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Intelligibility of Speech Produced by Children with Hearing Loss: Conventional Amplification versus Nonlinear Frequency Compression in Hearing Aids

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Abstract

Objective: This study aimed to 1) investigate the influence of nonlinear frequency compression (NLFC) in hearing aids on intelligibility of speech produced by children with hearing loss; and 2) examine whether clinicians' or parents' judgments might be correlated with those of inexperienced listeners.

Methods: Twenty-seven adult listeners with normal hearing who reported no experience listening to speech produced by people with hearing loss were asked to judge the intelligibility of speech samples of eight hearing-impaired children under four aided conditions. Also, the parents and the clinicians who provided services to the children provided ratings. The children were enrolled in a four-period multi-site trial that was aimed to compare the effects of conventional processing with NLFC in hearing aids on children's performance. In that study, the children were familiarized with each of four hearing-aid setting for at least six weeks before they were evaluated using a range of tests, including the production of 20 sentences. The current study used the recorded sentences as stimuli for intelligibility judgments. Each listener heard sentences produced by two child-talkers, 40 from each talker. The stimuli were presented to listeners at 65 dB SPL via headphones. Four child-talkers received ratings from eight listeners and four from seven listeners.

Results: Group-level results indicate that speech intelligibility was rated to be better by inexperienced listeners when children used NLFC than when they did not. Three child-talkers showed a significant advantage with NLFC activation. These results are consistent with the estimated audible bandwidth of hearing aids for individual talkers. Significant positive correlations for intelligibility ratings between inexperienced listeners and clinicians were found, but neither correlated with ratings from parents.

Conclusions: The use of NLFC improved intelligibility of speech produced by children, on average, as rated by inexperienced listeners. Clinicians' judgment of children's speech production is a clinically viable tool for evaluating the effectiveness of amplification for children.

Keywords Speech production; Intelligibility; Nonlinear frequency compression; Hearing aids; Hearing loss; Children

Introduction

Speaking in a way that allows a listener to understand what is being said, or speech intelligibility, is an essential skill that children need to develop to be able to participate fully during social interactions [1]. Typically developing children usually acquire this skill effortlessly, with 97% of children producing intelligible speech by four years of age [2]. However, children born with a hearing loss often do not - especially when their hearing loss is severe or profound [3,4].

Direct assessments of speech intelligibility have been proposed as a clinical tool for evaluating the effectiveness of early intervention resulting from newborn hearing screening, and the efficacy of sensory devices [5]. It has been shown that speech intelligibility of children with profound hearing loss improved after cochlear implantation [6-10], and improved with increased duration of implant use [11]. Younger age of implantation was also associated with higher levels of intelligibility for children with profound hearing loss [12].

However, studies on speech intelligibility of children with mild to severe hearing loss have been under-represented in the literature. One study reported the benefits of early hearing-aid fitting for speech intelligibility of children at 8-12 years of age, showing that about 50% of children who received their first hearing aids before 6 months of age were rated by their teachers to be fairly or very easy to understand, whereas only 10-15% of those who received later fitting produced intelligible speech [13].

There were very few studies that have directly assessed the effectiveness of hearing-aid signal processing on speech intelligibility of children. One signal-processing strategy that has become increasingly common in hearing aids for children is frequency lowering. This strategy shifts high-frequency components of sounds to a lower frequency range where there is better residual hearing [14-17].

Nonlinear frequency compression (NLFC) is a specific form of frequency lowering that maps a wide frequency range in the input signal into a narrower frequency range in the output through compressing inputs above a certain cut-off frequency by a specific compression ratio. The amount of compression is progressive, such that frequencies much higher than the cut-off are shifted by a larger amount than frequencies only slightly above the cut-off [17]. While the use of NLFC in amplification may increase the audible bandwidth [18] thereby allowing access to high-frequency sounds (notably/s/), it also distorts the spectral information in the amplified signal [19]. Although recent evaluations of the impact of NLFC on young children's language development has revealed no significant effect on receptive and expressive language [20,21], a randomized controlled trial examining consonant production indicated that children who used NLFC had production errors that were not observed in typically developing or children with hearing loss who used conventional amplification [20]. This suggests that the use of NLFC could potentially influence the intelligibility of speech produced by children.

