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The Effect of Frequency Transposition on Speech Perception in Adolescents and Young Adults with Profound Hearing Loss

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This paper reports on a clinical trial evaluating outcomes of a frequency-lowering technique for adolescents and young adults with severe to profound hearing impairment. Outcomes were defined by changes in aided thresholds, speech perception, and acceptance. The participants comprised seven young people aged between 13 and 25 years. They were divided into two groups based on their audiometric configuration. The first group consisted of four young people with pure tone thresholds of ≤100 dB at 1 kHz. The second group had more profound hearing loss, with pure tone thresholds of >100 dB at 1 kHz. All participants attended the Fundació Widex Audiologia in Barcelona, a charitable foundation offering intervention and habilitation programmes for hearing-impaired children of all ages. The participants were oral communicators integrated into mainstream high schools and universities. All were experienced hearing aid users with excellent spoken language and no other disability. The hearing aids were fitted using standardized procedures and were worn with the frequency transposition algorithm in the first programme for consistent everyday use. Phoneme and word recognition were assessed after 4, 8, and 12 weeks of use and compared with results for their own

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superpower hearing aids. Subjective comments from both the participants and their parents were recorded throughout the study. Notable improvements were observed in both sound-field-aided thresholds and speech perception after 12 weeks of use, suggesting that frequency lowering can be efficacious in improving speech perception in severely to profoundly hearing-impaired individuals who are past the critical age for language acquisition.

KEYWORDS frequency transposition, hearing aids, profound hearing loss, speech perception, speech recognition

Introduction

Children and adults with severe to profound or precipitously sloping hearing loss face a number of communicative challenges because they typically do not have access to the entire range of speech sounds. Limited access to speech sounds may have a detrimental effect on speech perception in severely or profoundly hearing-impaired adults, and may cause a delay or failure of normal language development in children (e.g. Boothroyd, 1984; Elfenbein et al., 1994; Flynn et al., 1998; Stelmachowicz et al., 2004). There is also evidence to suggest that limited perceptual access to speech sounds may also have a substantial impact on the development of literacy and academic skills in students with severe to profound hearing loss (e.g. Leybaert, 1993; Sterne & Goswami, 2000; Traxler, 2000; Qi & Mitchell, 2007). The ability to read and to communicate orally and in writing is essential to success in the educational system as well as in contemporary society. This provides a strong motivation for exploring the possibilities offered by new technologies that expand the range of audible speech sounds.

Accurate perception of speech sounds depends on the audibility of the different frequency regions. While the energy of vowel sounds is mainly located in the low and mid-frequencies, many consonant sounds have energy in the high-frequency region (Stevens, 1998). Plosive and fricative consonants, such as /s/, /z/, /ʃ/, /t/, /f/, and /θ/, can be difficult to perceive and produce for people with hearing loss in the high frequencies (e.g. Elfenbein et al., 1994; Flynn et al., 1998). Consequently, the ability to distinguish minimal pairs such as sake–shake–take and free–three will be impaired with high-frequency hearing loss. Moreover, the inability to accurately perceive and distinguish /s/ and /z/ will also have consequences for the perception and production of grammatical structures for speakers of English as these sounds are used for a number of grammatical purposes, including the marking of plurals, possessives, the third person singular tense, and contractions (Yavaş, 2006).

In cases of severe to profound or precipitously sloping hearing loss configurations, ensuring audibility of high-frequency content by means of amplification alone presents a considerable challenge. Studies have shown that when a hearing loss begins to exceed 55 dB in the high frequencies, participants may not benefit from high-frequency amplification (Moore, 2001). This lack of benefit of high-frequency amplification has been attributed to limitations of the hearing aid in the form of restricted bandwidth, low maximum output, or feedback before the necessary level of amplification is reached (Stelmachowicz et al., 2001; Auriemmo et al., 2009) as well as the existence of dead regions, that is, areas of the cochlea with no functioning inner hair cells (Moore, 2001; Baer et al., 2002; Preminger et al., 2005). Studies on speech perception in people with suspected high-frequency dead regions have shown that amplification of the high frequencies often fails to provide benefit and may in fact lead to poorer performance in some instances (Ching et al., 1998; Hogan & Turner, 1998; Turner & Cummings, 1999).

