Characterizing the speech-in-noise abilities of school-age children with a history of middle-ear diseases

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Recently, a number of studies have indicated that recurrent or chronic middle-ear disease during early childhood may lead to long-term supra-threshold hearing deficits. The current study followed up on this by investigating differences in monaural and binaural hearing abilities in noise among school-age children with or without a history of middle-ear diseases. Groups of children aged 6-12 years with either a history of recurrent otitis media (OM) with infection or effusion or without any previous ear diseases participated. All participants had normal middle-ear function and normal audiometric hearing thresholds at the time of testing. Measurements included monaural and binaural speech reception thresholds in the presence of stationary noise or competing speech. Sensitivity to binaural phase information was also assessed. Preliminary analyses based on the data from the first 31 participants suggest that, on average, OM children have poorer thresholds in conditions with binaural or spatial differences compared to children without any previous middle-ear problems. Follow-up analyses based on a larger dataset will substantiate these initial findings and relate them to information obtainable from the OM children's medical records (e.g., age of onset or duration of conductive hearing loss).

INTRODUCTION

Otitis media (OM) is the most common reason for temporary hearing loss in children before the age of four (Bennett & Haggard, 1999). OM can produce mild-to-moderate intermittent hearing loss of up to 40 dB HL, typically in the lower frequency range (Moore *et al*., 2003). Auditory abilities are known to develop greatly during early childhood (Cameron *et al*., 2009). Consequently, fluctuating and/or asymmetrical hearing loss caused by OM during this critical period has generated much speculation about potential longer-term effects on auditory system development, language acquisition and perception.

A number of studies have suggested adverse effects of conductive hearing loss due to OM during early childhood on higher-order auditory abilities including binaural hearing (Moore *et al*. 2003; Keogh *et al*., 2005; Tomlin & Rance, 2014; Graydon *et al*., 2017). To illustrate, Tomlin and Rance (2014) used the 'Listening in Spatialized

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Noise-Sentences Test' (LISN-S), which is an established tool for testing spatial processing abilities. They observed poorer abilities in OM children years after their hearing thresholds had returned to normal. In their case, OM history was determined based on parental reports. Graydon *et al*. (2017) also demonstrated longer-term effects of early-childhood conductive hearing loss on spatial processing abilities. In their study, OM history was determined based on the children's medical records. In contrast to Tomlin and Rance (2014) and Graydon *et al*. (2017), however, other researchers did not find evidence for long-term consequences of early conductive hearing loss on auditory development (e.g., Hartley *et al*., 2001). These inconsistent findings could be due to different aspects related to the history of middle-ear diseases (e.g., age of onset and duration of conductive hearing loss) and auditory system recovery (Keogh *et al*., 2005; Lawless *et al*., 1981; Moore *et al*., 2003).

Given the abovementioned inconsistences, the purpose of the current study was to look more closely at potential longer-term effects of early-childhood conductive hearing loss on binaural hearing abilities. We assessed binaural hearing using tone-in-noise, speech-in-noise and speech-on-speech stimuli with or without binaural differences between the competing signals. In this way, we examined the influence of early-childhood OM on different levels of auditory processing. Moreover, we will explore if these effects are associated with information obtainable from the OM children's medical records (e.g. age of onset and duration or of conductive hearing loss) in follow-up analyses based on a larger dataset. Our hypothesis was that early-childhood conductive hearing loss results in longer-term binaural hearing deficits and that this is associated with information about middle-ear status during early childhood.

MATERIALS AND METHODS

Ethical approval for the current study was obtained from the Regional Committees on Health Research Ethics for Southern Denmark.

Participants

Twenty children aged 6-12 years (mean: 10.8 years; standard deviation, SD: 1.7 years; 15 male) with a documented history of middle-ear infection or effusion ('OM group') and 11 children within the same age range (mean: 10.2 years; SD: 1.9 years; 4 male) without any previous ear diseases ('control group') participated. The inclusion criteria for all participants were normal middle-ear function (type-A tympanogram), pure-tone average (PTA) hearing thresholds calculated across 500, 1000, 2000 and 4000 Hz (PTA4) $\leq$ 20 dB HL, and normal speech, language and cognitive development at the time of testing. Fulfilment of these criteria was assessed using standard audiological measurements and parental questionnaires. Socioeconomic status is known to influence academic development. Therefore, comparability of the two groups in terms of socioeconomic status was also verified using a questionnaire. We used a custom-made questionnaire that included five questions related to the child's mother tongue, if the child was monolingual, the level of education of the child's parents and income of the child's parents. All the children who participated in the current study were monolingual, native Danish speakers with similar socioeconomic