It is widely acknowledged that speech intelligibility is influenced by the competence of the talker and the nature of the spoken material (isolated words or connected speech, e.g. [22]); and judgments of speech intelligibility are affected by factors relating to speech perception of the listener including but not limited to the acoustic listening conditions and the familiarity of the listener with the speaker ([4,23]). Measures of intelligibility have typically used either a transcription (write-down responses) or a scaling (overall rating) procedure for scoring [5]. The former requires the listeners to write down the words or syllables they heard, and scores performance as the percentage of written words or syllables that match the stimuli [11,24,25]. There are at least two potential limitations with this approach. The first has to do with the assumption that the number of words correctly transcribed by the listener strictly reflects the proportion that was accurately produced by the speaker. Research examining the effects of semantic and syntactic constraints on speech recognition has shown that listeners use their knowledge of language and world knowledge to take advantage of contextual redundancy [26,27]. Meaningful four-word sentences, for example, appear to be perceived as though they consist of around 2.5 independent perceptual units. This is consistent with reports suggesting that word scores accounted for 60-80% of variance in overall intelligibility ratings of children with hearing loss [28,29]. The second relates to the large amount of time required for transcribing each sentence for scoring, and the need to have more than one listener-judge to obtain a reliable score [24].

The scaling procedure requires listeners to rate each sentence they hear on an intelligibility scale. This judgment gives an overall impression of how much of what is said is understood. A scale that has been widely used for assessing speech produced by children with hearing loss is the Speech Intelligibility Scale (SIR) [30,31]. The SIR uses a 6-point scale that spans from 1 (always understand with no effort) to 6 (I never or almost never understand the child's speech). It has been used for assessing outcomes of cochlear implantation [30,32] and amplification for children [33]. Zhang et al (2014) reported ratings of parents of 31 hearing impaired children (mean age: 4.3 years; SD: 1.5) on whether their speech could be understood by unfamiliar persons in a comparison of conventional amplification with NLFC for young children. On average, the mean SIR ratings for speech produced by children when they used their personal hearing aids with conventional amplification were 2.8 (SD: 1.1). A slightly higher rating of 2.5 (SD: 0.85) was obtained when children used new hearing aids with NLFC. The rating difference, though insignificant, could be attributable to a halo effect due to the fitting of new hearing aids, or some intrinsic differences between the two sets of devices other than NLFC, or the older age of assessment when children used the new hearing aids. The findings were inconclusive due to methodological limitations, including the lack of blinded assessments.

Irrespective of which rating procedure is used, judgments are likely to be influenced by whether the listeners are familiar with the talkers or experienced with speech of people with hearing loss. If the goal of the rating is to assess whether children produce connected speech that is readily understandable by a listener at first introduction [34], ideal judges would be those with normal hearing who have little exposure to the speech of children with hearing loss. However, the recruitment of a panel of inexperienced listeners to serve as judges is a major barrier to the clinical use of speech intelligibility rating. To facilitate clinical adoption of this procedure, it is therefore necessary to know if parents' estimates of their child's general speech intelligibility are valid, and if a child's clinician can provide an assessment of a child's speech intelligibility that compares well with that of inexperienced listeners.

The present study aimed to 1) investigate the influence of nonlinear frequency compression (NLFC) in hearing aids on intelligibility of speech produced by children with hearing loss; and 2) examine whether clinicians' or parents' judgments might be correlated with those of inexperienced listeners.

Materials and methods

Participants

Child Talkers

The talkers included eight children who were participants in a cross-over, four-period, double-blind evaluation of NLFC in hearing aids [35]. Approval for this study was granted by the Australian Hearing Human Research Ethics Committee for studies carried out at the National Acoustic Laboratories (NAL). Consent from guardians of all children were obtained before participation in the study.

In the study, performance was evaluated at four periods, including two assessments when children wore their personal hearing aids using conventional amplification, and two assessments when they wore Phonak Naida V SP (n = 6) or UP (n = 2) hearing aids with NLFC either activated or deactivated. A blinding protocol was used during the latter two periods so that neither the researcher who collected evaluation data nor the participants (including parents and children) knew whether NLFC was activated in hearing aids. The order of NLFC condition was counterbalanced across participants in the study. Evaluations were completed after the children had used the devices at the assigned settings for at least 6 weeks. To be included in the present study, the children had to have good quality audio recordings of speech samples available from evaluations at all four periods. The age of the children ranged between 7.0 and 14.3 years (mean: 11.4; SD: 2.3). Figure 1 shows the audiograms of the child-talkers, and Table 1 gives their age and hearing-aid information.