The failure of conventional hearing aid amplification to restore high-frequency audibility has led to the development of alternative techniques. One such technique is linear frequency transposition where high-frequency content is shifted to a lower frequency region with functioning hair cell (Kuk et al., 2006). The linear frequency transposition technique has been implemented in the *Audibility Extender* feature in the mind440 hearing aid, manufactured by Widex. Based on the hearing loss configuration, the Audibility Extender chooses a start frequency, which functions as a line of demarcation. Frequency regions below the start frequency will be amplified in the conventional manner. The high-frequency region above the start frequency will be analysed by the *Speech and noise tracer* in the hearing aid to identify the frequency range (*source octave*) with the highest intensity. This frequency range will be selected for transposition, and the high-frequency information around the most prominent peak in the source octave will be moved down one or two octaves to a lower frequency region with aidable hearing. The sounds flanking the most prominent peak will be filtered out to minimize masking effects, and the transposed sound will automatically be amplified so that it is above the hearing threshold of the region to which it has been moved (Kuk et al., 2006).

Hearing care professionals are often concerned that the use of powerful hearing aids may cause additional damage to the residual hearing due to overamplification, and rightly so. Studies have shown that excessive amplification may lead to temporary as well as permanent threshold shift, resulting in greater hearing loss (e.g. Esser, 1984; Hawkins, 1982; Macrae, 1991, 1992, 1993). A literature review by Macrae (1994) concluded that the greater the hearing loss, the greater the risk of damaging the residual hearing due to overamplification. According to Macrae (1994), some hearing aid users prefer amplification that is 10–20 dB higher than recommended for their hearing loss. There is evidence to suggest that at normal input levels, amplification exceeding the recommended amount by 15 dB can aggravate the hearing loss in persons with three-frequency (0.5, 1, and 2 kHz) average thresholds of about 80 dB or greater. If the ambient sound level is high, overamplification can damage the residual hearing of people with three-frequency average thresholds of 50 dB or greater (Macrae, 1994). From a theoretical point of view, the linear frequency transposition technique should provide particular benefit to hearing aid users with severe or profound hearing loss, as it can render high-frequency sound audible without the use of large amounts of amplification, which reduces the risk of damage to the critical residual hearing from overamplification.

In practice, the linear frequency transposition technique has been found to produce successful outcomes for children with precipitously sloping high-frequency hearing loss (Auriemmo et al., 2008, 2009; Booysen et al., 2008; Verschoor et al., 2008; Smith et al., 2009). For example, Auriemmo et al. (2009) reported significant improvements in the consonant and vowel recognition and fricative articulation of 10 school-aged children with precipitously sloping hearing losses after 6 weeks of use of the Audibility Extender. Smith et al. (2009) reported an overall significant improvement in the speech perception and production of a group of six school-aged children after 24 weeks of use of the Audibility Extender, although individual benefits varied. Booysen et al. (2008) observed rapid increases in word-learning abilities in a group of seven children with moderate to severe hearing losses. Verschooer et al. (2008) found improved word recognition in both quiet and noise in the same group of children.

Various frequency-lowering strategies have been implemented in devices fitted to children with severe to profound hearing loss across the entire frequency range, with results dating back more than 30 years (Simpson, 2009). However, the benefit of the specific strategy applied in the Audibility Extender has not yet been investigated extensively for this group.

Even if the alternative signal processing feature can successfully render high-frequency content audible to listeners with severe to profound hearing loss, the question remains whether quick acclimatization and user acceptance is achievable in an older group of hearing aid users who have worn superpower hearing aids for many years. It has often been observed that severely and profoundly hearing-impaired listeners, who are very much dependent on their hearing aids because of the severity of their hearing loss, are sceptical about trying new processing strategies because they perceive the potential problems of trying new hearing aids to be greater than the potential benefits (Kuk, 2001; Keidser et al., 2007; Convery et al., 2008). The aim of the present study was therefore to obtain data on speech perception and user acceptance from a group of young people previously fitted with superpower hearing aids when refitted with less powerful aids with frequency transposition.

Method

Candidate selection and aid verification procedures were in accordance with the clinical best practice used at the Fundació Widex Audiologia. Hearing aid fitting was according to the protocols recommended by the hearing aid manufacturer. Aid evaluation protocols for speech perception tasks were an adaptation of the research methodology applied by Smith et al. (2009). All the procedures will be described in detail in the following sections.

Participants

Seven adolescents and young adults with congenital severe to profound hearing loss, particularly in the high frequencies, were recruited for the study. The age range was 13–25 years. All the participants had been fitted with superpower hearing aids (Widex P38: peak gain = 89 dB, Maximum Power Output (MPO) > 140 dB; Siemens Artis 2 SP: peak gain = 84 dB, MPO > 140 dB) at an early age (2 years or younger). The recommended fitting ranges of the participants' own aids and the experimental aid are shown in Figures 1–3.

The participants were oral communicators, Catalan being their first language and Spanish their second. They all participated in mainstream high school or university classes, and their spoken and written language competencies were good. There was no other disability. The participants' pure tone average under headphones and their binaural unaided sound field thresholds were initially obtained. The age and audiometric configuration of the participants are shown in Table 1.

