

# **Consequences of Early Conductive Hearing Loss on Long-term Binaural Processing**

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## **ABSTRACT**

**Objectives:** The aim of the study was to investigate the long-term effects of early conductive hearing loss on binaural processing in school-age children.

**Design:** One hundred and eighteen children participated in the study, 82 children with a documented history of conductive hearing loss associated with otitis media and 36 controls who had documented histories showing no evidence of otitis media or conductive hearing loss. All children were demonstrated to have normal hearing acuity and middle ear function at the time of assessment. The Listening in Spatialized Noise (LiSN-S) task and the Masking Level Difference (MLD) task were used as the two different measures of binaural interaction ability.

**Results:** Children with a history of conductive hearing loss performed significantly poorer than controls on all LiSN-S conditions relying on binaural cues (DV90  $p < 0.001$  and SV90  $p = 0.003$ ). No significant difference was found between the groups in listening conditions without binaural cues. Fifteen children with a conductive hearing loss history (18%) showed results consistent with a spatial processing disorder (SPD). No significant difference was observed between the conductive hearing loss group and the controls on the MLD task. Furthermore, no correlations were found between LiSN-S and MLD.

**Conclusions:** Results show a relationship between early conductive hearing loss and listening deficits that persist once hearing has returned to normal. Results also suggest the two binaural interaction tasks (LiSN-S and MLD) may be measuring binaural processing at different levels. Findings highlight the need for a screening measure of functional listening ability in children with a history of early otitis media.

## **INTRODUCTION**

Temporary disruptions to auditory cues during early childhood may significantly affect longer term listening ability (Sininger et al. 1999). Interruptions to such cues during key developmental periods are thought to account for longer term deficits (Whitton & Polley 2011). An association between early otitis media and impaired performance on binaural listening tasks has been established (Moore et al. 1991; Pillsbury et al. 1991; Tomlin & Rance 2014). However, what is yet to be determined is whether in the presence of a proven history of conductive hearing loss associated with otitis media, binaural interaction and functional listening ability is impaired. A retrospective study investigating binaural interaction and functional listening ability in children with a documented history of otitis media and conductive hearing loss may assist.

Otitis media is common in childhood, being most prevalent in the first two years of life (Kaplan et al. 1973; Hogan et al. 1997; Paradise et al. 1997). Otitis media with an associated conductive hearing loss has the potential to alter acoustical properties of the middle ear, attenuating sound reaching the cochlea (Fria et al. 1985). The presence of otitis media can affect sound detection throughout childhood (Clarkson et al. 1989; Rovers et al. 2005). The degree of hearing

attenuation associated with active otitis media ranges from 0 to 40-50 dB (Bluestone et al. 1973; Gravel & Wallace 2000). Otitis media presents both unilaterally and bilaterally and varies in duration, with an average episode usually lasting from five to eight weeks (Hogan et al. 1997). The fluctuating and in some cases long-standing nature of the hearing loss means children receive highly variable and mismatched signals, particularly in the first few years of life when the auditory system is learning to utilise and process complex acoustic cues (Kaplan et al. 1973; Sininger et al. 1999).

Interaural timing and intensity difference (ITD and IID) cues are integral for accurate localisation and spatial listening (Culling et al. 2004). These complex cues are utilised according to the listener's past experience and are initially compared at the level of the auditory brainstem (Bushara et al. 1999; Maeder et al. 2001). ITD cues are robust at low frequencies whereas IIDs arise predominantly from high frequency components (Henning 1974; Litovsky 2015). When precisely transmitted and combined, binaural cues can enable the listener to recognise distinct sound sources, assisting with selective attention towards the source of interest. This separation or 'streaming' of acoustic signals occurs when speech and noise are perceived to arise from different locations, that is, when sounds are spatially separated (Bronkhorst & Plomp 1988; Freyman et al. 1999; Ching et al. 2011). Rance et al. (2012) highlighted the importance of timing cues in particular for speech perception in noise, showing participants with temporal processing deficit to have reduced ability to isolate the target even when spatially separated from noise.

Otitis media with conductive hearing loss can affect the transmission of both interaural timing and intensity cues, with advantages normally obtained from binaural interaction

compromised or lost (Noble et al. 1994; Hall, Grose, & Mendoza 1995; Hartley & Moore 2003; Hirsh 2005). The fluid modifies the air conduction pathway, producing phase shifts ranging from 80 to 500 microseconds depending on the frequency (Hogan et al. 1995; Hartley & Moore 2003). Another explanation for temporal disruptions relates to mode of transmission. For greater degrees of conductive hearing loss ( $\geq 40$  dB HL), the acoustic signal which normally travels by air conduction, may also be transmitted by bone conduction (Zurek 1986). The combination and duplication of interaural timing and intensity cues reaching the cochlea through two different pathways is sufficient to disrupt the utilisation of interaural differences. Regardless of the mode of disruption, the transient and variable nature of hearing fluctuations due to otitis media (Paradise 1981) means interaural cues arrive at the brain in an inconsistent manner.

