stories by utilising inter-aural time and level spatial cues. The LiSN-S speech stimuli are convolved with head-related transfer functions to create a three-dimensional auditory environment presented through headphones. The LiSN-S is described in detail in Cameron and Dillon (2007a). In summary, the test has four conditions which are compared to the norms in order to determine whether or not a child has SPD (Cameron & Dillon, 2007a, 2007b, 2008). The target voice is always delivered from directly in front of the listener (0° azimuth). The conditions differ in where the distractors are coming from, i.e. ±90° azimuth in the spatially-separated condition or 0° azimuth in the co-located condition, and whether the distractors have the same voice or different voice to the target. SPD is determined by the spatial advantage measure which compares the same voice spatially-separated and co-located conditions. Typically children with SPD perform poorly on the spatially-separated condition but within the normal range on the co-located condition giving them a spatial advantage z score of < -2. The LiSN-S is a validated tool for diagnosing SPD (Cameron & Dillon, 2007a, 2008, 2011, Cameron et al., 2005, 2006, 2012, Glyde et al., 2013, 2011). However, the test is presented in English, so the listener must be proficient in English to be able to complete the test. For many Aboriginal and Torres Strait Islander children, English is their second or even third language, limiting the use of LiSN-S for such children.

Recently a language-independent version of the LiSN-S was created, called the Listening in Spatialized Noise – Universal test (LiSN-U) (Cameron, Mealings, Chong-White, Young, & Dillon, in press; Mealings, Cameron, Chong-White, Young, & Dillon, under review). Instead of English sentences, the stimuli for this test are consonant-vowel-consonant-vowel (CVCV) pseudo-words (e.g. ti-gu) where the consonants and vowels used are those that are common to many languages. The LiSN-U has two test conditions; a spatially-separated condition and a co-located condition. In both conditions, the distractors (also CVCV sounds), are spoken by the same talker as for the target. Comparing the listener's performance on both conditions allows the listener's spatial advantage to be calculated like in the LiSN-S.

SPD can develop as a result of the fluctuating hearing loss associated with early onset, chronic ear disease (Graydon, Rance, Dowell, & Van Dun, 2017; Tomlin & Rance, 2014). Even once the otitis media has cleared up, SPD can remain. Tomlin and Rance (2014) found significantly poorer listening-in-noise scores in children aged 6 to 12 years with a history of chronic otitis media compared to age-matched controls. They also found poorer scores were associated with children with early onset chronic otitis media and those who had it for longer periods of time.

Chronic ear disease resulting in conductive hearing loss is the most prevalent health issue among Aboriginal and Torres Strait Islander children (Boswell & Nienhuys, 1996; Williams & Jacobs, 2009). Otitis media is significantly more common for Aboriginal and Torres Strait Islander children than for non-Indigenous Australian children (Closing the Gap Clearinghouse (AIHW & AIFS), 2014). As a result, we expect SPD to be more prevalent in this population, so there is a need for a spatial processing test that can be used which does not depend on the child’s English proficiency.

The aim of this study was to compare the LiSN-U speech reception thresholds and z scores with those from the relevant conditions of the LiSN-S test in Aboriginal and Torres Strait Islander children to examine the strength of the relationship between the two tests. A second aim was to compare the consistency of the two tests in detecting SPD.

Method

Participants

The participants were 90 Aboriginal and Torres Strait Islander children all recruited from a regional school in Northern Queensland, Australia. The children were recruited as part of a larger study by Mealings et al. (2020). Children whose parents did not return the opt-out information and consent form were included in the study. There were 53 females and 37 males. Children were aged six to 14 years (mean = 9 years; 8 months). There were nine six-year-olds, 15 seven-year-olds, 16 eight-year-olds, 10 nine-year-olds, 13 10-year-olds, 11 11-year-olds, eight 12-year-olds, six 13-year-olds, and two 14-year-olds. Permission to conduct this study was obtained from the Australian Hearing Human Research Ethics Committee.

Tests

Audiometry

Each child's ear canal and tympanic membrane appearance was first examined using an otoscope. Then, the hearing sensitivity of each child was tested using conventional audiometry where the child was instructed to raise their hand when they heard a tone. Children's hearing thresholds were tested from 500 – 4000 Hz in octave intervals and screened down to 15 dB HL. If air conduction test results showed a hearing loss, the bone conduction thresholds were taken. Tympanometry was also used to determine the child's middle ear function. The child's middle ear function was considered normal if compliance values were greater than or equal to 0.3 ml and peak pressure was between -150 to +50 daPa (Clark, Roeser, & Mendrygal, 2007).

Listening in Spatialized Noise – Sentences Test (LiSN-S)

The Listening in Spatialized Noise – Sentences Test (LiSN-S) (Cameron and Dillon, 2009) measures a listener's ability to use inter-aural time and level spatial cues to differentiate a target talker from distracting talkers. The test has four conditions which are compared to norms to determine if a listener has SPD (Cameron & Dillon, 2007a, 2007b, 2008). The target voice is delivered from 0° in all conditions, but the location and type of distractors differ. In the Different Voices ±90° condition (DV90), one distracting voice comes from +90° and a different distracting voice comes from -90°, so the listener can use spatial and talker cues to differentiate the target voice from the distractors. The Same Voice ±90° condition (SV90) also has the distracting voices +90° and -90°, but they are the same voice as the target, so the listener can use only spatial cues to differentiate the target. In the Different Voices 0° condition (DV0), the target and the distractors are all delivered from 0°, so the listener can only use voice cues to differentiate the target speech. Finally, in the Same Voice 0° condition (SV0), the target and distractors are all delivered from 0°and all have the same voice, so neither spatial nor talker cues can be used to differentiate the target from the distractors. The software calculates the listener's speech reception threshold (SRT) in decibels and calculates z scores for each of these conditions. The software also makes comparisons between results across conditions to give SRTs and z scores to determine a listener's talker advantage, spatial advantage (SA), and total advantage. A listener with SPD would typically perform poorly on the DV90 condition and the SV90 condition (i.e. $z < -2$), but obtain scores within normal limits on the DV0 and SV0 conditions (i.e., $z > -2$) which would give them a poor spatial advantage score.