Based on the degree of hearing loss, the participants were divided into two groups. Group A ($n = 4$) had a pure tone level of $\leq$100 dB hearing threshold level (HTL) at 1 kHz, while Group B ($n = 3$) had a pure tone level of >100 dB HTL at 1 kHz. Thus,

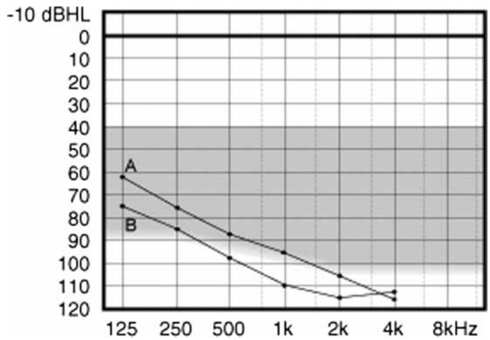


FIGURE 1 Recommended fitting range of Widex mind440 m4–19 (experimental aid). 'A' and 'B' refer to the average HTLs for the two groups in the study.

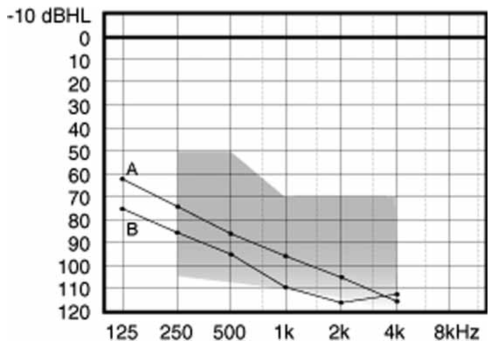


FIGURE 2 Recommended fitting range of Widex P38.

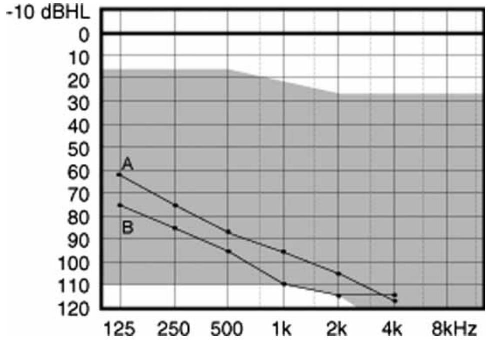


FIGURE 3 Recommended fitting range of Siemens Artis 2 SP.

Group A was within the fitting range of the experimental aid in the low and mid-frequencies, but not in the high frequencies where audibility would be provided through transposition. Group B's hearing losses exceeded the recommended range in the low and mid-frequencies as well as in the high frequencies where audibility would be provided through transposition (see Figures 1–3).

Fitting of experimental hearing aids

All participants were fitted binaurally with the Widex mind440 m4–19 power model. New impressions were taken and new hard acrylic shell moulds with a 0.8 mm vent were made for each ear. Hearing aids were fitted using the *in situ* fitting procedure recommended by the manufacturer, known as the Sensogram (Ludvigsen & Toepholm, 1997). The procedure involves determining audiometric thresholds for four ('Basic' option) or fifteen frequency channels ('Expanded' option), using the hearing aid as an audiometer. The results are used to determine the appropriate amplification and compression in accordance with the proprietary fitting rationale. The fittings were based on the four-frequency-channel option rather than the fifteen-channel option. A feedback test was performed to minimize the risk of whistling. In some cases, the results of the feedback test were not acceptable. In those cases, new impressions were taken or the venting removed to ensure that all the participants were able to achieve the required gain settings for all input levels.

The counselling of the participants, their families, and their speech therapists was an integral part of the fitting process. Efforts were made to anticipate difficulties that might arise when the candidates changed to a lower-powered hearing aid with a completely different signal processing strategy. It was important to encourage them to persevere and remain confident that even if sounds were perceived as softer or the hearing aid as less powerful, the end result might still be improved speech intelligibility.

An acclimatization period of 1–2 weeks was allowed to adjust to the signal processing in the new hearing aid. When the acclimatization period was over, frequency transposition was introduced via the Audibility Extender program, which was set up as the