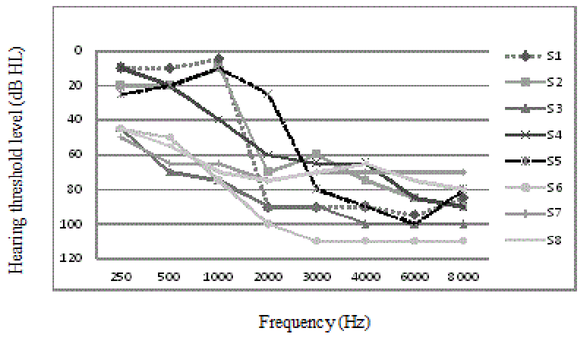

Figure 1: Hearing threshold levels in the better ear for each child-talker.

Listener-judges

Experienced judges included parents of the child-talkers, and clinicians (speech pathologists or audiologists). Inexperienced judges included a total of 27 first-year university students who were native speakers of Australian English. They had a mean age of 22 years (range: 18 - 30 years). All had hearing within normal limits, and reported no previous exposure to speech produced by children with hearing loss.

Approval for this study was granted by the Macquarie University Human Research Ethics Committee and all participants provided consent prior to participation in the study.

Estimates of maximum audible frequency in hearing aids of child-talkers

To estimate the audible bandwidth for each hearing aid amplification scheme for each individual child, the maximum audible output frequency (MOF) was first determined. The output of each hearing aid was measured using the MedRx® AVANT REM Speech+ Live Speech Mapping system, with speech-weighted noise at an input level of 65 dB SPL as stimuli. The MOF was the frequency at which the audiogram intersected with the aided speech spectrum. To estimate the maximum audible input frequency when NLFC was activated, a web-based software called the SoundRecover Fitting Assistant v2.0 (released in December 2012) was used [36]. The input parameters to the software included the MOF, and the compression threshold and compression ratio selected for the hearing aid of each child.

Subject No	Gender	Age (years) at first test session	Years using hearing aids	Personal hearing aids	Phonak hearing aids (CT/CR)
S1	Female	11.7	7.3	Siemens Explorer 500P	Naida V SP (2.1/1.8)
S2	Male	11.6	7.1	Siemens Intuis Dir	Naida V SP (3.2/2.1 to left ear; 2/1.8 to right ear)
S3	Female	7	5.7	Siemens Cielo 2P	Naida V UP (2/1.6)
S4	Female	14.3	9.2	Bernafon LS 12	Naida V SP (3.5/2.5)
S5	Male	13.2	8.8	Siemens Explorer 500M	Naida V SP (3/2.1)
S6	Female	10.7	4.3	Siemens Cielo 2P	Naida V UP (1.5/1.5)
S7	Female	9.7	9.3	Siemens Cielo 2P	Naida V SP (2.9/3.1)
S8	Female	12.9	9.4	Siemens Cielo 2P	Naida V SP (3.4/2.4)

Table 1: Age, gender, and hearing aid information of the eight child-talkers. *Abbreviations: CT, cut-off frequency (Hz); CR, compression ratio.

Procedure

Stimulus sentences for child production

The stimuli were sentences drawn from the Beginners' Intelligibility Test (BIT) [37] produced by the children. This test material is widely used for assessing speech production of children with hearing loss [8,11,37]. There are four lists, each comprising 10 sentences that are simple in content and syntactic structure (e.g. *The baby falls; the boy is under the table*). Sentences range in length from 2 to 6 words (mean = 3.8 words) and from 3 to 8 syllables (mean = 4.5 syllables). Each list of 10 sentences contained a total of 37 to 40 words (mean = 38.3 words) [37]. The lists were counterbalanced across hearing-aid conditions and across subjects. During test administration, a picture that conveyed the context of the target sentence was presented to the child, who was instructed to repeat the sentence that the researcher read from a script. With parents' permission, the child's production was audio-recorded using a Zoom H4N digital recorder with an AKG MicroMic C555L headset microphone, at a sampling rate of 44.1 kHz. Video-recordings of the production were also made at the same time. A total of 320 speech samples (8 subjects × 4 hearing aid conditions × 10 BIT sentences) were used for intelligibility judgments.