status. In addition, children belonging to the OM group were required to have had at least three episodes of middle-ear infection or effusion (type-B tympanogram and conductive hearing loss with PTA4 >25 dB HL in each affected ear) for several months in at least one ear before the age of five. If a given child had also experienced middle-ear issues afterwards but otherwise fulfilled the inclusion criteria at the time of testing, it was still included in the study. History of middle-ear diseases was verified using the medical records from the children's otologists.

Design and procedure

The participants attended three appointments lasting 45-60 minutes each at the audiological laboratory of the University of Southern Denmark. The first visit included (1) completion of the parental questionnaires, (2) otoscopy and tympanometry, (3) standard pure-tone audiometry, (4) monaural measurements of speech reception in quiet, and (5) monaural and binaural measurements of speech reception in noise. At the second and third visit, speech reception in the presence of competing speech and sensitivity to binaural phase information was assessed. For each participant and type of measurement, a set of test and retest measurements was performed. If a given retest measurement deviated by more than 3 dB from the corresponding test measurement, another repetition was carried out. For the data analyses, the median of each set of measurements was used. The experiments were controlled via customized MATLAB scripts. The stimuli were presented via an external sound card and free field-equalized Sennheiser HDA200 headphones. All measurements were conducted in a large sound-attenuating booth.

Sensitivity to binaural phase information

Sensitivity to binaural phase information in the presence of noise was assessed using binaural masking level difference (BMLD) measurements. A 3-interval, 3-alternative, forced-choice design with a 1-up 2-down procedure was used. On each trial, all three intervals contained bandpass-filtered, 65 dB SPL Gaussian noise that was interaurally in-phase and centred at either 500 or 1000 Hz. One randomly chosen interval contained a 500 or 1000 Hz pure tone (corresponding to the centre frequency of the noise) that was either interaurally in phase ('N0S0') or π radians out of phase ('N0Sπ'). Each interval was 500 ms long and included 25 ms raised-cosine on- and offset ramps. Intervals were separated by 333 ms of silence. The starting signal-to-noise ratio (SNR) was +1 dB with additive step sizes of 8, 4 and 2 dB. After 10 reversals, a measurement was terminated, and the threshold estimated as the geometric mean of the adaptive variable at the last six reversals. The BMLD was calculated by taking the difference between corresponding N0Sπ and N0S0 thresholds. Before the actual measurements, all participants completed a training run in the N0Sπ condition with a starting SNR of +7 dB. The participants responded by pressing one of three buttons displayed on a touch screen. In case of doubt, they were encouraged to guess. A break was given after half of the measurements and whenever a child felt tired.

Speech-in-noise reception

To assess speech-in-noise abilities, 50%-correct speech reception thresholds (SRTs) were measured in two conditions. Using anechoic head-related impulse responses (Gardner & Martin, 1994), the target speech was presented from in front (0º azimuth) and stationary speech-shaped noise from the side (90º or 270º azimuth) of the listener. The stimuli were presented either binaurally ('binaural SRT') or monaurally ('monaural SRT') to the ear opposite the noise. The speech level was initially set to 68 dB SPL and then varied according to the adaptive procedure of the Danish hearing in noise test (HINT; Nielsen & Dau, 2011). The noise was presented at 65 dB SPL. The target speech consisted of the sentence material from the pediatric DAT material (Koiek *et al.*, 2020). All of these sentences have a fixed, simple structure, i.e. they start with a name (Dagmar, Asta or Tine) and contain two short keywords, for example "Dagmar tænkte på en teske og en bjørn i går". The participants were instructed to repeat the two keywords per sentence. To quantify the binaural contribution to speech-in-noise reception, the binaural intelligibility level difference (BILD; Kollmeier, 1996) was calculated by subtracting the binaural SRTs from the monaural SRTs. For training purposes, the participants performed one binaural SRT measurement in quiet and one binaural SRT measurement in noise.