TABLE 1

AGE AND AUDIOMETRIC CONFIGURATION OF THE PARTICIPANTS

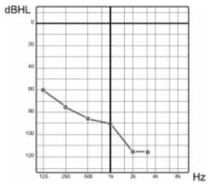
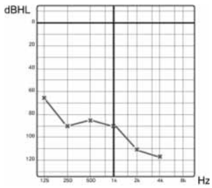
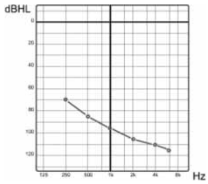
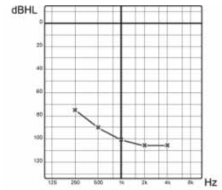
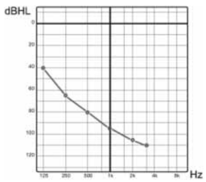
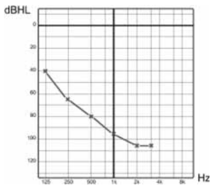
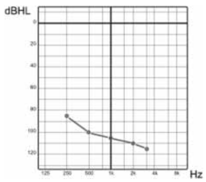
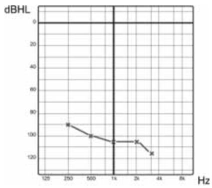
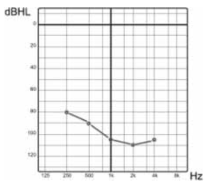
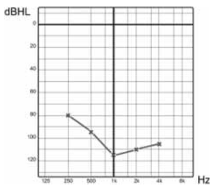
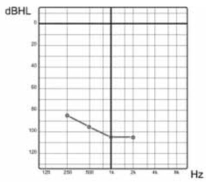
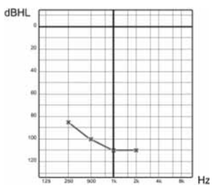
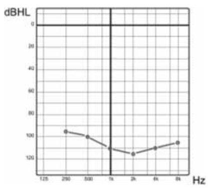
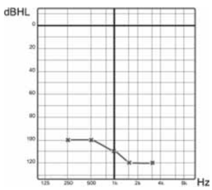
Participant	Age	Gender	Group	Right hearing loss	Left hearing loss	Own hearing aid
1	13	Male	A			Widex P38
2	16	Male	A			Widex P38
3	25	Female	A			Siemens Artis 2 SP
4	17	Male	A			Widex P38
5	20	Male	B			Widex P38
6	21	Male	B			Widex P38
7	17	Female	B			Widex P38

TABLE 2

FITTING PARAMETERS

Group A	Start frequency (Hz)	Octaves shifted	Gain added (dB)
Participant #1	2000	2	8
Participant #2	2000	2	6
Participant #3	2000	2	6
Participant #4	2000	2	4
Group B	Start frequency (Hz)	Octaves shifted	Gain added (dB)
Participant #5	2000	2	8
Participant #6	2000	2	8
Participant #7	2000	2	8

primary listening program. The Master program was included as the second listening program, which the users could revert to if they found the transposed signal unacceptable, but none of the participants used it. The initial frequency transposition settings were set by the manufacturer's software and then customized, based on the response of the participants and the observations of their parents and speech therapists. Typically, the start frequency was 2 kHz, which enabled normal acoustic gain to be provided for those sounds that are critical for intelligibility, with 2 octaves transposed and 4–8 dB added gain to give an acceptable perception of 'loudness' (see Table 2).

Measures

The quantitative performance of the old hearing aids and the test hearing aids was assessed when the frequency transposition setting had been finalized after 4 weeks of continuous use. Verification was by means of binaural-aided thresholds obtained in the free field using calibrated warble tones.

Phoneme and word recognition was assessed after intervals of 4, 8, and 12 weeks, using a battery of speech perception tests. Evaluations were performed using Monitored Live Voice at a distance of 1 m in a quiet room. Stimuli were produced at normal speech levels (60–65 dB) by a female experimenter with a considerable amount of experience producing Monitored Live Voice stimuli. A sound level meter was used to ensure that the stimuli were within normal speech levels. Except in the open set Catalan bisyllabic word task, the participants sat with their eyes closed so they could not rely on lip and face reading to identify the phonemes and words.

Phoneme identification tests

Phoneme identification was tested by means of the Ling six-sound test (Ling, 2002), and Huarte et al.'s (1996) closed-set vowel and consonant identification test with monosyllabic and bisyllabic Catalan words.

The Ling six-sound test typically uses the six phonemes /m, a, u, i, s, and ʃ/ to test the listeners' hearing across the speech spectrum. In the present study, the nasal consonant /m/, which is characterized by low-frequency energy, was replaced by the Catalan voiced alveolar fricative /z/, whose energy is primarily located in the high frequencies, in order to focus on the participants' ability to perceptually distinguish fricatives with high-frequency energy (/s, z, ʃ/).

Phoneme identification was tested further by means of a Catalan adaptation of Huarte et al.'s (1996) closed-set phoneme identification test. The experimenter generated twenty vowel tokens (/i, e, a, o, u/), which the participants had to repeat. Consonant identification was assessed by means of twelve VCV syllables (alla, oxa, ola, asa, anya, ora, ata, otxa, oga, oca, afa, and ona), containing one of the most commonly occurring consonants in Catalan flanked by the vowel /a/ or /o/. Participants were given a list of possible phonemes before the tests were initiated.