Procedure for speech intelligibility rating by inexperienced listeners

The rms level of the recorded BIT sentences was normalized, using the speech analysis software PRAAT version 5.3.57. The sentences were presented via headphones using the experiment presentation program DMDX [38] at an overall level of 65 dB SPL. Sentences from the 4 hearing-aid test conditions were blocked together with 4 blocks per test condition for each child-talker. The order of the presentation of sentences within test condition was randomized within the block.The order of presentation for the 4 blocks was also randomized. In this way

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each listener received a different order of presentation for the 10 sentences within each test condition as well as the order of the 4 test conditions in 4 blocks. Each listener heard sentences produced by two child-talkers containing a total of 80 sentences, 40 from each child-talker.

Four child-talkers received ratings from 8 listeners and four from 7 listeners. The listeners were instructed to listen to a series of sentences, with each sentence being played only once. They were asked to rate how well they could understand the sentence, using the rating scale provided.

A 6-point speech intelligibility rating (SIR) scale [30, 32], which is widely used for rating the speech production abilities of children with hearing loss, was used (see Table 2) [39]. The listening sessions were completed within 60 minutes.

Category	SIR description
1	I always or almost always understand the child's speech with little or no effort
2	I always or almost always understand the child's speech; however, I need to listen carefully.
3	I typically understand about half of the child's speech.
4	I typically understand about 25% of the child's speech.
5	The child's speech is very hard to understand. I typically understand only occasional, isolated words and/or phrases.
6	I never or almost never understand the child's speech.

Table 2: Speech Intelligibility Rating (SIR) Scale.

Speech intelligibility rating by experienced listeners

Parents were asked to estimate how well they thought an unfamiliar person would be able to understand their own child's speech production and provide a rating accordingly. Clinicians (speech pathologists or audiologists) that assessed the same children also provided a rating on how well they could understand speech produced by the children. The results from parents and clinicians were then compared to that of the inexperienced listeners.

Data Analysis

A repeated measures Analysis of Variance (ANOVA) was used to compare the ratings given by inexperienced listeners across 4 test conditions. For each child, the Friedman's test was used to compare the rating scales given by multiple inexperienced listeners across 4 test conditions. A product-moment correlation analysis was performed to analyze the relationship between ratings of inexperienced listeners and experienced listeners. Statistical calculations were performed using SPSS for Windows version 16 software and Statistica v10. Two-tailed p-values <0.05 were considered to indicate statistical significance in all tests.

Results

The speech intelligibility ratings by parents and clinicians are summarised in Table 3.

Subject No	Conventional amplification_1		NLFC activated		NLFC deactivated		Conventional amplification_2	
	Parent	Clinician	Parent	Clinician	Parent	Clinician	Parent	Clinician
S1	1	2	1	1	1	1	1	1
S2	1	1	1	1	1	1	1	1
S3	1	2	1	4	1	3	1	5
S4	1	1	1	1	1	1	1	1
S5	2	1	2	1	1	1	1	1
S6	1	1	1	1	1	1	1	1
S7	1	1	1	1	1	1	1	1
S8	1	1	1	1	2	1	1	1

Table 3: SIR ratings from parent and clinician for each child in each condition.

The mean ratings of parents, clinicians and inexperienced listeners for each aided condition are shown in Figure 2.

For inexperienced listeners, ANOVA analysis showed that there was a significant difference on the mean SIR scale across 4 test sessions ($F(1, 26) = 3.061$, $p = 0.033$). Further analyses using pairwise comparisons indicated that SIR scale for NLFC_ON condition were significantly different (indicating better intelligibility) than the three other conditions, with NLFC_OFF ($p = 0.002$), OWN_1 ($p = 0.015$), and OWN_2 ($p = 0.007$). These results suggest that children's speech intelligibility was rated best when wearing the new Naída hearing aids with NLFC activated. The analyses were repeated for ratings from experienced listeners. There were no significant differences across the 4 test conditions for the ratings provided by either parents or clinicians ($p > 0.05$).

