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Understanding the sound environments of young children: potential implications for radio aid use

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ABSTRACT

The objectives of this study were to describe, analyse and compare the sound environments to which deaf and typically hearing children between 3 and 18 months are typically exposed, and identify issues to support the development of guidelines for the use of radio aids in this age group. Thirty parents of children aged 3–18 months (14 deaf children and 16 who were typically hearing) took part. An online survey was devised for this study and was intended to capture the "soundscape" (sounds in the environment) to which both deaf and typically hearing children between 3 and 18 months were usually exposed in their everyday lives at multiple points during the day. The purpose of the survey was to map everyday routine experiences and interactions with their families to assess auditory access and environmental awareness or unawareness. Conceptual content analysis was used to evaluate participant descriptions of sound environments. Differences in child awareness of sound and distances between children and their parents were also analysed. Results showed that both deaf and typically hearing children experience rich and complex soundscapes with plenty of opportunities for learning about the world. Parents of deaf children changed their child's sound environment compared to parents of typically hearing children, particularly at home, in order to provide easier listening conditions. However, deaf children were often in noisy environments where hearing aids or cochlear implants alone were unlikely to be providing good access to speech and other salient sounds, and radio aids may be beneficial in these circumstances.

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Introduction

Sound environment

Audibility of the speech signal has understandably been prioritised for deaf children as this is of fundamental importance to spoken language development, the success of which has consequences for many factors including social development, educational attainment and emotional wellbeing (Ching et al., 2018, 2021; Culbertson & Gilbert, 1986). Parents of typically hearing children may maintain communication and contact using their voices, and offer reassurance to their child when further away than an optimum hearing aid/cochlear implant distance of one to two metres.

In a typically hearing child, auditory development is a prolonged process, and progresses through three stages: (1) maturation of sound coding; (2) maturation of selective listening and discovering new details in sound; and (3) maturation of perceptual flexibility (Werner, 2007). In the first stage of auditory development (full term birth to 6 months) the auditory system's ability to encode sound matures, but it is not until the second stage, which lasts until a child is about 5 years old, that the ability to focus on specific features of sound matures and most typically hearing children master selective listening by the time they start school (Leibold & Neff, 2007). The third stage, which sees increased sophistication in listening abilities in different listening conditions lasts into adolescence (Werner, 2007).

The immaturities in infants' hearing affects their ability to learn from sound in real environments, and it is important to consider the sound (and noise) environments which infants experience in their daily lives with the aim of optimising auditory learning opportunities. This assumes even higher importance for a deaf child developing communication through audition, and Erber (1977) emphasised a hierarchy moving from awareness through to discrimination, identification and onto comprehension in relation to the development of speech in deaf children.

In terms of auditory attention, four components have been recognised: arousal; orienting (i.e. noticing and responding to a source e.g. with eye movement); selective attention; and sustained attention (Gomes et al., 2000). Infants at 3 months of age have been shown to prefer speech to other naturally occurring sound signals (Shultz & Vouloumanos, 2010), and this persists in infancy, with Krentz and Corina (2008) also noting that infants under 10 months show a preference for listening to verbal rather than nonverbal sounds. However, it has also been shown that children begin to identify the relationship between sound and objects at around 7 months, and in an investigation of infant recognition of meaningful verbal and non-verbal sounds with children of 15, 20 and 25 months old, it was noted that sound-object associations increased with age (Cummings et al., 2009). The study also suggested that children who are more sensitive to these observations may also be more attentive generally to distinguishing characteristics in their environments and may have larger vocabularies.

Some studies have sought to understand the role of "overhearing" on children's language development. Akhtar et al. (2001) demonstrated that children of 18 months and 2 years of age can learn object labels by overhearing and in a later study found that learning object labels through overhearing was possible even when distracted (Akhtar, 2005). However, there is very little evidence about whether and how overhearing drives spoken language development, particularly in infancy.