Word identification tests

Word identification was tested by means of a Catalan translation of Huarte et al.'s (1996) closed-set word lists comprising twelve commonly occurring Catalan monosyllabic words (banc, sol, pa, flor, tos, gat, serp, arc, foc, rei, plat, and vent) or bisyllabic words (dona castell, fulles, vidre, cotxe, sastre, barret, figues, gasos, piles, branca, and capsa), as well as an open-set word list comprising twenty commonly occurring bisyllabic Catalan words (ulls, nova, coure, bou, sostre, ànims, mobil, soldat, planxa, cargol, bondat, quadre, balcó, platja, disquet, canya, sucre, globus, pesca, and flama) chosen by the experimenters. Participants had to identify the twelve closed-set monosyllabic and bisyllabic words from a written list. During the open-set word list test, participants had to repeat the words spoken by the experimenter. The open-set test was carried out twice. During the first trial, participants had no visual cues. During the second trial, they were able to rely on lip and face reading.

Results

Free-field-aided testing

The quantitative performance of the participants' old hearing aids and the mind440 m4–19 fitted with the Audibility Extender program was examined using Free Field-Aided Testing. The unaided thresholds, the thresholds obtained with the participants' own hearing aids, and with the Audibility Extender program are shown in Figure 4. The unaided thresholds, the thresholds obtained with the participants' own hearing aids, and the thresholds obtained with the experimental aids below 2 kHz comprise traditional audiometric thresholds. However, the stimuli presented at 2–8 kHz were shifted to a lower frequency region by the Audibility Extender program in the experimental aids, and so were not heard at the original source frequencies. Thus, the thresholds indicated for the Audibility Extender program above 2 kHz indicate the necessary sound level in order for stimuli with a source frequency

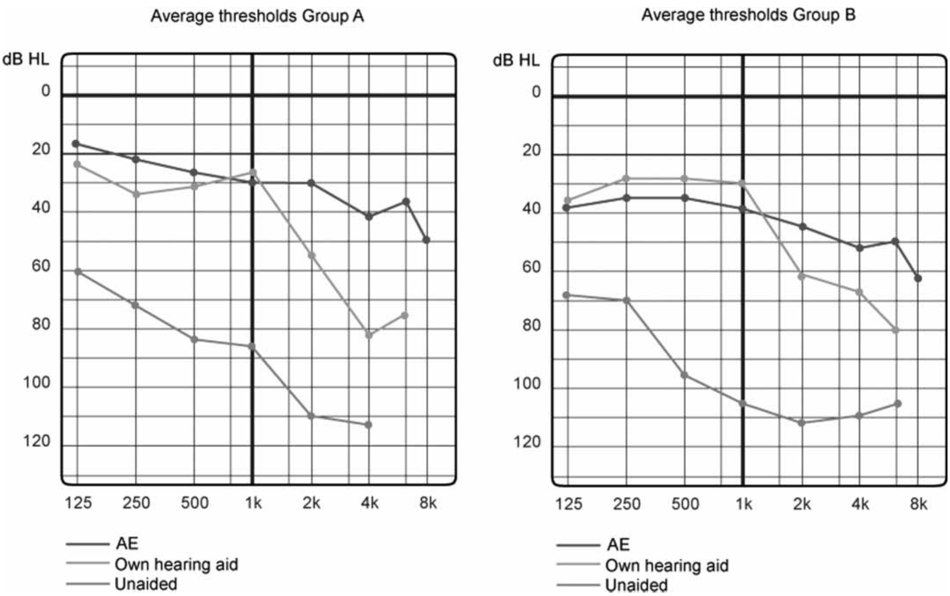


FIGURE 4 Average free-field hearing thresholds for Group A (left panel) and Group B (right panel) when listening unaided, with own hearing aids, and with the Audibility Extender after 4 weeks of use. The audiometric thresholds obtained with the Audibility Extender program indicate the necessary sound level in order for the source stimuli of 2–8 kHz to be heard at the lower frequency to which they have been transposed.

of 2–8 kHz to be audible in the lower frequency region to which they have been transposed.

The results indicated considerable improvement in the high-frequency region for both groups. Group A showed general improvements in the average aided hearing threshold across the entire frequency range, with the exception of 1000 Hz where a small decrease in the average hearing threshold of 4 dB was seen. Substantial improvements were observed for stimuli at 2 kHz (20 dB), 4 kHz (39 dB), and 6 kHz (36 dB). These results are not a consequence of amplification but reflect the new access to high-frequency sound provided by the linear frequency transposition algorithm. Improvement was also seen at 125 Hz (8 dB), 250 Hz (10 dB), and 500 Hz (6 dB).