Speech reception with competing speech

In addition to the speech-in-noise measurements, we assessed speech reception in the presence of competing speech (speech-on-speech measurements). Using anechoic head-related impulse responses, sentences from the pediatric DAT material (see above) were presented from in front (0º azimuth) of the listeners. As interferers, two female talkers with different voice characteristics were used. These were either collocated with (0º azimuth; '$S_fV_fV_f$') or spatially separated from (±90º azimuth; '$S_fV_rV_l$') the target speech. The spatial advantage was determined by subtracting the SRTs of the $S_fV_rV_l$ condition from the SRTs of the $S_fV_fV_f$ condition. The target speech level was initially set to 62 dB SPL and then varied according to the adaptive procedure of the Danish HINT. The level of the two competing talkers was fixed at 55 dB SPL. Before the start of the measurements, the participants were instructed to pay attention to the sentence starting with a specific name (Dagmar, Asta or Tine) and to repeat the two keywords in that sentence. For training purposes, they performed an SRT measurement in the $S_fV_rV_l$ condition. Following the training, two measurements (test and retest) per condition were performed.

Statistical analyses

To examine the distributions of the collected datasets, Shapiro-Wilk's test, normal Q-Q plots and box plots were used. To verify equality of variances, Levene's test was used, showing equality for all datasets (all $p > 0.05$). To explore differences between the two groups of children, two-sample *t*-tests were applied for the normally distributed datasets. For the non-normally distributed datasets (i.e. the N0Sπ data at 500 Hz, the binaural SRTs in noise, and the spatial advantage scores), non-parametric Mann-Whitney *U* tests were applied.

RESULTS

Sensitivity to binaural phase information

The mean and SD of the N0S0, N0Sπ and BMLD scores for the 500 and 1000 Hz conditions and two groups of participants are shown in Table 1.

Condition	Control group	OM group
N0S0, 500 Hz	−6.7 ± 2.7 dB SNR	−7.4 ± 3.4 dB SNR
N0Sπ, 500 Hz	−21.0 ± 2.6 dB SNR	−19.6 ± 5.4 dB SNR
BMLD, 500 Hz	14.2 ± 2.5 dB	12.3 ± 4.2 dB
N0S0, 1000 Hz	−8.0 ± 1.6 dB SNR	−7.9 ± 2.8 dB SNR
N0Sπ, 1000 Hz	−18.3 ± 3.2 dB SNR	−16.0 ± 3.7 dB SNR
BMLD, 1000 Hz	10.3 ± 3.1 dB	8.1 ± 3.0 dB

Table 1. Mean and SD for the N0S0, N0Sπ and BMLD scores for the 500 and 1000 Hz conditions and two groups of participants.

For the OM group, mean thresholds were higher and mean BMLDs were smaller than for the controls. However, the statistical tests revealed no significant differences in terms of these outcomes (all $p > 0.05$).

Speech-in-noise reception

Figure 1 shows the monaural and binaural SRT measurements as well as the BILD scores.

Fig. 1: Box plots showing the median, interquartile range and overall range of the monaural SRT, binaural SRT and BILD scores.

The mean binaural SRT was −5.7 dB SNR (SD: ±1.9 dB SNR) for the OM group and −6.6 dB SNR (SD: ±1.1 dB SNR) for the controls. On average, the BILD was reduced by 0.5 dB in the OM group. However, this difference was not significant ($t_{29} = 1.2$,

$p = 0.23$). Nor were there significant differences between the monaural ($t_{29} = -0.8$, $p = 0.43$) or binaural ($W = 139.0$, $p = 0.13$) SRTs of the two groups.