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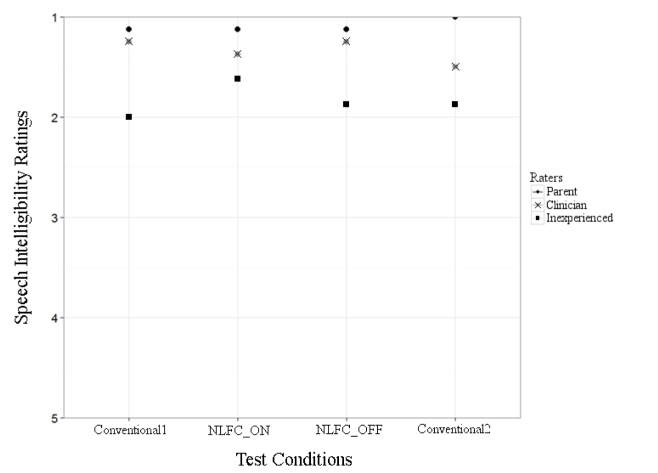

Figure 2: Mean Speech Intelligibility Ratings from parents (filled circles), clinicians (crosses) and inexperienced judges (filled squares) for children with conventional amplification at time 1 (Conventional 1), NLFC activated (NLFC_ON), NLFC deactivated (NLFC_OFF) and conventional amplification at time 2 (Conventional 2). Ratings of 1 denote "Always understand", and ratings of 5 denote "Very hard to understand" (see Table 2).

Mean ratings by inexperienced listeners for each individual child-talker are shown in Figure 3. The ratings provided by multiple inexperienced listeners across 4 test conditions for each child were analysed using the Friedman's test. With alpha set at 0.05, four child-talkers received significantly different ratings across the different hearing-aid conditions. Post-hoc pairwise comparisons were conducted between NLFC activated with deactivated, own conventional amplification at time 1 and time 2 using a Wilcoxon test. Type I errors were controlled across comparisons at the 0.05 level using the LSD procedure.

Four child-talkers showed significant variability in the ratings received across the 4 test conditions, three of whom presented with an advantage for NLFC activation. The remaining 4 children did not show a significant difference across test conditions.

S2 ($\chi2$ (3, N = 8) = 9.10, $p = 0.03$) had Kendall's coefficient of concordance of 0.38 indicating moderate rating differences among the four hearing-aid test conditions. The mean ratings were significantly higher (poorer) for NLFC activated (mean = 1.23) than deactivated (mean = 1.14) ($p < 0.04$), but not different from conventional hearing aid at times 1 and 2. The observed effect size, though statistically significant, is close to zero.

S5 (χ^2 (3, N = 7) = 15.66, $p < 0.01$) had Kendall's coefficient of concordance of 0.75 indicating fairly high rating similarities among the four hearing-aid test conditions. The mean ratings were significantly lower (better) for NLFC activated (mean = 1.49) than deactivated (mean = 1.99) ($p = 0.03$), and conventional hearing aid at time 2 (mean = 2.57) ($p = 0.02$), but not different from own hearing aid at time 1 ($p > 0.05$).

S6 ($\chi2$ (3, N = 7) = 17.40, $p < 0.01$) had Kendall's coefficient of concordance of .83 indicating fairly high rating similarities among the four hearing-aid test conditions. The mean ratings were significantly lower (better) for NLFC activated (mean = 1.87) than conventional hearing aid at time 1 (mean = 2.70) ($p = 0.02$), higher (poorer) than conventional hearing aid at time 2 (mean = 1.41) ($p = 0.02$), but not different with NLFC deactivated ($p > 0.05$).

S7 (χ^2 (3, N = 7) = 13.37, $p < 0.01$) had Kendall's coefficient of concordance of .65 indicating moderate rating similarities among the four hearing-aid test conditions. The mean ratings were significantly lower (better) for NLFC activated (mean = 1.44) than deactivated (mean = 2.10) ($p = 0.02$), conventional hearing aid time 1 (mean = 2.06) ($p = 0.02$), and time 2 (mean = 2.06) ($p = 0.02$).