The results for Group B also indicated large improvements in the average hearing threshold in the mid- and high-frequencies. Improvements of 18 dB were observed for stimuli presented at 2 and 4 kHz and of as much as 38 dB for stimuli presented at 6 kHz. However, in the lower frequencies a decrease of the average hearing threshold was observed at 125 Hz (–2 dB), 250 Hz (–7 dB), 500 Hz (–7 dB) and 1 kHz (–12 dB). The decrease in the average hearing threshold in the low frequencies may reflect that the participants did not receive sufficient amplification in the low frequencies.

The results from the free-field test indicated considerable improvements in audibility in the mid- and high-frequency region with the Audibility Extender for both groups. However, aided threshold measures are essentially an indicator of whether the signal at each frequency will be audible. Whether the observed improvements in audibility translate into intelligibility must be assessed by means of speech perception tests.

The results for both speech identification and comprehension showed a marked improvement for both groups after 12 weeks of use. These results are consistent with the improved aided thresholds. In Group A, the total number of correct identifications almost doubled, increasing from 46 per cent with the participants' own hearing aids to 86 per cent with the Audibility Extender after 12 weeks of use. In Group B, the leap was even greater. Correct identifications went from 39 per cent with their own hearing aids to near-perfect identification of 94 per cent with the Audibility Extender after 12 weeks of use. The results were analysed using the McNemar test for two related samples. The test results indicated that both Group A's and Group B's correct identification scores had increased significantly (McNemar test, Group A: chi-square = 10.08, $n = 24$, df = 1, $P = 0.00075$ (one-tailed); Group B: chi-square = 8.1, $n = 18$, df = 1, $P = 0.0022$ (one-tailed)). The distribution of correct identifications and errors is shown for each phoneme in Figure 5.

The results of the phoneme and word identification tests obtained with the old hearing aids and after 12 weeks of use of frequency transposition are shown in Figure 6.

It may be observed that with the Audibility Extender program, Group A showed improvements on all the tests performed, especially on monosyllabic and bisyllabic word identification. These results are consistent with the improved aided thresholds

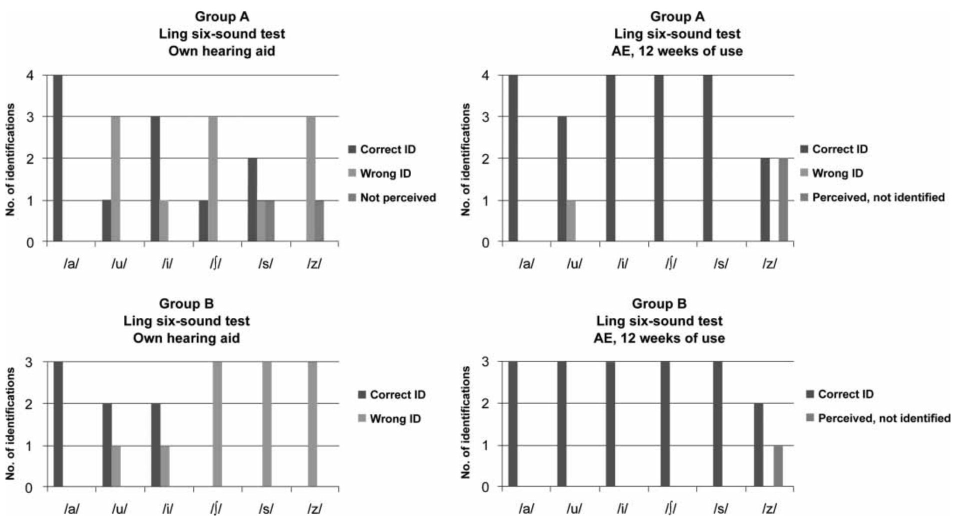


FIGURE 5 Distribution of correct and incorrect identifications of each phoneme with the participants' own hearing aids and with the Audibility Extender after 12 weeks of use in Group A (upper panels) and Group B (lower panels). Incorrect identifications have been subdivided according to whether they were wrongly identified as another phoneme, perceived but not identified, or not perceived at all.