In the UK, the use of radio aids for very young children has been a controversial question for audiologists and teachers of the deaf for some time. The Quality Standards for use of personal radio aids; promoting easier listening for deaf children published by the National Deaf Children's Society and the UK Children's FM Working Group states that "In an ideal world, every deaf child would receive a complete amplification package, including a radio aid, at first fitting" (National Deaf Children's Society, 2017, p. 5). Whilst there is ample and powerful evidence for the benefits of using radio aids in school aged children, and less but still strong evidence for use with preschool children, there is little or no published research in relation to children in the first year to 18 months of life. Because of the well-known benefits of enhancing access to the speech signal for children developing spoken language, many audiology and education professionals feel instinctively that use of a radio aid must confer advantages, even in the earliest months. However, a typically hearing child also has the opportunity to "overhear" in their everyday communication environment and to access a range of environmental sounds which may enhance their understanding of the world around them. As a preliminary stage for considering how radio aid use for young children may impact on their opportunities for learning, it is important to understand the sound environments they are routinely immersed in, and whether parents of deaf young children make adaptations that may limit the efficacy of a radio aid, and this study aims to address some of these questions.

The limitations of hearing aids and cochlear implants

Hearing speech in noise, at a distance and in reverberant spaces are all major challenges for those who are deaf/hard of hearing. Hearing aids and cochlear implants work best at 1–2 metres in quiet non-reverberant rooms but this is not the reality of the world in which children live (Benítez-Barrera et al., 2020). The evidence for the use of digital features such as noise reduction and directional microphones in children under 18 months is limited, and guidelines tend to suggest that some of these features be deactivated for young children (American Academy of Audiology, 2013). Directional microphones may impair localisation abilities as well as reducing sound awareness and interfering with the ability to overhear in young children (American Academy of Audiology, 2013). Although noise reduction is generally considered not to impair speech recognition in children (Crukley & Scollie, 2014; Pittman, 2014), studies in those under 18 months are lacking.

Remote microphone technology

Remote microphone technology such as a radio aid comprises a receiver which is integrated or attached to a hearing aid or cochlear implant and a transmitter which is generally worn by the person speaking to the hearing aid wearer. Hearing aids and cochlear implants are unable to selectively amplify sounds of interest; they also amplify background sounds which may result in an unfavourable signal to noise ratio. This can be particularly problematic for deaf children who require a higher signal to noise ratio than their typically hearing peers (Crandell & Smaldino, 2000). Increasing distance from the talker results in a decrease of the signal of interest making hearing aid/cochlear implant microphones much less effective past a distance of about 2 metres. A radio aid is a simple solution to these issues as it increases the signal to noise ratio and overcomes the problem of distance.

The benefits of using radio aids with preschool children (aged approximately 2–4 years old) are becoming increasingly widely appreciated, as research evidences positive gains in relation to speech perception and speech and language development with this age group (Allen, Mulla, Yen Ng, et al., 2017; Benítez-Barrera et al., 2018; Mulla & McCracken, 2014). Studies have also demonstrated acceptability to parents, who have welcomed the technology particularly to overcome the challenges of distance and noise, thereby enabling enhanced access to speech in a variety of social and early learning settings (Allen, Mulla, Ng, et al., 2017; Statham & Cooper, 2013). There has however been little focus on the use of this technology with infants and young children under 18 months of age and with increasing integration of radio aid receivers into hearing aids and cochlear implants usage is now practical and safe for this age group.

Research approaches

The field of remote microphone technology is advancing rapidly and therefore the need for evidence and guidelines is becoming ever greater. Although there have been some small practical trials with younger children in services where Audiologists and Educational Audiologists/Teachers of the Deaf feel positive about, and can resource, the equipment to implement the provision, the feeling persists amongst some professionals that radio aids principally serve to enable access to education settings. A recent study by the UK National Deaf Children's Society in conjunction with the Ear Foundation, Nottingham, however, has reinforced the perception of benefit by most, but not all, participating parents of preschool children (mostly aged 3–5 but a few as young as 18–24 months) in wider situations, and clearly further evidences the positive impact on adult–child communication and interaction in the family context (Allen, Mulla, Ng, et al., 2017).

LENA technology is a powerful tool for evaluating early childhood language development and has been used in several studies with young deaf children in order to evaluate various aspects of language development as well as acceptability of the technology for parents (Allen, Crawford et al., 2017; Ambrose et al., 2014; Perry et al., 2022; VanDam et al., 2012). It has also been used to evaluate, for example, the effects of TV exposure on child language development (Christakis et al., 2009; Zimmerman et al., 2009).