Fluctuating and asymmetrical signals have been shown to modify the development of auditory pathways responsible for binaural processing in animal models (Feng & Rogowski 1980; Gray et al. 1982; Tucci et al. 2002). Neural changes were only apparent if the hearing loss was present during particular developmental periods, indicating in at least these animal models critical periods are essential for correct pathway development (Webster 1983; Knudsen et al. 1984). Similar structural modifications may also occur in humans (Gunnarson & Finitzo 1991; Gordon et al. 2010) but anatomical proof of changes is difficult to obtain. In humans, evidence does however exist in the form of long-term listening deficits, in children who have received abnormal early auditory input (Moore et al. 1991; Pillsbury et al. 1991). More specifically, studies have found that listening deficits persist as a result of early conductive hearing loss even once hearing is restored (Pillsbury et al. 1991; Gravel & Wallace 1992; Hall, Grose, & Pillsbury 1995; Moore et al. 2003; Tomlin & Rance 2014). Most have relied on the Masking Level Difference (MLD) task as a

measure of binaural processing (i.e. the advantage achieved when utilising interaural timing cues for detecting a tone in noise). Children with a reported history of otitis media have shown consistently depressed MLD scores even once hearing returns to normal.

The implications of a history of otitis media on longer term functional listening has also been investigated. Tomlin and Rance (2014) looked at whether a reported history had any effect on speech perception in background noise. They established that a history of otitis media resulted in poorer spatial listening years after sound detection returned to normal. The past history of otitis media was, however, determined only by parental account. Evidence in the form of audiological histories detailing hearing and middle ear status throughout early childhood would ensure evidence of a history of otitis media and conductive hearing loss.

This study aims to investigate binaural processing ability in school-age children with a documented history of early conductive hearing loss associated with otitis media. The hypothesis is that binaural processing ability will be negatively impacted by a history of conductive hearing loss associated with otitis media.

## **METHODS**

### **Ethics**

This study carries approval from the Ethics Committee of the Royal Victorian Eye and Ear Hospital (13/1117H). All testing conformed to the tenets of the Declaration of Helsinki (2013) and informed consent was obtained from all participants after explanation of the nature, purpose and expected outcomes of the study.

## Participants

One hundred and eighteen children aged 6.0 to 13.3 years participated in the study; 82 children with documented history of conductive hearing loss (mean age  $8.9 \pm 1.9$  years; 32 girls) and 36 controls (mean age  $8.6 \pm 2.1$  years; 16 girls). Children were recruited from two audiology clinics (The University of Melbourne and Taralye) based on their clinical histories. To be eligible, children had at least two audiology appointments in their first four years of life (for the conductive hearing loss group the mean number of appointments was  $7.1 \pm 2.9$  and for the control group the mean number of appointments was  $3.6 \pm 1.9$ ).

Middle ear and hearing history for both groups was obtained retrospectively from clinical records. Criteria for inclusion in the conductive group was at least one documented episode of otitis media. An episode was defined by the presence of either unilateral or bilateral hearing loss (4 FAHL, calculated as the average of 500 Hz, 1 kHz, 2 kHz and 4 kHz air conduction threshold greater than 20 dB HL) combined with the presence of a flat low volume tympanogram (type B) in either ear, observed using a 226 Hz probe tone (Jerger 1970). The number of documented episodes in the conductive hearing loss group ranged from one to nine (mean  $3.7 \pm 2.1$  episodes). A final inclusion criterion was demonstration of normal hearing thresholds (4 FAHL  $\leq 20$  dB HL) with resolution of the otitis media as evidenced by tympanometry. Conversely, children in the control group had documented histories showing no evidence of otitis media (type A tympanograms) or conductive hearing loss.

No children had documented speech and language delay or cognitive impairment at the time of assessment. Socioeconomic status was established for both groups using the Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD). No significant difference in this score ( $t=0.66$ ,  $df=68$ ;  $p=0.51$ ) was found between the control and the conductive hearing loss group using a two-sample t-test.

## **Materials**

**Binaural interaction** • Binaural interaction was assessed using two listening tasks; the masking level difference (MLD) test (Wilson et al. 2003) and the Listening in Spatialised Noise Sentence (LiSN-S) test (Cameron & Dillon 2007).