The LiSN-S was administered using Sennheiser HD215 circumaural headphones (Hanover, Germany) connected to an iPad Air 2 (Apple Inc., California). The child was asked to repeat the sentences spoken by the target speaker. The distracter track level was set at a constant level of 55 dB SPL. The initial target presentation level was at +7 dB SNR (62 dB SPL) and adjusted adaptively depending on the number of words correctly identified. The test condition order is DV90, SV90, DV0, SV0. To minimise testing time and fatigue, testing was discontinued if a child obtained a z score greater than -1.5 on the DV90 condition, as it is unlikely that he or she would have a spatial processing disorder with this score. All 90 children were tested on the LiSN-S. Forty-seven completed the DV90 condition only, and the other 43 completed the whole LiSN-

S.

Listening in Spatialized Noise – Universal Test (LiSN-U)

The LiSN-U (Cameron et al., in press; Mealings et al., under review) is a new language-independent version of the LiSN-S. Instead of using English sentences as the targets, it uses CVCV non-words, e.g. ti-gu, where the consonants /p, b, t, d, k, g, m, n, s, h/ and vowels /i, a, u/ are those common to many languages. The LiSN-U uses the same premise as the LiSN-S, however it has only the SV90 and SV0 conditions which are subtracted to give a spatial advantage score (i.e. the improvement in threshold when the target speech and maskers are spatially separated) and determine whether a child has SPD. There is also a familiarisation phase at the beginning where the listener is asked to repeat back a sample of the non-words without the distractors. Children needed to repeat back all of the phonemes correctly to move on to the test. The LiSN-U was administered using Sennheiser HD200 Pro circumaural headphones (Hanover, Germany) connected to an iPad Air 2 (Apple Inc., California). The child was asked to repeat the sentences spoken by the target speaker. The distracter track level was set at a constant level of 65 dB SPL. The initial target presentation level was at +11 dB SNR (76 dB SPL) and adjusted adaptively depending on the number of words correctly identified. The test condition order is SV90 then SV0. All 90 children were tested on the LiSN-U, however two children only completed the SV90 condition and did not finish the SV0 condition due to non-compliance. Table 1 shows the number of participants who completed each test.

Table 1: Number of participants who completed each test.

Test	Number of Participants

Audiometry	90
LiSN-S DV90	90
LiSN-S SV90, DV0, SV0	43
LiSN-U SV90	90
LiSN-U SV0	88
LiSN-S and LiSN-U SV90	43
LiSN-S and LiSN-U SV0	42

Procedure

All testing took place in quiet rooms at the children's school. The children completed audiometry first and then the LiSN tests. The order that the children completed the LiSN-S and LiSN-U was counterbalanced across the participants.

Data Analysis

Statistical analysis was performed using Statistica version 13 and R version 3.5.2. Pearson correlations were conducted to assess the strength of the relationship between the LiSN-S and LiSN-U SV90 and SV0 SRTs and z scores, as well as the spatial advantage dB scores and z scores.

Results

Audiometry

Seventy-nine of the 90 children involved in the study showed normal hearing, defined as a four frequency average hearing threshold (4FA) ≤ 20 dB HL in both ears. Ten children had a hearing loss as shown in Figure 1. Ten of these children had a mild hearing loss in at least one ear (i.e. 4FAHL 21-40 dB HL). Five of these children had mild unilateral conductive hearing losses (three with tympanometry type B in the affected ear, two with tympanometry type C in the affected ear), one had a mild bilateral conductive hearing loss (tympanometry type C), one had a mild bilateral sensorineural hearing loss (tympanometry type A in both ears), and three children had mild unilateral losses that were not classified (tympanometry type A in both ears). The remaining child had a moderate unilateral conductive hearing loss (4FAHL in left ear of 42.5 dB HL, with a tympanometry result of type B in the affected ear). The children's otoscopy results and tympanometry results are shown in Table 2 and Table 3. Ninety percent of children had clear otoscopy results, and 70% had normal Type A tympanometry results.