A recent study used LENA to evaluate whether the predictability of the home auditory environment impacted on infants' ability to sustain attention in laboratory assessments (Werchan et al., 2022) showing that a more predictable environment led to longer sustained attention. This was a large study of 98 three-month-olds but did not include deaf children. A further study also used LENA to examine the characteristics of the home auditory environment for children under two with cochlear implants compared to those with typical hearing (Yuanyuan Wang et al., 2022). This study used a longitudinal design and showed both differences and similarities in the home auditory environment of young children who use cochlear implants and typically hearing children. For example, typically hearing children were in noise significantly more than those with cochlear implants, however it was emphasised that this does not necessarily mean that the speech signal was audible for those with cochlear implants. This study also demonstrated that increased spoken interactions between children and adults were related to a decreased amount of television/media and noise in both children with CI and those with typical hearing.

LENA is able to segment audio files into live human sounds and background sounds, including child speech, adult speech and background sounds such as TV/electronic noises. However, there are three main limitations with LENA technology which restrict its usefulness for the current study: firstly, although LENA can identify electronic media in the environment, it cannot identify the source or whether it is in the foreground or background (Ambrose et al., 2014; Christakis et al., 2009); secondly, LENA has a radius of 4–6 feet meaning that sounds which may be important or relevant for the child, but which are originating at a greater distance, will not be recorded (Ye Wang et al., 2017); finally, LENA it is not able to assign importance to background sounds. This is problematic as environmental sounds can effectively be considered as a form of language as they are produced by real events and therefore have meaning associated with them (Ballas & Howard, 1987).

There is a lack of research concerning the real world sound environments of deaf young children and the adaptations their parents make to improve listening. This evidence is crucial for understanding the potential value of radio aid usage in this age group, and how the use of radio aid devices might be managed.

Aims of the current study

The aims of this study were to:

1. Describe and analyse the sound environments to which deaf and typically hearing children between 3 and 18 months are typically exposed, mapping their everyday routine experiences and interactions with their families to assess auditory access and environmental awareness or unawareness.
2. Compare deaf and typically hearing children's experiences to discover whether parents of deaf children make changes to the environment compared to parents of typically hearing children.
3. Identify issues to support the development of guidelines for using radio aids for this age group to not only ensure essential high-quality access to speech, but also to understand the importance of other sounds in the environment.

Materials and methods

Ethical considerations

The study was approved by the UCL Research Ethics Committee (project ID: 12585/005). Informed consent was given by all participants. Data were stored in compliance with the European Union's General Data Protection Regulation (2016/679). Personal identifiers were removed for analysis.

Recruitment

Parents of deaf and typically hearing children age between three and 18 months were eligible to take part in the study. Deafness was defined as any degree of hearing loss. Those who were unable to access online tools in written English were excluded. Information about the study was sent to Qualified Teachers of the Deaf (QToDs) via professional mailing lists. QToDs then gave study information to families who met the entry criteria. The National Deaf Children's Society included the study on their mailouts to families. Interested families then filled in an online contact and expression of interest form that included a basic eligibility check (age of child). The study team subsequently contacted the interested families either by telephone or by email with further details about the project which included a link to a video and explanation on a website. A link to a consent and demographics questionnaire was included in the email. Once the participant had consented to the study, they were sent a link to their observational tool.

In order to recruit parents of typically hearing children, participants with deaf children were asked to forward study information to friends or acquaintances with typically hearing children in the study age range. This helped to ensure that the sample of parents with typically hearing children was reasonably similar in terms of socioeconomic status and geographical areas to the parents of deaf children. A public and patient involvement (PPI) survey was carried out prior to the start of the study to ensure that this was an acceptable method of recruitment for parents of young children.

Procedures

All data collection took place online using the web-based survey tool, Opinio, between May 2021 and January 2022. For part of this time, some COVID-19 pandemic restrictions were still in place in the UK. Demographics information collected included data about parental education level, child's hearing status and any amplification (deaf children only), parental awareness of radio aid technology (deaf children only), family history of deafness, and whether the child had any additional needs.

An online survey was devised for this study and was customised to capture the "soundscape" (sounds in the environment) to which both deaf and typically hearing children between 3 and 18 months were typically exposed to in their everyday lives. The survey attempted to map everyday routine experiences and interactions with their families to assess auditory access and environmental awareness or unawareness. The survey was piloted by two families and revisions to instructions were made based on their feedback. The survey asked parents to report the following for each observation:

- Activity taking place.
- Sounds in the environment.
- Estimates of distance from child.
- Whether child noticed sounds in the environment.