In the MLD task, the listener was required to identify a signal (a train of five 500 Hz tone bursts with 25 msec rise-fall times) in the presence of narrow band noise (a 3 second segment of broadband noise digitally generated around 500 Hz with a 25 msec rise-fall time) in two listening conditions (antiphasic and phasic). In the antiphasic condition the signal was presented 180 degrees out-of-phase between the ears (equivalent to a two millisecond delay). In this condition, the listener was able to take advantage of the release from masking achieved from subtle timing differences between the ears. In the phasic condition the signal is in-phase at the ears and interaural timing cues are not available. Interspersed throughout the test is a third condition, with no tones, to ensure understanding of the task (if the participant responded ‘yes’ more than once to this condition, they were instructed and the testing started again). In each condition, a single-interval ‘yes-no’ response task was used. When the participant detected the tones in the noise burst they would respond ‘yes’, and when no tones were detected they would respond ‘no’. The test was

composed of 10 phasic, 12 antiphasic and 11 bursts of no tone. The protocol progresses from the most favourable signal-to-noise ratios to the least favourable in the three conditions (Wilson et al. 2003). The signal level was reduced in each test condition (i.e. in-phase and out-of-phase) until no longer detectable by the listener in the noise (kept constant at 50 dB HL). The threshold signal-to-noise ratio (S:N in dB) required to detect the 500 Hz tones in the masking noise was established in the two conditions. The MLD score represents the advantage in dB achieved when the signal at the two ears is out-of-phase compared to when it is in-phase. For a more detailed explanation of the procedure and stimuli used, see the methods outlined by Wilson et al. (2003).

The LiSN-S task required the listener to repeat target sentences in the presence of competing background speech. The test simulates spatial listening under headphones by processing target sentences and background speech with standardised head related transfer functions (Cameron & Dillon 2007). Target sentences are presented at 0° azimuth. Four different listening conditions are created that vary the location (0° versus ±90° azimuth) and characteristics of the competing background speech (same voice (SV) or different voice (DV)). These four conditions are termed SV0, SV90, DV0, and DV90 (Figure 1). Target sentences are initially presented at 62 dB SPL and the competing speech at a constant level of 55 dB SPL. The signal-to-noise ratio is adjusted in each condition to establish a speech reception threshold (SRT). The SRT is defined as the level at which the listener can understand and repeat 50% of the words in the target sentences. Advantage scores are then generated using the SRTs from each of the four listening conditions. Specifically, the spatial advantage score represents the SRT improvement (in dB) when the target sentence is separated by 90° from the competing speech (i.e. when same voices are used for both target and background speech (SV90 – SV0)). The spatial advantage measure

not only establishes the advantage achieved when spatial cues are utilised, it also ensures the effect of language, attention and memory are factored in, with the child their own control (Cameron et al. 2012). The inability to effectively utilise spatial cues (i.e. subtle timing and intensity differences between the ears) is defined as a spatial processing disorder (SPD) (Cameron & Dillon 2008). Specifically, SPD is characterised by significantly depressed scores (i.e.,  $\leq -2.0$  standard deviations from age normalised data) on the spatially separated measures when compared to the co-located measures (Cameron et al. 2012).