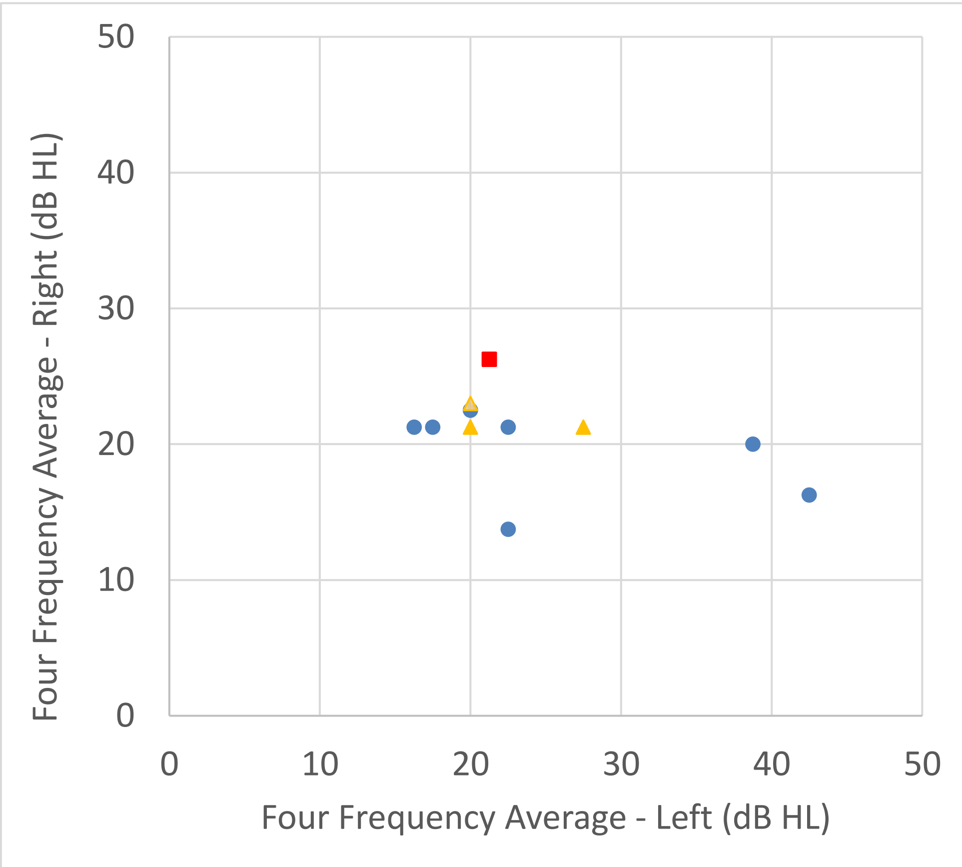

Figure 1: Four frequency average hearing thresholds for participant's left and right ears where the 4FA in a least one ear is greater than 20 dB HL. Blue circles = conductive

hearing loss, red square = sensorineural hearing loss, orange triangle = unclassified hearing loss.

Table 2: Participants' otoscopy results for their left and right ears.

		Right Ear		
		Clear	Wax	Perforation
Left Ear	Clear	81 (90%)	0 (0%)	0 (0%)
	Wax	4 (4%)	4 (4%)	0 (0%)
	Perforation	1 (1%)	0 (0%)	0 (0%)

Table 3: Participants' tympanometry results for their left and right ears.

		Right Ear		
		Type A	Type B	Type C
Left Ear	Type A	63 (70%)	4 (4%)	3 (3%)
	Type B	6 (7%)	6 (7%)	2 (2%)
	Type C	3 (3%)	0 (0%)	3 (3%)

LiSN-S versus LiSN-U

The LiSN-S versus LiSN-U results are shown in Figure 2 and Table 4. We identified one outlier via visual inspection of the scatterplots which was removed for the analysis for the DV90, SV90, and spatial advantage measures. This outlier gave very poor LiSN-S results on the DV90 and SV90 conditions, but normal LiSN-U results on the SV90 condition. It is possible that the child's English proficiency level hindered their performance on the LiSN-S. Sixty percent of participants performed better on the

LiSN-U SV90 condition than the LiSN-S SV90 condition (i.e. had a LiSN-U advantage). Fifty-five percent of participants had a LiSN-U advantage on the SV0 condition. Fifty-two percent of participants had a LiSN-U advantage on the spatial advantage measure. Pearson correlations were conducted to assess the strength of the relationship between the LiSN-S and LiSN-U SV90 and SV0 SRTs and z scores (*n* = 42), as well as the spatial advantage dB scores and z scores (*n* = 42). The LiSN-U SV90 condition was also compared to the LiSN-S DV90 condition as this allowed for a greater number of participants to be included (*n* = 89), rather than only the children who completed the whole LiSN-S. The correlation graphs are shown in Figure 2. Those children with hearing impairments were included in this analysis as we were still interested in the correlation of their results between tests, but we have marked them separately in the graphs. The spread in the data for the subjects with normal 4FAHL was roughly the same as for subjects with 4FAHL greater than 20 dB HL. As both the LiSN-S and LiSN-U contain measurement error, and as we do not wish to predict either of these measures from the other, the regression lines in Figure 2 are based on orthogonal regression. This regression method produces the same correlation coefficient as standard regression, but minimises the total deviation of the data points from the regression line, summed across both the x and y dimensions. Orthogonal regression lines are used to minimise the error between the data points and the regression line in the x and y dimensions, as we are not predicting one variable from the other. The correlation statistics are shown in Table 4. Strong correlations were found for the LiSN-S DV90 vs. LiSN-U SV90, LiSN-S SV90 vs. LiSN-U SV90 (though this was only moderate when correlating the z scores rather than the SRTs), and LiSN-S SV0 vs.

LiSN-U SV0. A moderate correlation was found between the LiSN-S SA vs. LiSN-U spatial advantage difference scores in dB and z scores.