Participants could add up to five environmental sounds per recording. They were asked to respond to the survey several times per day across three days and were given a £20 voucher if they completed at least 12 responses.

Participants

Sixty-five people filled in the screening questionnaire. Five were ineligible as their child was over 18 months old. Twenty people did not respond following email invitation and two reminders. Forty families (represented by 39

Table 1. Participant characteristics and between group comparisons.

Variable	Deaf group (n = 14) *M* (SD)	Typically hearing group (n = 16) *M* (SD)	Statistic	*p*	Effect size	95% CI
Age of child (months)	9.74 (4.14)	9.68 (4.95)	t = 0.03	.973	0.01	[−0.74, 0.76]
Parental education level (SS:C/V:UG:PG:NS)	0:3:7:3:1	0:1:7:8:0	χ^2 = 4.16	.245	9.70	-
Family history of deafness (yes:no)	3:11	2:14	χ^2 = 0.03	.870	1.17	-
Additional needs in child (yes:no:not stated)	1:13:0	0:15:1	χ^2 = 0.00	.972	1.03	-
Number of observations completed	11.57 (6.61)	11.38 (4.96)	t = 0.09	.928	0.03	[−0.72, 0.78]

All comparisons on scale data were *t* tests. Group comparisons on family history and additional needs were done using chi-square tests. Effect size = Cohen's d for *t* tests, and odds ratio (OR) for chi-square tests. CI = confidence interval. Parental education level abbreviations: SS = secondary school; C/V = college/vocational; UG = undergraduate; PG = postgraduate; NS = not stated.

mothers, one father; 22 with deaf children and 18 with typically hearing children) consented to take part in the study. Two subsequently withdrew from the study (both from the deaf group). A further eight participants were unable to complete observations (six from the deaf group, two from the typically hearing group) and their data were removed from the final analysis. The final group comprised 30 participants: parents of 14 deaf children and 16 typically hearing children. Group characteristics and between group comparisons are shown in Table 1.

There were no observed differences between groups on any of the participant characteristics or the number of observations completed. Parental report of family history of deafness was similar between groups. However, on closer inspection, the three parents in the deaf group reported immediate family history (sibling or parent with permanent hearing loss), whereas the two parents reporting family history in the hearing group described deafness in grandparents or uncles/aunts.

All parents in the deaf group reported that their child had been diagnosed with deafness within 8 weeks of birth. All had bilateral deafness and parent descriptions of severity ranged from mild-moderate to profound (one parent did not know the severity of their child's deafness). Twelve children wore bilateral hearing aids while two were unaided. None of the children had received cochlear implantation. One child had a radio aid, and twelve parents reported knowledge of radio aids. The two parents who reported no knowledge of radio aids were those whose children were unaided.

Data analysis

Conceptual content analysis was used to categorise the parent reported sound environments (Graneheim & Lundman, 2004). Parents' descriptions of the sound environments were read and coded independently by two members of the research team (HEC and GC). No sounds were excluded (e.g. both background and child directed speech were included for coding). Meaning units were agreed upon following discussion and parent descriptions were again coded according to these meaning units. Discrepancies were resolved through discussion and debate. Codes which related to the general sound environment were developed (main sound environment). Further codes which related more particularly to the sounds in the environment were also generated (subsidiary sound environments and background). All sounds were included and the full context of each entry was considered when condensing and labelling information in order to reflect the data as closely as possible. A third coder (AD) reviewed and checked all coding. T-tests, ANCOVA and Chi-square testing was used to evaluate the differences between groups on quantitative and coded qualitative data where appropriate.

Results

Sound environments of deaf and typically hearing children

Data collected by many participants were rich in information and illustrated complex scenes and family interactions. For example, the following situation was recorded by the parent of a deaf child aged 9 months: The child was sitting in a highchair with one parent sat facing the child and feeding them. The parent felt their child heard them speaking within this close environment. The other parent was in the same kitchen area washing up and preparing food. There was cutlery on the table at arm's length that the parent felt their child heard when it was moved. The kettle was reported to be boiling at a distance of roughly 1 m which again, the parent felt the child could hear. Pans were also boiling on the hob but the parent was unsure whether their child could hear that. The tap was also running in the kitchen and the parent felt the child could hear that.