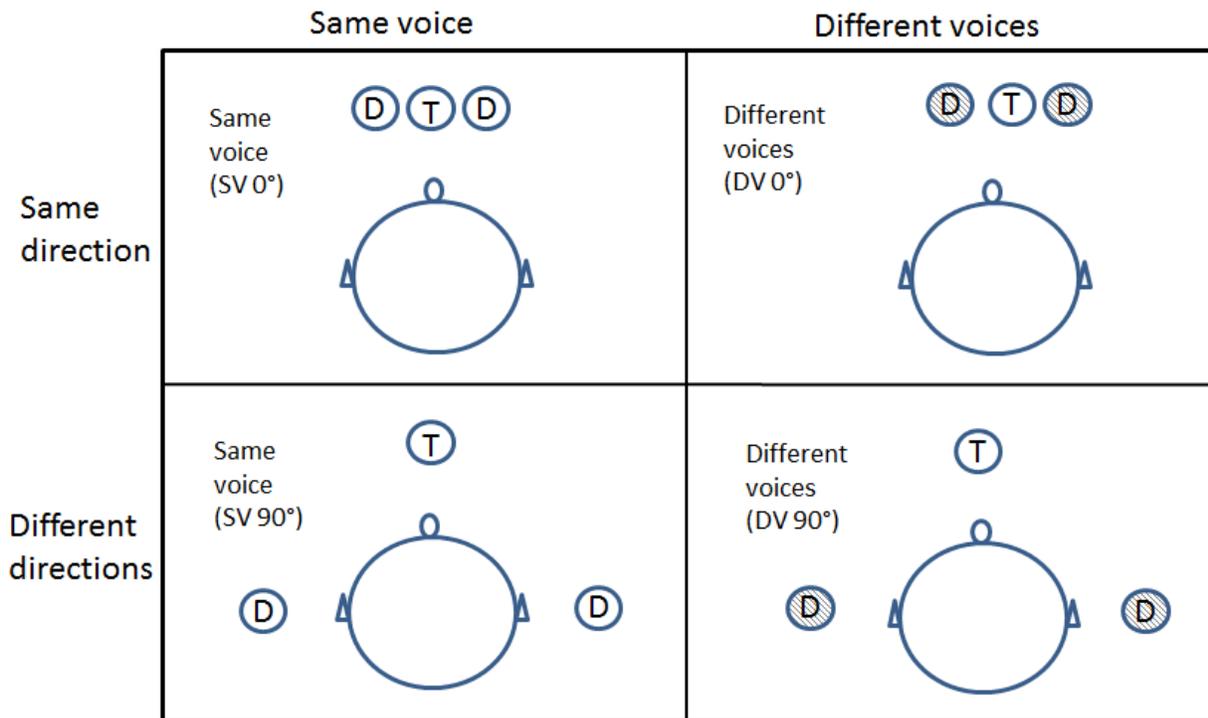


Figure 1. Illustration of the four LiSN-S conditions with the target (T) always from the front and the distracter stories (D) either from the front or the sides. In the different voice conditions, the D differs in voice quality.

## **Design and procedure**

All participants were assessed in quiet conditions either at an audiology clinic or in the participant's home using TDH 39 headphones with either the Affinity 2.0 AC 440 module (Interacoustics) or the A177 Plus portable two channel audiometer (Amplaid). Hearing was assessed using standard audiometric procedures, and normal hearing acuity was established prior to proceeding (defined as hearing thresholds of 20 dB HL or better from 500 Hz to 8000 Hz). All participants were also shown to have normal middle ear function at the time of assessment (Jerger type A tympanograms (Jerger 1970)), defined as a peak compliance within 0.2-1.6 mmhos, and peak pressure within -100 to +20 dPa.

No significant differences were observed between the 4 FAHL in the left and right ears in either the conductive hearing loss history group or the control group (paired t-tests showed p values of 0.86 ( $t=0.18$ ,  $df=81$ ) and 0.78 ( $t=-0.29$ ,  $df=35$ ) respectively). Two sample t-tests also showed no difference between the 4 FAHL in the control group compared to the conductive hearing loss history group (left  $t= -1.34$ ,  $df=84$ ;  $p=0.18$  and right,  $t= -1.31$ ,  $df=79$ ;  $p=0.19$ ).

Both binaural interaction tasks were presented through Sennheiser HD 215 headphones connected to a Dell laptop computer and took approximately 30 minutes to complete. The LiSN-S task was conducted according to the recommended test order DV90, SV90, DV0 and SV0 (Cameron & Dillon 2008). MLD testing was then undertaken in a smaller cohort of children (55 conductive history participants and 20 controls).

## **Expression of results**

To account for age differences and enable comparisons within and between groups, z-scores for both the LiSN-S and MLD tasks were generated. The z-score is a score relative to the mean and is expressed in standard deviation units normalised for age ( $z\text{-score} = [(\text{mean score} - \text{actual score})/\text{standard deviation}]$ ). A z-score of zero represents a score equal to the age-corrected mean, the more negative a z-score, the poorer the performance in that listening condition (i.e. a score of minus one is equal to performance one standard deviation from the mean). For the LiSN-S, z-scores for each of the four conditions as well as the spatial advantage measure were generated according to age specific normative data (Cameron & Dillon 2011). Results for the DV90, SV0 and the spatial advantage measures are generated automatically by the software as described by Cameron and Dillon (2008). Z-scores for the DV0 and SV90 conditions were generated based on normative data from Cameron and Dillon (2011). For the MLD, z-scores were derived using normative data from Tomlin et al. (2015). Normative data was not available for children under seven years. Z-scores for six year olds were therefore extrapolated from Tomlin et al. (2015). All six year olds deemed to understand the task had z-scores within two standard deviations of the age corrected mean.

## **RESULTS**

### **Masking Level Difference**

The MLD results for the controls and the conductive hearing loss history group are displayed in Figure 2. Mean scores were determined for the controls; MLD ( $10.90 \pm 2.94$ ), NoSo ( $-11.50 \pm 2.89$ ), NoS $\pi$  ( $-22.40 \pm 3.70$ ) and for the conductive hearing loss history group; MLD ( $11.89 \pm 3.99$ ), NoSo ( $-11.78 \pm 3.02$ ), NoS $\pi$  ( $-23.67 \pm 3.69$ ). Two sample t-tests revealed no

significant differences between the two groups for the MLD score ( $t=1.17$ ,  $df=45$ ,  $p=0.25$ ), NoSo ( $t=0.37$ ,  $df=35$ ,  $p=0.71$ ) or NoS $\pi$  ( $t=1.32$ ,  $df=33$ ,  $p=0.20$ ). MLD z-scores also showed no significant difference between the groups ( $t=0.79$ ,  $df=49$ ,  $p=0.43$ ).