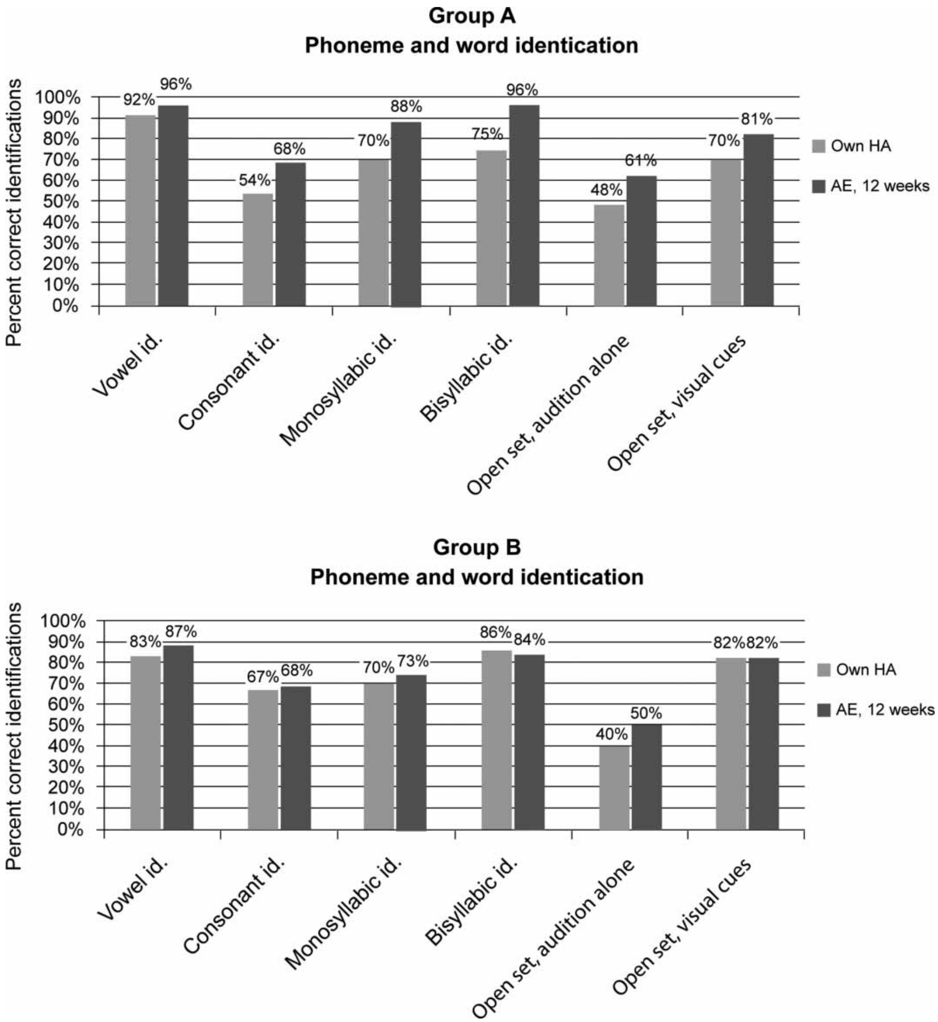


FIGURE 6 Correctly identified phonemes and words by Group A (upper panel) and Group B (lower panel) with the participants' own hearing aids and with the Audibility Extender after 12 weeks of use.

and may reflect their better unaided thresholds. Improvements in Group B were generally smaller. In one instance, the participants' average performance was actually 2 per cent better with their old hearing aids than with the Audibility Extender (bisyllabic identification), and in one instance, their average performance was the same (open set, visual cues).

Given the substantial improvements observed in Group A's speech identification results, statistical analyses of the results were warranted. The most commonly applied method when data have been collected twice on the same subjects is the *t*-test. However, due to the small sample size, a normal distribution of the data could not be assumed. A decision was therefore made to analyze the data by means of its non-parametric equivalent, the Wilcoxon's matched-pairs signed-rank test. This test is less powerful than the *t*-test, but does not require a normal distribution of the data (Siegel, 1956).

Wilcoxon's matched-pairs signed-rank tests performed on the correct identification scores obtained with the participants' own hearing aids and the experimental aids with the Audibility Extender feature after 12 weeks of use showed a significant improvement in Group A's speech identification scores with the Audibility Extender program when compared with their own aids ($Z = 2.201$, $P = 0.014$ (one-tailed)), while no significant difference could be demonstrated for the speech identification scores obtained by Group B in the two conditions ($Z = 1.511$, $P = 0.655$ (one-tailed)).

Discussion

For the seven severely to profoundly hearing-impaired young people who participated in this study, the frequency transposition system provided increased high-frequency audibility compared to conventional hearing aids, resulting in considerably higher aided thresholds and significantly improved identification and discrimination of isolated phonemes (Ling test).

Results from the phoneme and word recognition tests suggested that the participants who received the most benefit from the increased audibility were those with the least profound hearing loss. The participants whose pure tone level was ≤100 dB HTL at 1 kHz (Group A) showed significant improvements on the speech identification tests performed. These results are an indicator of the potential for wider application of linear frequency transposition for hearing aid users with severe to profound hearing loss.