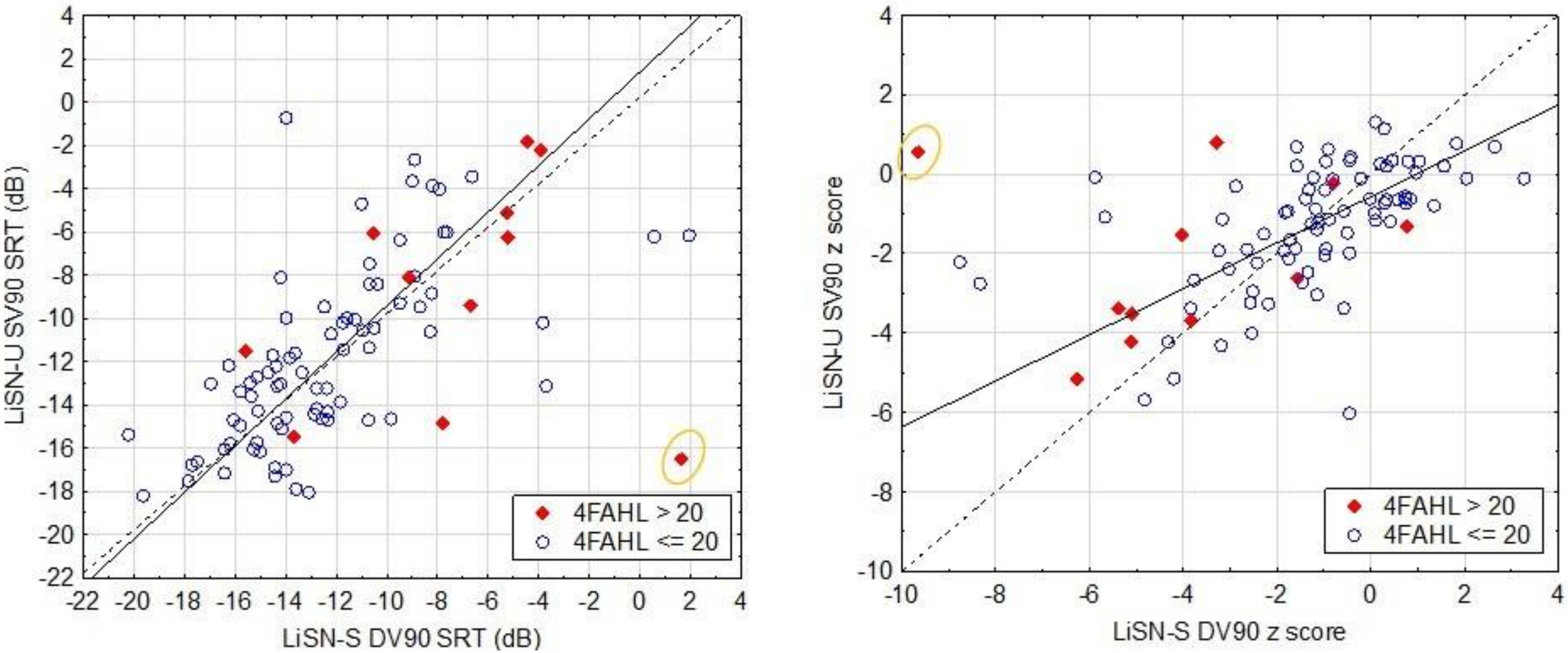

Figure 2: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S DV90 and LiSN-U SV90 condition (*n* = 89). The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels). Outlier is circled.

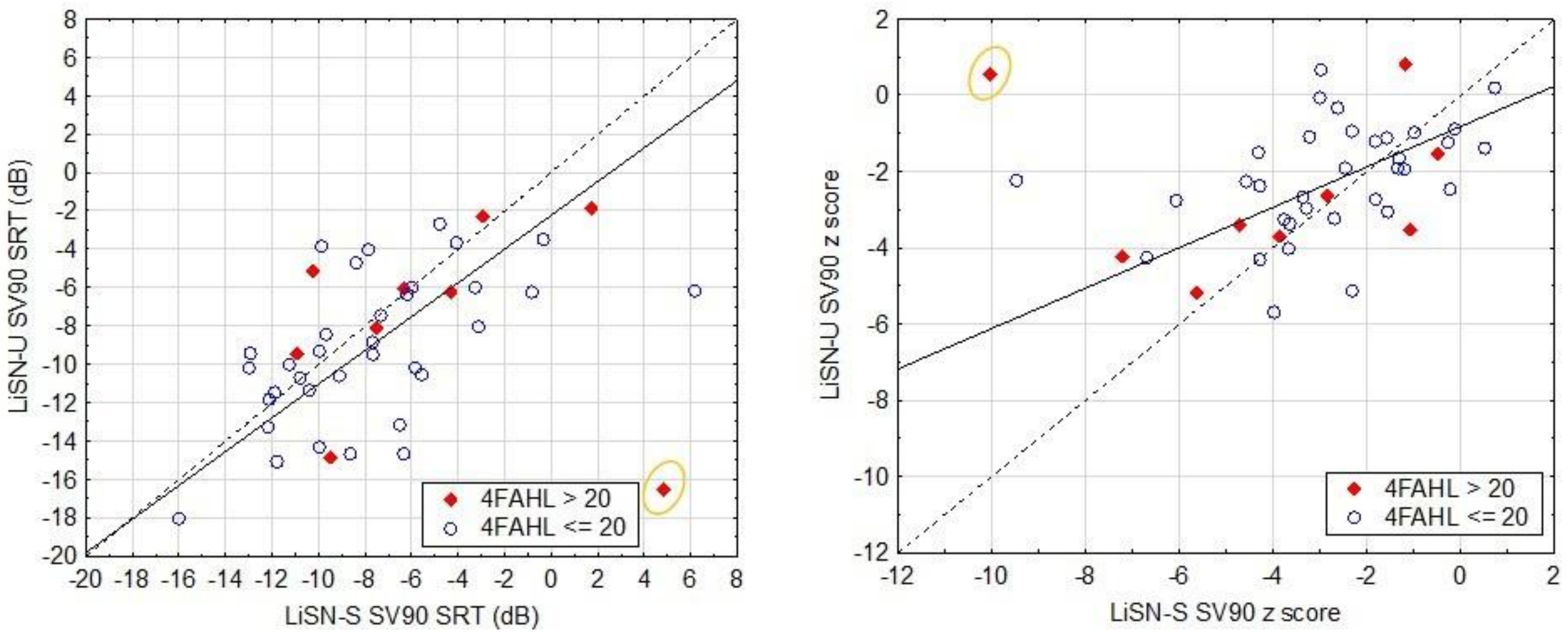

Figure 3: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S and LiSN-U SV90 conditions (n = 42). The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels). Outlier is circled.