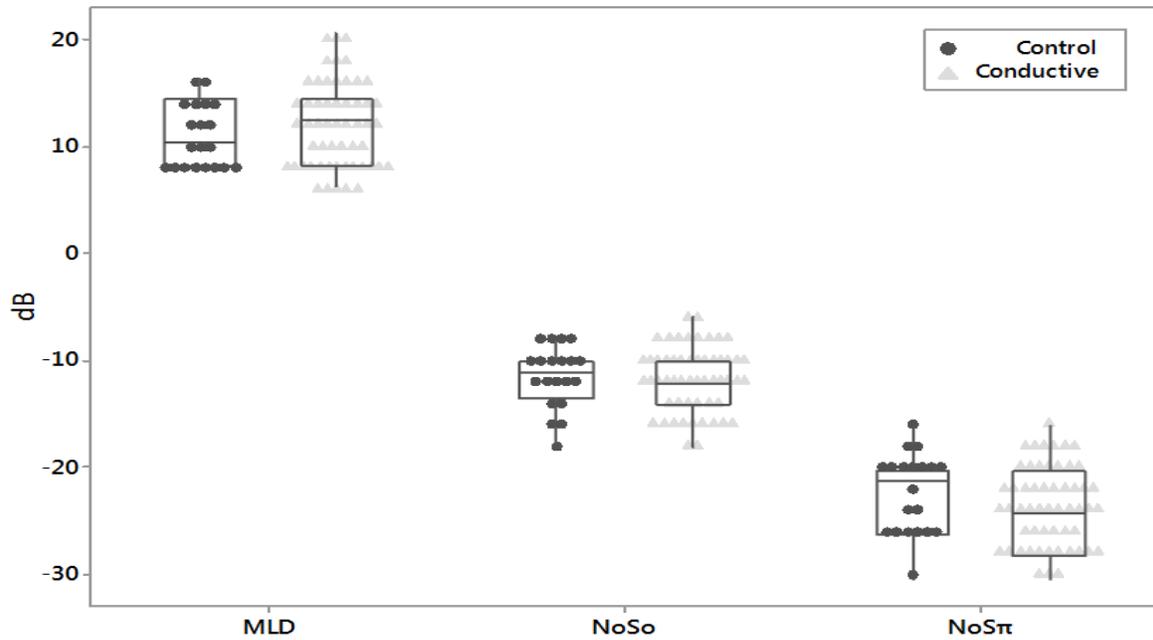


Figure 2. Box and whisker plots showing the median, interquartile, and range of dB scores for the masking level difference (MLD) as well as the distributions for both the control and conductive hearing loss group.