The sound environment therefore provided many opportunities for the child to note the sound or for the parent to direct shared attention to the sound and its meaning. Use of a radio aid could have facilitated access to both the environmental sounds and any contingent conversation between the two parents.

Conceptual content analysis showed that children were in a variety of different sound environments during the day. Eight codes were extracted which related to the main sound environment. Reported situations were assessed and an overall description of each sound environment was developed. This included inside and outside environments, home and public environments, and loud and quiet situations. A single main sound environment category was then allocated for each entry recorded by participants. Eight further codes were identified relating more specifically to the sounds present in the environment. Again, all reported situations were evaluated and categories were developed

Table 2. Sound environment codes and examples.

Category	Sub-category	Example	Meaning unit count
Main sound environment	Inside quiet public environment	Library/quiet shop	0
	Inside noisy public environment	Coffee shop/noisy shop	18
	Outside quiet public environment	Trees rustling	11
	Outside noisy public environment	Walking next to traffic	25
	Inside quiet home environment	Playing quietly	203
	Inside noisy home environment	Sibling shouting/bath time	75
	Outside quiet home environment	One child playing in the garden	9
	Outside noisy home environment	Multiple children playing in the garden	4
Subsidiary sound environments and background	Quiet household sounds	Bags rustling	2
	Loud household sounds	Washing machine/hoover	5
	Loud external sounds	Building work outside home	2
	Background media	Background TV/radio/music etc	111
	Child directed speech – adult	Parent talking to child	73
	Child directed speech – child	Sibling talking to child	23
	Background speech	Multiple background talkers in coffee shop	87
	Transport	In the car/on the bus	11

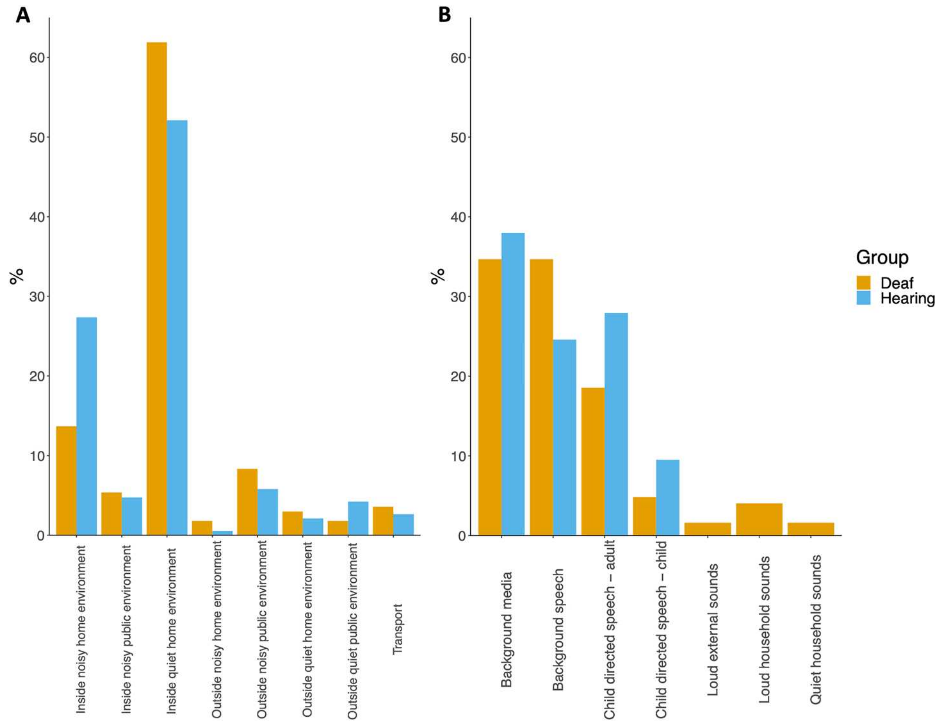

Figure 1. Bar graph showing group differences in parent reported sound environments of deaf and typically hearing children derived from conceptual concept analysis. The percentage of reported environments for each group is illustrated. Panel A shows the main sound environments children were in. Panel B shows subsidiary sound environments and backgrounds.

including household sounds, background media, speech and transport. Up to two specific sound categories were allocated to each survey response. Categories, examples and counts are shown in Table 2.