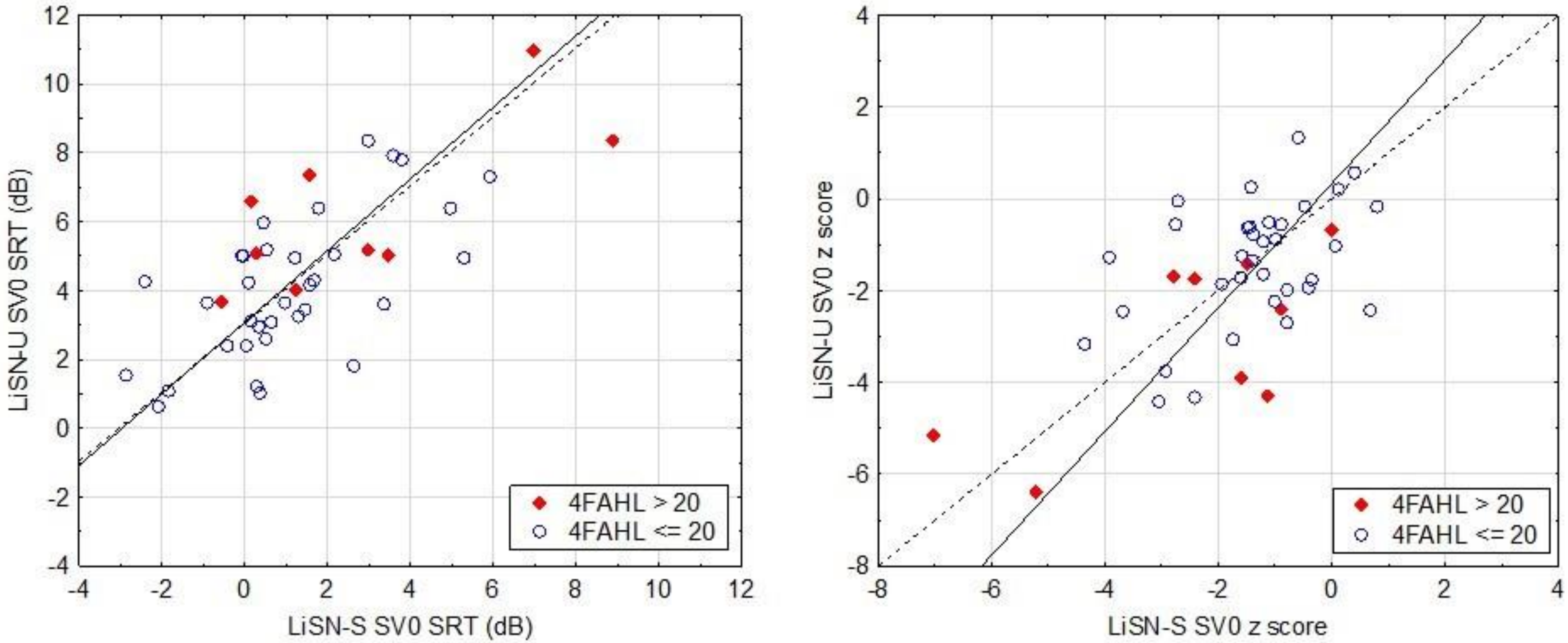

Figure 4: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S and LiSN-U SV0 conditions (*n* = 42).. The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels).