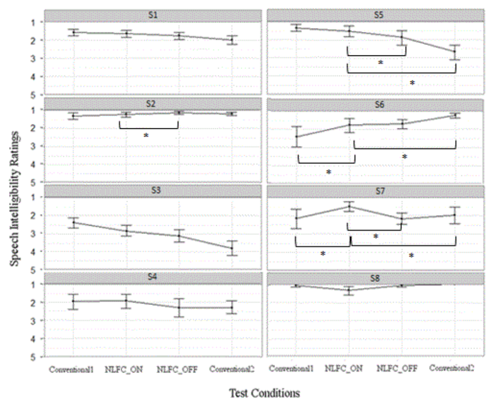

Figure 3: Mean Speech Intelligibility Ratings from inexperienced judges (filled symbols) for each child with conventional amplification at time 1 (Conventional 1), NLFC activated (NLFC_ON), NLFC deactivated (NLFC_OFF) and conventional amplification at time 2 (Conventional 2). Error bars indicate 95% confidence intervals. Ratings of 1 denote "Always understand", and ratings of 5 denote "Very hard to understand" (see Table 2). Significant differences ($p < 0.05$) between conditions linked by horizontal lines were marked by asterisks.

Table 4 shows the maximum audible frequency for each participant wearing their personal hearing aids using conventional amplification, or wearing the Naida hearing aids with NLFC activated or deactivated. On average, NLFC activation extended the range of maximum audible frequency relative to deactivation in the same hearing aids ($t = 3.41$ [df = 15], $p < 0.01$). The activation of NLFC extended the range of frequencies audible to 5 children (S2, S4, S6 S7, and S8) in at least one ear.

Agreement between speech intelligibility ratings of inexperienced and experienced listeners (parents and clinicians) was analyzed using bivariate correlations. With alpha set at 0.05, a moderate positive correlation was found between inexperienced listeners and clinicians ($r = 0.58$, $p < 0.01$). However, ratings of parents did not correlate with ratings of either clinicians or inexperienced listeners.

Subject No	Better ear	Maximum audible frequency (Hz)_Left ear			Maximum audible frequency (Hz)_Right ear		
		Conventional amplification	NLFC deactivated	NLFC activated	Conventional amplification	NLFC deactivated	NLFC activated
S1	Right	1777	1612	1612	1661	1752	1647
S2	Right	1303	1542	1542	3494	3433	5581
S3	Right	1455	1746	1746	1627	1741	1741
S4	Left	3550	4591	7354	4098	4597	7378
S5	Right	2697	2557	2557	2876	2927	2927
S6	Right	914	1670	1861	1494	1706	1921
S7	Right	2828	5630	7280	3076	5635	7280
S8	Left	4470	5386	7920	3060	5586	7920

Table 4: Maximum audible frequency (Hz) for each child-talker wearing personal hearing aids and Naida hearing aids with NLFC deactivated and activated.

Discussion

The present study was a first attempt to evaluate NLFC technology by using a panel of inexperienced listeners to rate the relative intelligibility of sentences produced by children when using different amplification schemes. In particular, it examined the intelligibility judgments of listeners who reported no previous exposure to speech produced by people with hearing loss, and compared the judgments to ratings of parents of the children and clinicians who provided services to them. Age-appropriate language material was used to elicit production of continuous discourse. As the material has high contextual redundancy, an overall rating method rather than a word scoring method was used. This reduced coding time, and allowed for ratings of multiple listeners to be used to provide a reliable estimate [32]. To partly control for subjectivity in rating, a panel of inexperienced listeners was used for rating productions of more than one child, using the SIR scale with accompanying descriptions. The specific aims were to 1) investigate the influence of NLFC on intelligibility of speech produced by children using hearing aids; and 2) examine whether ratings by inexperienced judges correlate with those of parents and clinicians.