Comparisons between the sound environments of deaf and typically hearing children were made in order to determine whether parents of deaf children changed the environment relative to typically hearing children. Figure 1 shows group differences in sound environments. Although Chi-square testing showed no significant difference overall between groups for main sound environment ($\chi^2 = 13.87$, $p = .054$) deaf children appeared to be in inside noisy home environments significantly less than typically hearing children (see Figure 1(A)). Chi-square testing showed that there was a significant difference overall between groups for subsidiary sound environments and background sounds ($\chi^2 = 20.58$, $p < .005$; see Figure 1(B)). However, post-hoc pairwise comparisons (Bonferroni corrected) were unable to identify where the differences lay.

Grouping all noisy and all quiet situations together showed that deaf children were in noisy situations 33% of the time and typically hearing children 42% of the time. There was no significant difference between groups ($\chi^2 = 2.24$, $p = .134$) for total time in noisy situations.

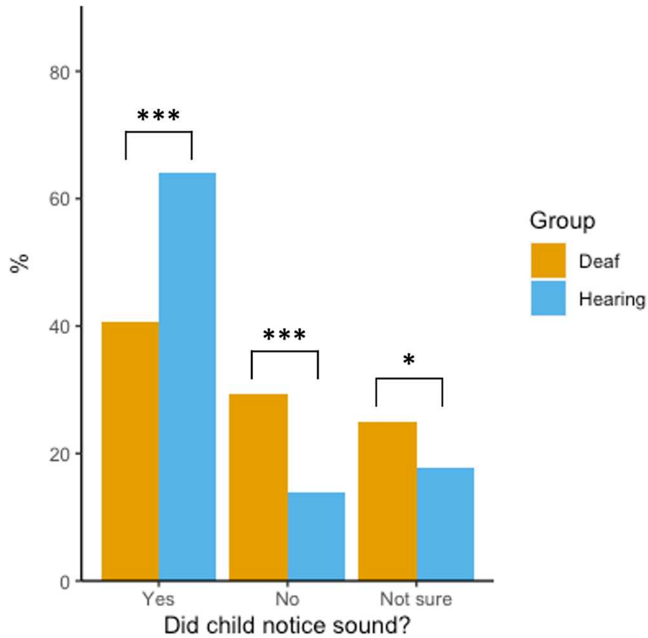

Figure 2. Parent report of their child's awareness of environmental sounds for deaf and hearing children.

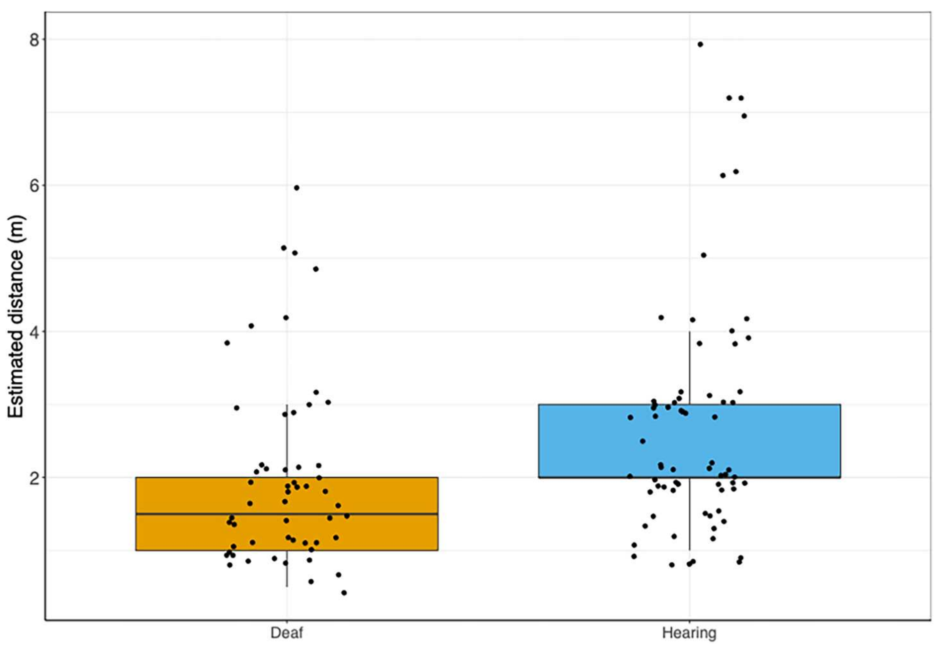

Figure 3. Box and whisker plot showing the distribution of parent estimated distance (in metres) from parent to child when at greater than arm's length away for deaf and typically hearing children. Points represent single observations (with jitter added to prevent overlap of points).