The more profoundly hearing-impaired participants with pure tone levels of >100 dB HTL at 1 kHz (Group B) improved notably in terms of aided threshold and vowel and fricative recognition in the Ling test, but only marginally on vowel identification and word identification. This could be a consequence of insufficient amplification in the lower frequencies. While the average aided hearing threshold generally improved in Group A with the frequency-lowering programme, it decreased by between 2 and 12 dB in the 125 Hz–1 kHz frequency range in Group B. Consequently, the more profoundly hearing-impaired participants may not have received sufficient amplification in the low-frequency region to ensure audibility of speech sounds with energy concentrations in the low frequencies, or environmental sounds.

In general, the severely to profoundly impaired participants in Group A found the transition to the new signal processing easy to accept and were positive in their subjective comments regarding perceived aid benefit. Comments made by this group included phrases such as '…much better than my old ones…', 'I heard much more clearly', '…I understand better in group conversations…', '…Now I have what I thought I was missing'. This last statement is particularly perceptive, as the user is identifying sounds he can now hear rather than just presuming the sound is present. The families of Group A were also committed to the benefits of these hearing aids and actively encouraged continuing long-term use. The more profoundly impaired participants in Group B had a lower acceptance of the alternative technology. This group may have been more dependent on low-frequency and vibro-tactile cues for communication and were less able to make the transition and integrate high-frequency cues as easily. Comments made by this group were mixed. There were positive comments such as: 'I heard voices nearer and I understand them better…', or '…I talk quietly and slowly…', but this group also said '…I can't hear the sounds I used to, like the basketball bouncing'.

Insufficient amplification of mid- and low-frequency information could also explain the lack of improvement in the profoundly impaired group's phoneme and word identification scores. Vowel and sonorant consonant energy is primarily concentrated below 1 kHz (O'Shaughnessy, 2008; Stevens, 1998), so the participants may have had difficulties hearing vowel and nasal consonants in the test items used in the Huarte et al. (1996) test battery. This is not supported by the profoundly impaired group's Ling results for vowels, which were at ceiling with the experimental hearing aids after a 12-week trial period. However, it could be speculated that vowel recognition may be easier in a Ling test since vowels are typically produced with shorter duration and target undershoot in a syllable-context compared to when they are produced in isolation (Strange et al., 1976, 1983). Thus, the acoustic cues that characterize the vowels will in all likelihood have been available for a shorter stretch of time when the vowels were produced in the mono- and bisyllabic conditions, and the spectral targets that characterize steady-state vowels will probably not have been attained. In addition, there may have been a learning effect as the phonemes used in the Ling test are small in number and comprise relatively simple input compared to syllables and words.

It is important to note that although the profoundly impaired participants did not perform better on the entire battery of speech perception tests, they did not perform significantly worse either. In this study, participants had 12 weeks to adapt to the linear frequency transposition scheme. It is possible that, given more time, greater improvements may have been observed for the profoundly impaired participants' speech perception also. These results suggest that candidates with severe to profound hearing loss can obtain significant benefit from alternative frequency-lowering technology. Candidates with more profound hearing loss (>100 dB at 1 kHz) may benefit more from linear frequency transposition if it can be incorporated into a device with more overall power in the low- and mid-frequency regions where audibility is provided through traditional amplification.

Conclusion

This study identified positive outcomes for linear frequency transposition as defined by changes in aided thresholds, speech perception, and acceptance. It evaluated the changes observed in seven adolescents and young adults with severe to profound hearing loss who trialled the frequency transposition scheme for 12 weeks. The participants were fitted with high-power hearing aids that incorporated frequency transposition. Four of the participants' audiometric configurations were within the fitting range of the experimental aid, while three exceeded the recommended range in both the low- and mid-frequencies where traditional amplification would be applied, as well as in the high frequencies where audibility would be provided through transposition. Positive outcomes in the form of improved aided thresholds in the high frequencies and better speech identification accuracy were noted for both groups. There was good acceptance of the new technology by the group with thresholds within the recommended fitting range and these candidates continue to wear the alternative technology for everyday use.

The results suggested that linear frequency transposition, as incorporated into the Widex mind440 m4–19 hearing aid, is also efficacious in improving speech perception in individuals with severe to profound hearing loss. The candidates who appeared to have received the most benefit were those with thresholds within the defined fitting range for low- and mid-frequency sound. The positive improvements in speech perception are very encouraging as candidates were all outside the critical age for language acquisition. In addition, the subjective acceptance of this group is a very positive outcome as they would normally be considered as candidates who find transitioning to new signal processing strategies particularly challenging.

Conflict of interest

None of the authors have a financial interest in the commercialization of any product or knowledge arising from this study.

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