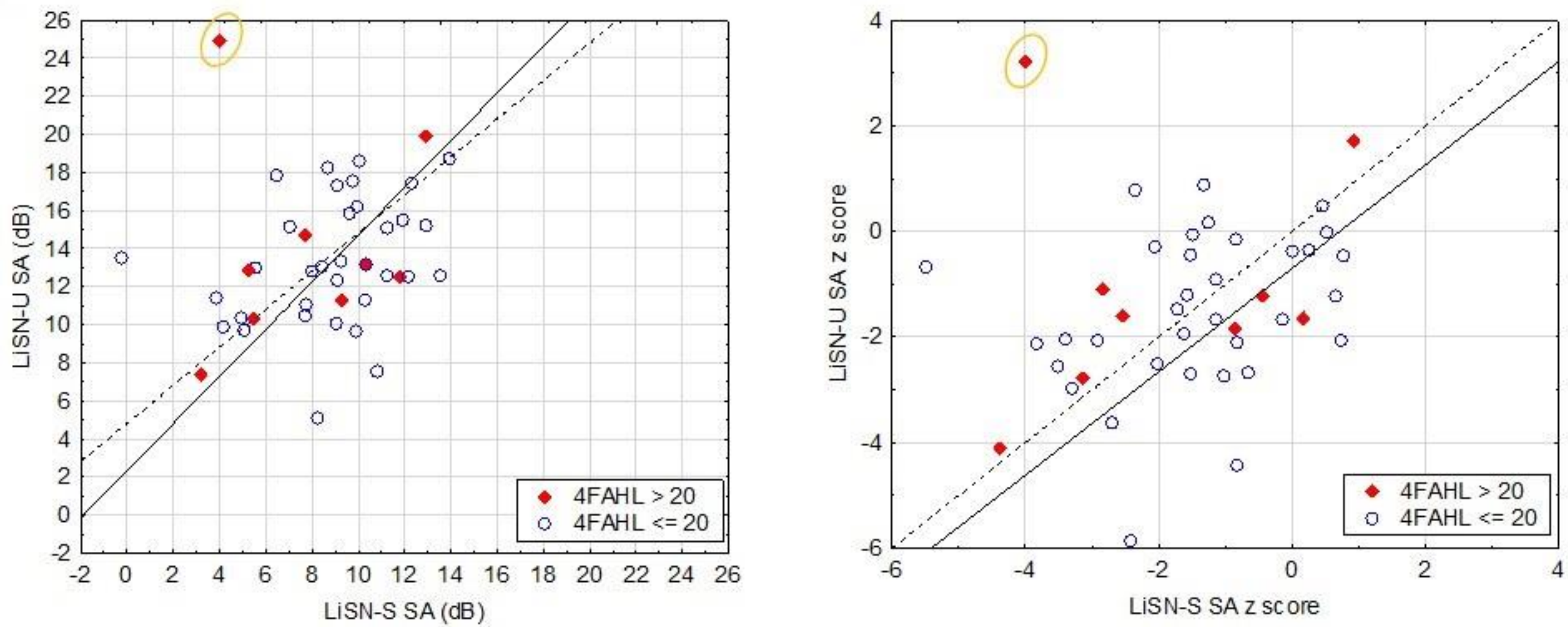

Figure 5: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S and LiSN-U spatial advantage scores (n = 42). The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels). Outlier is circled.

Table 4: Correlation results between LiSN-S and LiSN-U SRT and z scores excluding outlier. The *n* of 42 refers to the children who completed the full LiSN-S and LiSN-U. The *n* of 89 refers to the children who completed only the DV90 condition of the LiSN-S and the LiSN-U SV90 condition. SA=spatial advantage.

	Variables	*n*	*Equation*	*r*	r^2	*p*
dB SRT Comparison	LiSN-S DV90 vs. LiSN-U SV90	89	y = -2.959 + 0.715x	0.678	0.460	<0.0005
	LiSN-S SV90 vs. LiSN-U SV90	42	y = -4.606 + 0.559x	0.606	0.367	<0.0005
	LiSN-S SV0 vs. LiSN-U SV0	42	y = 3.533 + 0.694x	0.675	0.456	<0.0005
	LiSN-S SA vs. LiSN-U SA	42	y = 9.554 + 0.418x	0.384	0.148	0.012
z Score Comparison	LiSN-S DV90 vs. LiSN-U SV90	89	y = -0.811 + 0.420x	0.579	0.335	<0.0005
	LiSN-S SV90 vs. LiSN-U SV90	42	y = -1.339 + 0.347x	0.477	0.227	0.001
	LiSN-S SV0 vs. LiSN-U SV0	42	y = -0.761 + 0.619x	0.528	0.279	<0.0005
	LiSN-S SA vs. LiSN-U SA	42	y = -0.961 + 0.381x	0.384	0.147	0.012

Spatial Processing Disorder

The children's spatial advantage z scores on the LiSN-S and LiSN-U were compared to determine whether a child had SPD on one or both tests. A child was considered to have SPD if their spatial advantage was < -2 SD. The 43 children who completed the full LiSN-S and LiSN-U were included in this analysis. Consistent results were found for 72% of children as shown in Table 5.

Table 5: Number (and percentage) of children who i) passed both the LiSN-S and LiSN-U; ii) showed SPD on the LiSN-S but passed the LiSN-U; iii) passed the LiSN-S but showed SPD on the LiSN-U; and iv) showed SPD on both the LiSN-S and LiSN-U.

		LiSN-S	
		Non-SPD	SPD
LiSN-U	Non-SPD	**21 (49%)**	6 (14%)
	SPD	6 (14%)	**10 (23%)**

Discussion

The aim of this study was to examine the strength of the relationship between the LiSN-S and LiSN-U tests when applied to Aboriginal and Torres Strait Islander children. Strong correlations were found for the LiSN-S DV90 vs. LiSN-U SV90 and LiSN-S SV0 vs. LiSN-U SV0. A strong correlation was also found for the LiSN-S SV90 vs. LiSN-U SV90 SRTs but only a moderate correlation was found when correlating the z scores compared to the SRTs as when scores in dB are compared, age differences between the children contribute to inter-subject differences and hence the observed correlations, whereas age effects are removed when z scores are compared.

In addition to the strong correlations, the regression lines relating the SRTs of the two tests had a slope close to unity. This indicates that, on average, children's SRTs in noise are almost independent of whether the test is based on English sentences or nonsense syllables. This occurs despite the regression line for the co-located condition having a non-zero intercept. That is, when there are no spatial cues to assist segregation of the target from the competition, identifying nonsense syllables is harder than identifying sentences.

When the tests are compared on the basis of z scores (which removes the effect of age as the results are compared to norms from children of the same age) two further implications become clear. First, most of the data points cluster around the line of equality, indicating that for most of the children, both tests similarly rank the children relative to their age peers. Second, there are, however, some children who have much poorer performance relative to age peers on the LiSN-S test than they do on the LiSN-U test. This should not be surprising: the LiSN-S test unlike the LiSN-U, depends in part on proficiency in English. Any child with reduced English language proficiency will be less able than others to use context in the sentence to correctly perceive sounds masked by the competition. For some Aboriginal and Torres Strait Islander children, English is not their first language as they grow up learning the traditional language(s) of their community. The examiners administering the LiSN-S made sure that the children had sufficient English to be able to complete the testing by ensuring they could complete the practice items, however, it is still possible that the language barrier impacted on the children's results.