Awareness of environmental sounds

Parents reported that typically hearing children noticed significantly more environmental sounds than deaf children ($\chi^2 = 52.18$, $p < .001$; see Figure 2). Parents of deaf children also reported that they were unsure whether their child heard a sound more often than parents of typically hearing children (post-hoc testing $p < .01$).

Distance from child to parent

The amount of time children were close to their parents (defined as being held or up to arm's length away) was not significantly different between groups with deaf children being close 65% of the time and typically hearing children being close 60% of the time ($\chi^2 = 3.47$, $p = .063$). However, when parents reported that they were at a distance from their child (defined as being greater than arm's length away) they estimated that deaf children were significantly closer than typically hearing children when controlling for age ($F(1,457) = 12.24$, $p < .001$) with deaf children being at a mean distance of 1.5 m and typically hearing children at a mean distance of 2 m (see Figure 3).

Discussion

The primary aims of this study were to map the everyday sound environments of deaf and typically hearing young children, and to compare their experiences. This study has shown that parents of deaf children make changes to their child's environment including reducing noise at home and keeping their child closer compared to typically hearing children. Promotion of good hearing tactics and communication environments is a key part of the role of professionals working with families of deaf children, as is relating an understanding of the limitations of hearing aids. It is clear from our findings that parents have an understanding of this advice and put it into practice to support positive listening environments for their children. However, we need to consider whether changing the environment of deaf young children because of the limitations of hearing aid and cochlear implant technologies may be detrimental to their development. If they are unable to stray further from their parent than 1–2 metres, this may limit their opportunities for learning and development as they become mobile. There may be crucial benefits for radio aid usage in this situation, enabling an increasingly mobile deaf child to maintain clarity of speech access whilst still being at a distance from the parent, in common with typically hearing children.

Our findings that deaf children are in noisy situations for 33% of the time is similar to Jones and Launer (2010) who showed that deaf children under the age of four years may be in noisy environments for a quarter of their day. Without the use of a radio aid, a clear speech signal may be hard to achieve for a substantial period of a deaf child's day. However, we do need to think about meaningful sounds which may be found within "noise", and radio aid usage, at this age in particular, will need to be managed carefully in order to ensure meaningful environmental sounds are not excluded, and can be capitalised upon to promote both conceptual understanding and vocabulary learning. The signal to noise ratio (SNR) of deaf children's typical home environments was investigated by Benítez-Barrera et al. (2020). They showed that the average SNR for children aged between 2 and 5 years was approximately +7.9 dB which is below the +15 dB recommended by the American Speech-Language Hearing Association (2005).

Unsurprisingly, this study has shown that typically hearing children have a greater awareness of environmental sounds compared to deaf children. This is likely to mean that deaf children have fewer opportunities to explore their sound environments as parents will often use a cue from their child to talk about what is happening around them, thereby reinforcing learning and curiosity (Curtin et al., 2021). The ability of parents to follow their deaf child's lead in interactions and communication has been shown to be correlated with deaf children's word production (Vohr et al., 2010), and parental sensitivity (i.e. the responsiveness of the parent to their child's attempts at communication) is a predictor of language function (Pressman et al., 1999).

A striking finding of this study is that deaf children are in environments with background media (mostly television) 35% of the time and typically hearing children 38% of the time. Television was only occasionally reported to be the primary activity and was mostly reported as an environmental sound in addition to the main activity. While screen viewing is not necessarily of detriment to young children per se, poor quality television, such as background television, is related to lower vocabulary (Guellai et al., 2022). This is particularly pertinent for deaf children as delays in language development continue to exist despite early identification and intervention (Werfel et al., 2022). However, shared attention to the television providing a stimulus for conversation could be a beneficial activity and support vocabulary growth. Strategic use of a radio aid could enhance access to this activity.