Speech reception with competing speech

The results of the speech-on-speech measurements are shown in Figure 2. The mean $S_fV_rV_l$, $S_fV_fV_f$ and spatial advantage scores for the control group were -4.7 dB SNR, 0.7 dB SNR and 5.4 dB (SDs: 2.3 dB SNR, 3.6 dB SNR and 3.9 dB, respectively). For the OM group, the corresponding values were -3.8 dB SNR, 2.7 dB SNR, and 6.5 dB (SDs: 2.8 dB SNR, 3.1 dB SNR and 3.0 dB, respectively). The statistical analyses revealed no significant group differences in mean $S_fV_rV_l$ ($t_{29} = -0.8$, $p = 0.41$), $S_fV_fV_f$ ($t_{29} = -1.6$, $p = 0.11$) or spatial advantage ($W = 150.0$, $p = 0.28$) scores.
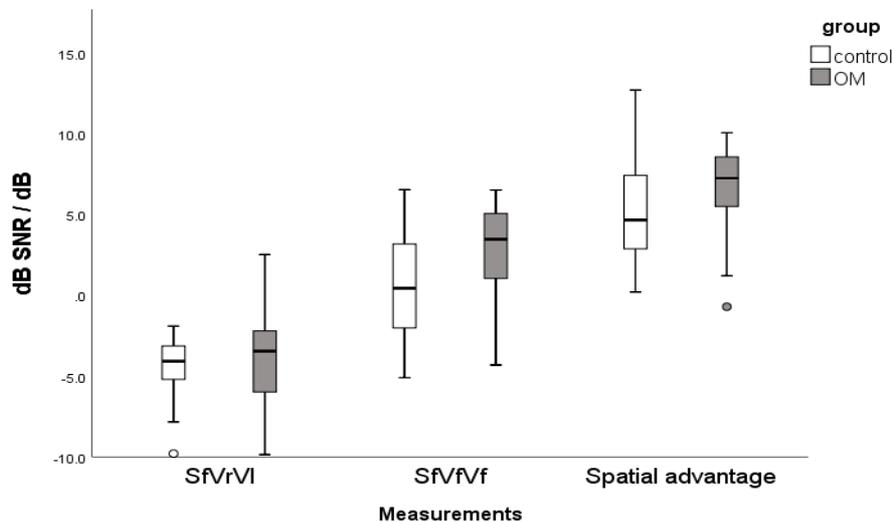

Fig. 2: Box plots showing the median, interquartile range and overall range of the $S_fV_rV_l$, $S_fV_fV_f$ and spatial advantage scores.

DISCUSSION

The aim of the current study was to characterize the longer-term effects of early-childhood conductive hearing loss on binaural hearing abilities. We used tone-in-noise, speech-in-noise and speech-on-speech stimuli with or without binaural (or spatial) differences between the competing signals to examine these effects on different levels of auditory processing. Preliminary analyses indicated higher (poorer) thresholds in conditions with binaural differences for the OM children compared to the controls. However, these results were not statistically significant.

In general, tone-in-noise detection performance tended to be poorer in the OM group compared to the control group. For instance, the BMLD scores of the controls were on average ~2 dB higher (better). The lack of a statistically significant difference between the BMLD mean scores of the OM and control groups observed here is consistent with some (Graydon *et al.*, 2017) but not all (Hall *et al.* 1995b; Moore *et al.* 2003) previous studies. Regarding speech-in-noise performance, the results of the

present study suggest comparable BILD scores in children with or without a history of conductive hearing loss. Regarding the speech-on-speech measurements, the OM children required an SNR that was ~1 dB higher than that of the controls in the $S_fV_rV_1$ condition. However, the mean spatial advantage was similar for the two groups. This is in contrast to the findings of Tomlin and co-workers (Tomlin & Rance, 2014; Graydon *et al.*, 2017) who observed reduced spatial advantage in OM children, even when hearing thresholds had returned to normal. One explanation for the inconsistent findings could be differences across studies in terms of OM history (e.g., age of onset or duration of middle-ear disease). For instance, Werker and Tees (2005) suggested that the first two years of life are the most critical for speech and language development. Consequently, auditory deprivation during this period may influence development the most. Tomlin and Rance (2014) also provided support for the idea that the age of onset influences the spatial processing abilities of OM children. They observed a significant correlation between the duration of OM and speech reception in the presence of two spatially separated speech interferers. Furthermore, the time interval since the occurrence of the last OM episode could play a role. Graydon *et al.* (2017) suggested that longer time intervals after the last OM episode in the case of their participants compared to those of Hall *et al.* (1995b) could be an explanation for why they did not observe an influence of OM on BMLD, whereas Hall *et al.* did. Hogan *et al.* (1996) also indicated that reduced BMLD scores in children with a history of OM improve over time as hearing thresholds return to normal. In the case of our study, the mean age of the children was 10.8 years. Thus, there may have been a rather long time interval between the last OM episode and the point in time when the measurements reported here were performed.

The data presented here constitute preliminary results from an ongoing study that eventually will include more participants. A larger sample size may well change the results of the statistical analyses reported here. Future work will also relate the psychoacoustic and speech perception measurements to information obtainable from the OM children's medical records. In this manner, it will be possible to investigate the influence of factors such as age of onset, time interval since the last OM episode and duration of early-childhood conductive hearing loss.

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