The correlation between the LiSN-S and LiSN-U spatial advantage measures was not as strong as for their respective DV90/SV90 and SV0 baseline measures. This should not be surprising, as the spatial advantage measures in dB are the difference between the SV0 and SV90 SRTs. This means that spatial advantage measures for both the LiSN-S and LiSN-U contain a greater degree of random measurement error than the two scores from which they were calculated. This greater error component weakens the correlation between the two spatial advantage measures. Reassuringly, however, the points when expressed as z scores mostly cluster around the line of equality (Figure 2(d), right panel). That is, the two tests give similar indications of the children's spatial processing ability relative to their age peers. This is consistent with Table 4, in which consistent SPD or non-SPD results were found for 72% of children. For the 28% of children, however, the tests give different verdicts, which is also not surprising. The diagnosis of SPD is given if the spatial advantage z score is poorer than, somewhat arbitrarily, -2. Even if exactly the same test were to be repeated, children with true scores around the cut-off chosen (whatever value is chosen) will sometimes have scores on opposite sides of the cut-off when the test is repeated. Any z scores within the range -1.5 to -2.5 should be regarded as being near the lower limit of the normal range.

An interesting finding of the study was the prevalence of children diagnosed with SPD on the LiSN-S. In the current study the prevalence of SPD was 16 out of 90 (18%). While a study to determine the prevalence of SPD in the general English-speaking population has not been conducted, it is unlikely to be more than 2% based on outlier results from the normative data for the LiSN-S test (Cameron & Dillon, 2007a). This higher prevalence in the current study may be because otitis media is significantly more common for Aboriginal and Torres Strait Islander children than for non-Indigenous Australian children (Closing the Gap Clearinghouse (AIHW & AIFS), 2014). Even though few children still showed otitis media or a conductive hearing loss, they may have experienced it as younger children which may have contributed to them developing SPD. Our rate of 18% is also higher than the 7% prevalence rate found in Aboriginal and Torres Strait Islander children in the regional school visited in Cameron, Dillon, Glyde, Kanthan, and Kania (2014), but is the same rate as found by Graydon et al. (2017) for children with a conductive hearing loss history.

Limitations

Unfortunately for this study we were unable to obtain information on the children's specific language backgrounds. We know that many of the children at the school had their first language as a traditional Aboriginal language, however, we did not know the specific details of when each child started learning English and we did not have a standardised measure to test their English proficiency. It would therefore be beneficial for future research to examine the link between children's LiSN-S and LiSN-U performance and their English proficiency.

Additionally, for this study we were unable to obtain information on the children's hearing case history. While it is well established that many Aboriginal and Torres Strait Islander children suffer from otitis media, we did not have specific individual information to examine a link between those who had otitis media in the past and their performance on the LiSN-S and LiSN-U.

Conclusions

The moderate-to-strong relationships and agreement between diagnoses found for the LiSN-S and LiSN-U show promise for the LiSN-U being used as a tool to investigate the spatial processing disorder in children. The advantage of the LiSN-U is that it is language-independent, so the listener does not need to be proficient in English to be able to complete the test. This test could therefore be a good option for assessing spatial processing in children from Aboriginal and Torres Strait Islander backgrounds who have a higher prevalence of otitis media which may result in spatial processing disorder.

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Professional meeting details. None to report.

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References

Boswell, J. B., & Nienhuys, T. G. (1996). Patterns of persistent otitis media in the first year of life in Aboriginal and non-Aboriginal infants. *Annals of Otology, Rhinology & Laryngology, 104*(7), 542–549.

Cameron, S., & Dillon, H. (2007a). Development of the Listening in Spatialized Noise-

Sentences Test (LISN-S). *Ear and Hearing*, *28*(2), 196–211. doi:10.1097/AUD.0b013e318031267f

Cameron, S., & Dillon, H. (2007b). The listening in spatialized noise-sentences test (LISN-S): Test-retest reliability study. *International Journal of Audiology*, *46*, 145–153. doi:10.1080/14992020601164170

Cameron, S., & Dillon, H. (2008). The Listening in Spatialized Noise–Sentences Test (LISN-S): Comparison to the prototype LISN and results from children with either a suspected (central) auditory processing disorder or a confirmed language disorder. *Journal of the American Academy of Audiology*, *19*(5), 377–391.

Cameron, S., & Dillon, H. (2009). Listening in Spatialized Noise – Sentences test (LiSN-S) (Version 2.4). Murten, Switzerland: Phonak Communications AG.

Cameron, S., & Dillon, H. (2011). Development and evaluation of the LiSN & Learn Auditory Training Software for deficit-specific remediation of binaural processing deficits in children: Preliminary findings. *Journal of the American Academy of Audiology*, *22*(10), 678–696. doi:10.3766/jaaa.22.10.6

Cameron, S., Dillon, H., Glyde, H., Kanthan, S., & Kania, A. (2014). Prevalence and remediation of spatial processing disorder (SPD) in Indigenous children in regional Australia. *International Journal of Audiology*, (November 2013), 326–335. doi:10.3109/14992027.2013.871388

Cameron, S., Dillon, H., & Newall, P. (2005). Three case studies of children with suspected auditory processing disorder. *Australian and New Zealand Journal of Audiology*, *27*(2), 97–112.

Cameron, S., Dillon, H., & Newall, P. (2006). The Listening in Spatialized Noise test: An auditory processing disorder study. *Journal of the American Academy of*

Audiology, *17*(5), 304–318.

Cameron, S., Glyde, H., & Dillon, H. (2012). Efficacy of the LiSN & Learn auditory training software: Randomized blinded controlled study. *Audiology Research*, *2*(e15), 86–93. doi:10.4081/audiores.2012.e15

Cameron, S., Mealings, K., Chong-White, N., Young, T., & Dillon, H. (n.d.). The Development of the Listening in Spatialized Noise – Universal Test (LiSN-U). *International Journal of Audiology*.

Clark, J. L., Roeser, R. J., & Mendrygal, M. (2007). Middle ear measures. In R. J. Roeser, M. Valente, & H. Hosford-Dunn (Eds.), *Audiology Diagnosis* (2nd ed., pp. 380–399). New York: Thieme.