The complexities of mapping the sound environment accurately mean that evaluating the impact of "missing out" on sounds in the environment is challenging to measure. LENA technology can identify background sounds but cannot determine the source of those sounds or the importance. There are two important factors to consider here: firstly, the limitations of technology, and secondly, the priority of the speech signal. We may question whether prioritising the speech signal over other environmental sounds (as when we use a radio aid) is the best approach. However, we must be aware that current hearing technology is limited when sounds of interest (which may not necessarily be the speech signal) are at a distance or there is competing noise. The complexities of using a radio aid to give young children access to other sounds of interest (such as the doorbell ringing, birds singing, household appliances) are such that the use of this technology is limited to speech. This research has shown though, that one microphone is unlikely to capture all child direct speech, and two microphones are likely to be preferable to enable greater access to speech sounds. The goal for child listening is to be able to hear multiple speakers as well as having access to environmental sounds. The example described above shows that one microphone would give access to only one half of a conversation, with competing sounds meaning that hearing aids alone may have limited benefit in this situation, and the rich data provided by many parents in this study include multiple examples where this would be the case. This is supported by evidence from Benítez-Barrera et al. (2020) who suggest that radio aids should be used consistently in the home (albeit with slightly older children to those investigated in our study), but with caution so that access is not limited to a single speaker.

Hearing aid and cochlear implant technology is likely to go through a revolution in efficacy over the next few years as artificial intelligence and deep learning technologies are applied to processing strategies (Lesica et al., 2021). However, these advances are some way off being readily available and it is important to consider now how best to use remote microphone technologies as well as other assistive listening devices to optimally support deaf young children. Radio aids are often seen as educational, or more commonly, "school" devices. With learning and development happening most rapidly in the youngest age groups, it is fundamental that we optimise the use of technologies for deaf young children, and this includes appropriate use of remote microphones. Radio aids are powerful tools for overcoming some of the limitations of hearing aids and cochlear implants but innovative use of devices is not common. It may be possible to use remote microphones along with other assistive devices (e.g. flashing doorbells) to promote spontaneous recognition of sounds in the environment (not limited to speech), and further research is needed to establish guidance for this.

This work has shown that radio aids may be a key tool for deaf children age 3–18 months who use hearing aids and/or cochlear implants, as they are often in noisy sound environments which may make speech intelligibility difficult. However, it is important to recognise the salience of environmental sounds and therefore, in common with Benítez-Barrera et al. (2020), we suggest that radio aid guidance should be individualised for each family and not issued without specific guidance.

Limitations

There are several limitations which should be considered when evaluating this study. Firstly, the sample size was small and not all those who consented to the study were able to record any observations. This was potentially a challenging study for parents of very young children with many competing priorities, and also during a time when COVID-19 restrictions still impacted on their daily lives. Secondly, the survey was relatively cumbersome and relied on parents remembering to fill it in during the day. An app which had more straightforward navigation and was able to send push notifications would have been preferable but the budget was not available to develop this. Thirdly, there is an inherent difficulty in categorising environmental sounds. As Ballas and Howard (1987) observed, sampling all sounds which may occur in the environment would be virtually impossible, and therefore there is an inevitable amount of subjectivity and conjecture when coding such sounds. However, we used two independent coders and a third independent checker in order to mitigate this issue as far as possible.

Conclusion

This study has shown that the sound environments of both deaf and typically hearing young children are rich and complex, with many opportunities for experiencing and learning about the world. Parents of deaf young children change the sound environment, particularly in the home, to ensure that it is quieter and to keep their child closer to them, in order to achieve better listening conditions for speech. It is possible that with radio aid technology, parents would not worry about the effects of distance and the distance may increase to that experienced by typically hearing children. Deaf young children are in noisy environments for a third of their day meaning that they are often in situations where hearing aids or cochlear implants will not give them good access to sounds, particularly speech sounds. Radio aids may be of benefit in these situations, overcoming issues of noise and distance from the speaker, and considerations need to be given to the optimal use of this technology in order to facilitate awareness of important environmental sounds as well as crucial access to speech. This is important as there is evidence that the sound environment can enrich development, and therefore further research is needed to ensure that hearing technologies, including radio aids, can be used to maximise access to the full soundscape for deaf young children.

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