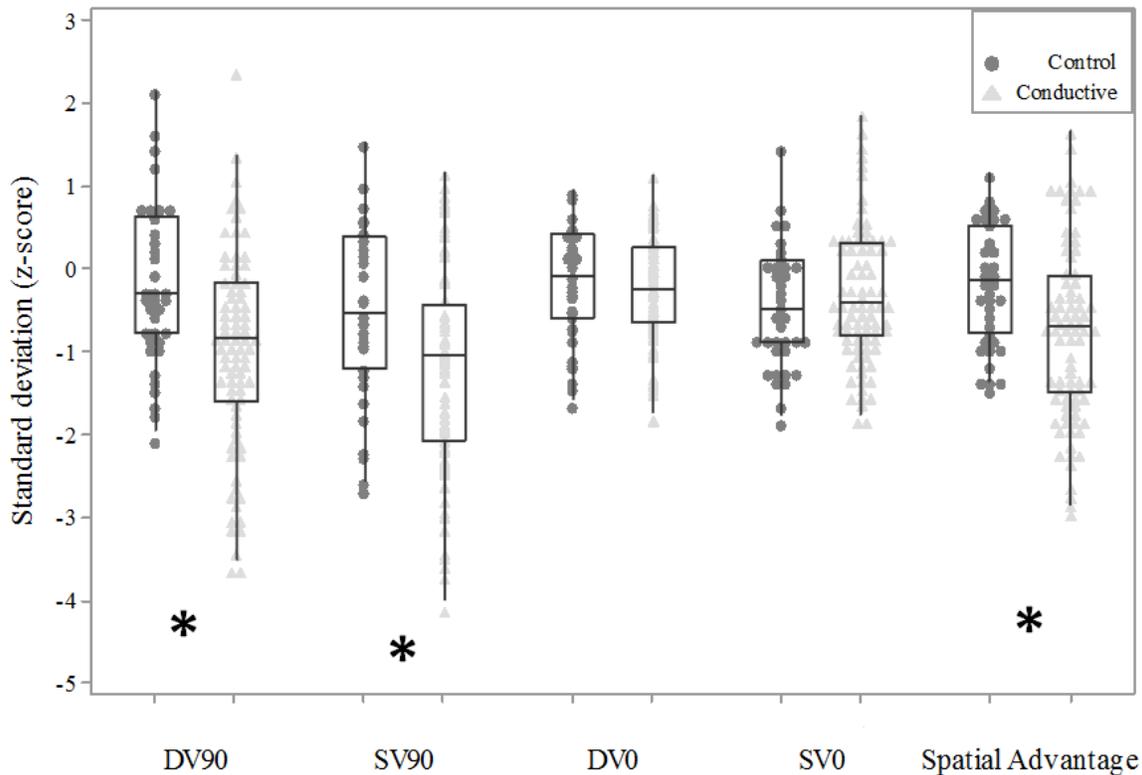
## LiSN-S

The LiSN-S mean speech reception thresholds for both the controls and conductive hearing loss history group are summarised in Figure 3.

<u>Same Voice 0° (dB)</u>		<u>Different Voices 0° (dB)</u>	
<b>Controls</b>	<b>Conductive</b>	<b>Controls</b>	<b>Conductive</b>
0.01 (1.21) -3.20 to 2.30	-0.23 (1.27) -3.60 to 2.40	-3.48 (2.12) -8.50 to 0.20	-3.57 (1.98) -8.20 to 1.00
<u>Same Voice ±90° (dB)</u>		<u>Different Voices ±90° (dB)</u>	
<b>Controls</b>	<b>Conductive</b>	<b>Controls</b>	<b>Conductive</b>
-11.03 (2.10) -14.50 to -7.60	-10.20 (2.79) -16.10 to -3.90	-13.50 (2.3) -18.3 to -9.10	-12.23 (2.34) -17.6 to -6.70

**Figure 3.** Summary of mean speech reception thresholds (standard deviations) and ranges in dB on LiSN-S measures including the spatial advantage measure.

To compare the two groups, results were analysed using z-scores (based on published normative data) which were calculated for the four listening conditions (DV90, SV90, DV0 and SV0) as well as the spatial advantage measure. Mean z-scores were determined for the controls; DV90 (-0.25±0.99), SV90 (-0.60±1.04), DV0 (-0.24±0.67), SV0 (-0.52±0.74), spatial advantage (-0.26±0.73) and for the conductive hearing loss history group; DV90 (-1.06±1.20), SV90 (-1.27±1.24), DV0 (-0.33±0.64), SV0 (-0.39±0.81), spatial advantage (-0.84±1.08). To investigate the effect of conductive hearing loss history on LiSN-S results, each condition as well as the spatial advantage measure was compared to the control group z-scores (Figure 4).



**Figure 4.** LiSN-S z-scores (median, interquartile and range of z-scores) as well as distributions for each of the four listening conditions and spatial advantage measure. Significant results are represented by \*.

In order to enable multiple comparisons between the control group and the conductive hearing loss group, a Bonferroni correction was applied. For both the DV90 and the SV90 conditions, two-sample t-tests revealed a significant difference between the conductive hearing loss history group and controls ( $t = -3.79$ ,  $df=80$ ;  $p < 0.001$  and  $t = 3.02$ ,  $df=79$ ;  $p = 0.003$  respectively). That is, children in the conductive hearing loss history group had significantly poorer speech reception thresholds than controls in conditions containing spatial cues. No significant differences between the groups were found in the DV0 ( $t = -0.69$ ,  $df=64$ ;  $p = 0.495$ ) and SV0 ( $t = 0.86$ ,  $df=73$ ;  $p = 0.395$ ) conditions, i.e., the two conditions without spatial cues. The spatial advantage measure was also significantly different between the groups ( $t = -3.38$ ,  $df=95$ ,  $p = 0.001$ ). On

average, the spatial processing advantage measure was reduced by 0.84 z-score units if there was a conductive hearing loss history.