Closing the Gap Clearinghouse (AIHW & AIFS). (2014). *Ear disease in Aboriginal and Torres Strait Islander children. Resource sheet no. 35.* Canberra: Australian Institute of Health and Welfare.

Glyde, H., Cameron, S., Dillon, H., Hickson, L., & Seeto, M. (2013). The effects of hearing impairment and ageing on spatial processing. *Ear and Hearing*, *34*(1), 15–28. doi:10.1097/AUD.0b013e3182617f94

Glyde, H., Hickson, L., Cameron, S., & Dillon, H. (2011). Problems hearing in noise in older adults. Spatial processing disorder? *Trends in Amplification*, *15*(3), 116–126.

Graydon, K., Rance, G., Dowell, R., & Van Dun, B. (2017). Consequences of early conductive hearing loss on long-term binaural processing. *Ear and Hearing*, *38*(5), 621–627. doi:10.1097/AUD.0000000000000431

Mealings, K., Harkus, S., Hwang, J., Fragoso, J., Chung, K., Harkus, S., & Dillon, H. (2020). Hearing loss and speech understanding in noise in Aboriginal and Torres Strait Islander children from locations varying in remoteness and socio-educational advantage. *International Journal Pediatric Otorhynolaryngology.*, *129*. doi:10.1016/j.ijporl.2019.109741

Mealings, K. T., Cameron, S., Chong-White, N., Young, T., & Dillon, H. (n.d.). Listening in Spatialized Noise – Universal Test (LiSN-U) Test-Retest Reliability Study. *International Journal of Audiology*.

Tomlin, D., & Rance, G. (2014). Long-term hearing deficits after childhood middle ear disease. *Ear & Hearing*, *35*, e233–e242. doi:10.1097/AUD.0000000000000065

Williams, C. J., & Jacobs, A. M. (2009). The impact of otitis media on cognitive and educational outcomes. *Medical Journal of Australia. Supplement: Otitis Media 2009: An Update*, *191*(9), 69–72.

Tables

Table 1: Number of participants who completed each test.

Test	Number of Participants
Audiometry	90
LiSN-S DV90	90
LiSN-S Full	43
LiSN-U SV90	90
LiSN-U Full	88
LiSN-S and LiSN-U Full	43

Table 2: Participants' otoscopy results for their left and right ears.

		Right Ear		
		Clear	Wax	Perforation
Left Ear	Clear	81 (90%)	0 (0%)	0 (0%)
	Wax	4 (4%)	4 (4%)	0 (0%)
	Perforation	1 (1%)	0 (0%)	0 (0%)

Table 3: Participants' tympanometry results for their left and right ears.

		Right Ear		
		Type A	Type B	Type C
Left Ear	Type A	63 (70%)	4 (4%)	3 (3%)
	Type B	6 (7%)	6 (7%)	2 (2%)
	Type C	3 (3%)	0 (0%)	3 (3%)

Table 4: Correlation results between LiSN-S and LiSN-U SRT and z scores excluding outlier. The n of 42 refers to the children who completed the full LiSN-S and LiSN-U. The n of 89 refers to the children who completed only the DV90 condition of the LiSN-S and the LiSN-U SV90 condition. SA = spatial advantage.

	Variables	*n*	*Equation*	*r*	r^2	*p*
dB SRT Comparison	LiSN-S DV90 vs. LiSN-U SV90	89	y = -2.959 + 0.715x	0.678	0.460	<0.0005
	LiSN-S SV90 vs. LiSN-U SV90	42	y = -4.606 + 0.559x	0.606	0.367	<0.0005
	LiSN-S SV0 vs. LiSN-U SV0	42	y = 3.533 + 0.694x	0.675	0.456	<0.0005
	LiSN-S SA vs. LiSN-U SA	42	y = 9.554 + 0.418x	0.384	0.148	0.012
z Score Comparison	LiSN-S DV90 vs. LiSN-U SV90	89	y = -0.811 + 0.420x	0.579	0.335	<0.0005
	LiSN-S SV90 vs. LiSN-U SV90	42	y = -1.339 + 0.347x	0.477	0.227	0.001
	LiSN-S SV0 vs. LiSN-U SV0	42	y = -0.761 + 0.619x	0.528	0.279	<0.0005
	LiSN-S SA vs. LiSN-U SA	42	y = -0.961 + 0.381x	0.384	0.147	0.012

Table 5: Number (and percentage) of children who i) passed both the LiSN-S and LiSN-U; ii) showed SPD on the LiSN-S but passed the LiSN-U; iii) passed the LiSN-S but showed SPD on the LiSN-U; and iv) showed SPD on both the LiSN-S and LiSN-U.

		LiSN-S	
		Non-SPD	SPD
LiSN-U	Non-SPD	**21 (49%)**	6 (14%)
	SPD	6 (14%)	**10 (23%)**

Figures Captions

Figure 1: Four frequency average hearing thresholds for participant's left and right ears where the 4FA in a least one ear is greater than 20 dB HL. Blue circles = conductive hearing loss, red square = sensorineural hearing loss, orange triangle = unclassified hearing loss.

Figure 2: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S DV90 and LiSN-U SV90 condition (n = 89). The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels). Outlier is circled.

Figure 3: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S and LiSN-U SV90 conditions (n = 42). The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels). Outlier is circled.

Figure 4: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S and LiSN-U SV0 conditions (n = 42). The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels).

Figure 5: Correlation results between the LiSN-S and LiSN-U SRTs (left panel) and z scores (right panel) for LiSN-S and LiSN-U spatial advantage scores (n = 42). The solid line represents the orthogonal regression line. The dotted line is a line of unity slope, fitted to the data in the case of dB scores (left panels) and with zero intercept in the case of z scores (right panels). Outlier is circled.