In regards to the first aim, group-level results suggest that speech intelligibility of child-talkers was rated by inexperienced listeners to be better when NLFC was activated than when it was deactivated. On an individual level, three of the children exhibited significant differences. S5 had a sloping hearing loss, and NLFC activation did not extend the audible bandwidth although it did lead to a significant improvement in speech intelligibility. S7 had moderately severe flat hearing loss, and NLFC activation resulted in an extension of audible bandwidth from 5.6 kHz to 7.3 kHz. This was associated with a significant improvement in intelligibility. S4 had a sloping hearing loss, and NLFC activation extended the audible bandwidth from 4.5 kHz to 7.4 kHz. The ratings for NLFC activated were better than for NLFC deactivated, although the difference did not reach significance level. For S2, speech intelligibility ratings were minimally higher without NLFC than with NLFC activation, but this effect was close to zero. This child had a steeply sloping hearing loss, with near-normal hearing up to 1 kHz and severe to profound loss at higher frequencies. Although the use of NLFC increased the audible bandwidth in one ear from 3.4 kHz to 5.6 kHz, it might also have introduced audible distortions. For three of the remaining children, speech was rated to be highly intelligible across all test conditions, suggesting that they were well supported by conventional amplification for development of speech production. The use of NLFC did not result in further improvement because of ceiling effect. For instance, the hearing aid measures for S8 revealed an extension of audible bandwidth from about 5.3 kHz to 7.9 kHz, and no effect of this extension on speech intelligibility was indicated because the child could be easily understood across all test conditions.

It has been suggested that previous evaluations of NLFC for children that were based on comparisons between children's own hearing aids with conventional amplification and new Naida hearing aids with NLFC could potentially be confounded by inherent differences between hearing aids in addition to the difference in signal processing [15]. The findings in this study provide some support for this conjecture – the ratings for conventional amplification provided by children's own hearing aids and by Naida hearing aids (NLFC deactivated) were significantly different for two child-talkers (S2, S6). The rated intelligibility was higher when Naida hearing aids were used. As shown in Table 4, the audible bandwidth was slightly extended with the Naida hearing aids compared to the children's own hearing aids, but activation of NLFC did not further increase high-frequency audibility. This is likely a limitation related to the hearing loss configurations – S6 had a moderate to profound sloping hearing loss, and S2 had hearing within the normal range up to 1 kHz, but severe to profound hearing loss at higher frequencies.

The second aim of this paper was to assess whether parental and clinician reports of children's speech production intelligibility are indicative of how well the child's speech can be understood by the general hearing public. This study found that speech intelligibility ratings by inexperienced listeners correlated well with experienced listeners who are clinicians, but that neither group's ratings correlated with parental ratings. This suggests that clinician's ratings of children's speech intelligibility is a good indicator of how well children can be understood by the general hearing public. Parental reports, on the other hand, are not good indicators of children's speech intelligibility by unfamiliar listeners. These results suggest that a clinician's judgment of a child's speech production intelligibility may be used as a valid tool for evaluation of the effectiveness of amplification. The findings of this study on the intelligibility of speech produced by children when fitted with NLFC relate to the use of Naida V hearing aids, and cannot be generalized to other frequency-lowering schemes available in commercial hearing aids.

Limitations

The present findings suggest that the use of speech intelligibility ratings is a useful clinical tool for evaluating the effect of NLFC on speech production of young children at a group level. Given the small sample size, the findings cannot be generalized. The effect size was small. Therefore, future investigations will require a larger sample, with audiometric configurations that meet manufacturer's criteria for selection of NLFC, to examine the impact of NLFC on children. More sensitive test material, such as the use of non-words or anomalous sentences, are likely to reveal the influence of signal processing more effectively than the use of simple short sentences that have high contextual information as in the BIT sentences used in this study. This will allow ratings to be based exclusively on characteristics of the acoustic speech signal produced by children rather than on a combination of acoustic cues with contextual and linguistic cues [40]. It will then be possible to determine the effect of NLFC on speech intelligibility of children with different audiometric characteristics.

This study found a lack of correlation between ratings of parents and those of inexperienced judges. This may be due to a difference in the protocols for judging intelligibility, or the relative familiarity with speech produced by children with hearing loss for the two groups of listeners. Whereas parents rated overall intelligibility of their own child, the inexperienced listeners rated the intelligibility of recorded sentences produced by several children who were not familiar to them. Future work using a consistent protocol with the same test material for both parents of children with hearing loss and inexperienced judges will shed light on the relative effects of talker-familiarity and listening experience on intelligibility ratings.

Conclusion

The present study found that, on average, the use of NLFC improved the speech intelligibility of children with hearing loss, based on ratings of a panel of inexperienced listeners. Significant correlations between ratings of inexperienced listeners and clinicians based on a 6-point scale support the use of clinicians' judgments of children's speech intelligibility as a clinically viable tool for evaluating the effectiveness of amplification for children.

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