### **Spatial Processing Disorder (SPD)**

The presence of SPD was defined using the following formula (National Acoustic Laboratories 2016). Children with a pattern measure  $\leq -2.0$ , a score equivalent to two or more standard deviations from the age corrected mean, were defined as having SPD.

$$\text{SPD pattern} = ((\text{SV0} - \text{SV90}) + (\text{DV0} - \text{DV90})) / 2.$$

The SPD pattern score is then converted into a z-score using the following equation when comparing to age normalised data (Cameron & Dillon 2008).

$$\text{SPD pattern (z-score)} = (\text{SPD pattern} - 10.65) / 1.56).$$

The SPD pattern score was also recalculated based on control findings in the current study using the following equation.

$$\text{SPD pattern (z-score)} = (\text{SPD pattern} - 10.51) / 1.22).$$

SPD was identified in 15 of the 82 children in the conductive hearing loss history group (18%) when compared to normalization data and 20 of the 82 children in the conductive hearing loss history group (24%) when compared to control data. There were no children in the control group identified with a SPD as defined by the pattern measure.

### **MLD and LiSN-S**

No significant correlations were observed between any LiSN-S measure (z-score) and MLD z-score in either the conductive hearing loss history children SV0 ( $r(53)=0.153$ ,  $p=0.265$ ), SV90 ( $r(53)= 0.059$ ,  $p=0.670$ ), DV0 ( $r(53)= -0.016$ ,  $p=0.905$ ), DV90 ( $r(53)= 0.046$ ,  $p=0.740$ ),

spatial advantage ( $r(53) = -0.037, p = 0.787$ ) or the control group SV0 ( $r(18) = 0.259, p = 0.271$ ), SV90 ( $r(18) = 0.259, p = 0.271$ ), DV0 ( $r(18) = 0.263, p = 0.263$ ), DV90 ( $r(18) = 0.293, p = 0.210$ ), spatial advantage ( $r(18) = 0.226, p = 0.338$ ).

## **DISCUSSION**

The aim was to investigate binaural processing in school-age children with a documented history of conductive hearing loss associated with otitis media. Children with a known history of conductive hearing loss with otitis media showed poorer binaural processing ability than children without a known history on the spatial processing tasks of the LiSN-S, but not on the MLD. Children with a history of conductive hearing loss with otitis media showed poorer spatial processing ability (or spatial release from masking) than children without such a history.

### **Masking Level Difference**

The MLD scores did not differ significantly between controls and children with a conductive hearing loss history, with both groups having mean scores within the normal range  $11.21 \pm 1.67$  (Aithal et al. 2006). Results are, however, in contrast to other studies that have utilised the MLD as a measure of binaural interaction, with findings showing consistently reduced MLDs in children with a conductive hearing loss history even once hearing has returned to normal (Pillsbury et al. 1991; Hall et al. 1995; Moore et al. 2003). In the current study, the mean MLD score for the conductive hearing loss group was 11.89, a score slightly better than reported in previous studies for children with a conductive hearing loss history (Moore et al. 1991; Pillsbury et al. 1991; Hall, Grose, & Pillsbury 1995). While it is unclear why results in the current study differ from previous studies, one possible explanation relates to the time since the last episode.

The current study measured MLD in the majority of cases many years after the last episode of otitis media, whereas the longest time after the last known episode of OME in Hall, Grose, & Pillsbury (1995)'s study, for example, was only two years. Given the MLD has been shown to improve over time following restoration of hearing (Hogan et al. 1996), it is feasible the lack of difference between controls and children with a conductive hearing loss history in the current study may be explained by a recovery in MLD since the last known otitis media insult.

### **LiSN-S**

Children with conductive hearing loss history performed significantly poorer than controls in all LiSN-S conditions utilising spatial cues. In conditions without spatial cues, there were no differences between groups suggesting a binaural processing problem as opposed to an effect of language, attention or memory (concluded by the lack of difference in the conditions without binaural cues). Specifically, children in the conductive hearing loss group required a higher signal-to-noise ratio than controls in listening conditions utilising spatial cues. Furthermore, 18% were identified as having a spatial processing disorder, that is, their ability to utilise spatial cues was significantly outside the normal range. This figure is slightly lower than the 24% identified with SPD when compared to control data (as a result of differing standard deviations). Although the current study may have therefore underestimated the prevalence of SPD by using the normative data comparison, a conservative estimate was preferred. It has been suggested that better-ear glimpsing is one of the binaural mechanisms which spatial release from masking relies on: the ear with the better signal-to-noise ratio is used to extract the signal of interest (Glyde, Buchholz et al. 2013). Hence, when the brain has not learned to fully exploit better-ear glimpsing due to a history of otitis media, a binaural processing problem emerges. Overall, findings support an association

between conductive hearing loss history with otitis media and binaural processing difficulties later in life (Pillsbury et al. 1991; Moore et al. 2003; Cameron et al. 2014; Tomlin & Rance, 2014). The inclusion of only children with documented history, as defined by audiological records, has made conclusions from the current study unique, in particular conclusions regarding SPD prevalence, given previous retrospective studies relied on parental report rather than audiological evidence.

Long-term deficits are likely due to disruptions to normal cues in the presence of a conductive hearing loss, affecting development of neural pathways responsible for spatial processing (Feng & Rogowski 1980; Gray et al. 1982; Whitton & Polley 2011; Cameron et al. 2014; Liberman et al. 2015). Critical periods that have been established in animal models are yet to be identified in humans. Tomlin and Rance (2014) alluded to the presence of critical periods after finding spatial processing at school age was poorer when onset of otitis media was earlier, concluding the age effect was likely accounted for by critical periods of development. Without prospective testing, age of onset and critical periods are difficult to establish. At the very least, the current study would support the notion that the first four years of life are critical for the development of processing and utilising spatial cues (Sininger et al. 1999; Litovsky 2015).

All children in the current study had at least one documented episode of otitis media with a unilateral or bilateral conductive hearing loss (defined as 4FA >20 dB). While it is probable that the children had other episodes not recorded, all had at least one episode of conductive hearing loss and as a consequence, a time in their first four years of life where spatial listening was compromised. The proposed mechanism relates to disruptions to interaural cues in the presence of a conductive hearing loss, with fluid producing phase shifts affecting, in particular, ‘typical’

interaural timing delays reaching the brainstem (Thornton et al. 2012). The average degree of conductive hearing loss in the current study was only of mild degree, and so, temporal disruptions were more likely a result of mechanical changes to the middle ear rather than sound being predominantly propagated by bone conduction (Békésy 1948). A factor likely to have a more pronounced effect on interaural cue disruption is asymmetrical hearing. Differences of only 2 dB, a level not considered clinically relevant, can disturb normal interaural timing and intensity relations (Häusler et al. 1983; Moore 1991; Glyde et al. 2013). While the current study could not assess asymmetries accurately given some results were binaural only, all children in the current study had otitis media in the first four years of life that appears to have affected longer term processing ability.

### **Binaural processing (MLD and LiSN-S)**

MLD and LiSN-S are both measures of binaural interaction yet recent discussion has focussed on whether MLD is representative of functional listening (Cameron & Dillon 2008). To date, direct comparisons between the measures in a group of children with conductive hearing loss history have not been made. The current study showed no correlation between MLD and LiSN-S. This finding is in line with a study conducted by Cameron and Dillon (2008), for a group of children with suspected auditory processing disorder. The authors hypothesised the lack of association between the measures may be related to the level of processing required, suggesting the MLD is limited to lower level processing at the brainstem rather than higher level processing and streaming in the cortex (Besing et al. 1998; Jerger & Musiek 2000; Cameron & Dillon 2008). Given the differing degrees of complexity, with the LiSN-S detection of a sentence rather than a tone, it is possible the MLD is measuring binaural interaction at a more rudimentary level along

the auditory pathway, a notion supported by elevated MLDs in cases of brainstem dysfunction (Bellis, 2003). With the differing findings between the two tasks in the current study, it is plausible that early conductive hearing loss has a stronger impact on higher levels in the auditory system, for example, the auditory cortex (Alain 2007; Cameron & Dillon 2008).

### **LIMITATIONS AND FUTURE DIRECTIONS**

Investigation of children with later onset of otitis media as well as children with otitis media without hearing loss may provide additional evidence on developmental periods and the type of auditory cue disruption that is detrimental. Also, prospective testing would enable detailed measures of degree, configuration and duration of hearing impairment to enable specific guides for management and intervention. While the current study confirmed that a history of otitis media with conductive hearing loss leads to disrupted longer term functional listening ability, it is unclear whether this has implications in the classroom. Children in the current study diagnosed with a spatial processing disorder on average required a 4 dB higher signal-to-noise ratio in a listening condition replicating the classroom environment. This is predicted to significantly affect school performance (Glyde et al. 2013). Investigations are currently underway to further examine the effects of a spatial processing disorder on communication in a realistic environment.

### **CONCLUSIONS**

Results in this study confirmed that the presence of a conductive hearing loss associated with otitis media in the first four years of life can influence functional listening in the longer term. School-age children who experienced at least one episode of conductive hearing loss in their first four years of life required significantly higher signal-to-noise ratios in all conditions utilising

spatial cues when compared to children with no otitis media history. More specifically, 18% of this group performed more than two standard deviations poorer than their normal peers. Long-term difficulties are likely due to disruptions during developmental years, having a negative impact on auditory pathway development. Findings did differ between the two binaural interaction tasks; with no significant association found between MLD and LiSN-S results. Outcomes highlight the need for earlier intervention when children present with otitis media and conductive hearing loss. Results also suggest school screening measures of functional listening in children with a history of middle ear dysfunction may be necessary in order to provide appropriate remediation.

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