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Preliminary Results with the AVR ImpaCt Frequency-Transposing Hearing Aid

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Abstract

Currently, the only behind-the-ear hearing aid that provides a frequency transposition function is the ImpaCt DSR675, recently introduced by AVR Communications Ltd. of Israel. In tests with three hearing-impaired adults, the performance of the ImpaCt aid(s) was compared with that of each subject's own (nontransposing) hearing aids. Recognition of monosyllabic words and medial consonants did not differ significantly between the two types of aids. This suggests that the transposition function of the ImpaCt was not effective at providing these subjects with increased high-frequency speech information, at least for the programmable parameters applied in the experiments. However, the subjects' understanding of sentences in a competing noise was significantly poorer with the ImpaCt than with the subjects' own aids. In that test, the ImpaCt aids were programmed to attenuate parts of the noise. The decreased sentence recognition may have resulted from this program, which effectively reduced the bandwidth of the ImpaCt aids.

Key Words: Frequency transposition, hearing aids, speech perception

Abbreviations: AGC = automatic gain control, ANOVA = analysis of variance, CFE = Clinician Fitting Environment, CNC = consonant-vowel nucleus-consonant, DCB = dynamic consonant boost, FCVL = frequency compression for voiceless sounds, HPF = high-pass filter, LPF = low-pass filter, SNR = signal-to-noise ratio

Over the past several decades, numerous schemes have been proposed for frequency lowering in hearing aids. Although the details of such schemes differ, in general, the aim is to improve audibility of sounds having relatively high frequencies by presenting information about those sounds at lower frequencies. If audibility of high-frequency sounds is improved by frequency lowering, there is the possibility that discrimination and identification of sounds will also be improved. This could enable better speech perception for some hearing-aid users.

Frequency-lowering schemes have usually been developed for use by people with a sensorineural hearing impairment characterized by a sloping audiogram, which indicates that sensitivity to tones at high frequencies is much poorer than at low frequencies. In extreme cases of sloping hearing loss, lowering may be the only feasible way of providing information about some high-frequency sounds. However, few of the proposed schemes appear to have been made available in practical hearing aids. For recent reviews, see Turner and Hurtig (1999) and McDermott et al (1999).

One frequency-lowering scheme that has been implemented successfully in a wearable, real-time processor has been developed by AVR Communications Ltd. and incorporated in their TranSonic hearing aid. The function of the TranSonic is described in detail in McDermott et al (1999). Briefly, acoustic signals are transposed downward in frequency only under certain conditions. First, incoming signals are analyzed to determine whether they are dominated by components at frequencies above 2.5 kHz. If so, all frequencies are shifted by a factor that is programmable for each aid user. Such

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proportionate transposition may be superior to alternative methods of lowering because it maintains the frequency ratios between important spectral components, such as the speech formants (Neary, 1989). If the input is not dominated by frequencies above 2.5 kHz, signals are amplified with no frequency transposition. When transposition is activated, signals can be amplified additionally by an adjustable factor, called the dynamic consonant boost (DCB). Although the overall gain of the TranSonic with or without DCB can be controlled by the user via the volume control, the frequency response and characteristics of the automatic gain control (AGC) are not adjustable. A further disadvantage of the TranSonic is that it is a relatively large, body-worn device.

Recently, AVR introduced the ImpaCt DSR675 hearing aid, which provides essentially the same transposition scheme in a behind-the-ear instrument. In the ImpaCt, the amount by which frequencies are divided when the transposition is activated is called FCVL (frequency compression for voiceless sounds). For example, when FCVL is set to 2, and transposition is activated (because the dominant frequencies are above 2.5 kHz), all input frequencies are shifted downward by one octave. Rather than the single DCB parameter in the TranSonic, the ImpaCt provides two. DCB1 provides a gain boost when the input signal is dominated by frequencies in a range that is higher than the range that activates DCB2. The method used to select appropriate values of these parameters for each subject is detailed later.

The frequency response of the ImpaCt can be adjusted by means of a high-pass filter (HPF) and a low-pass filter (LPF). The response of each filter can be selected individually from a set of 10 alternatives. A number of other processing parameters are also digitally programmable, but their effects were not specifically studied in the experiment reported below.

Published studies have shown that the transposition scheme implemented in the TranSonic may be helpful for some hearing-aid users (e.g., Davis-Penn and Ross, 1993). For example, two of the four subjects who participated in one trial obtained significant increases in scores on speech perception tests with the TranSonic compared with their own (nontransposing) hearing aids (Parent et al, 1997). In a more recent study with five adult subjects, all but one subject obtained higher scores with the TranSonic than with their own aids on at least one of the tests (McDermott et al, 1999). However, detailed analysis of the data in that study suggested that the amplification characteristics of the TranSonic in the low frequencies, rather than the transposition, might have provided most of the benefit. Only two of the subjects seemed to obtain additional information about speech from the transposed signals.

The primary objective of the current experiment was to compare speech recognition using the ImpaCt aid (with its TranSonic-like transposition scheme) with speech recognition by the same subjects using their own hearing aids. The ImpaCt aids were fitted to the subjects generally in accordance with the manufacturer's recommendations using the Clinician Fitting Environment (CFE) software, which was developed by AVR specifically for the ImpaCt instrument (AVR Communications Ltd., 1999). Using a procedure similar to that followed during the previous evaluation of the TranSonic device (McDermott et al, 1999), each subject's speech recognition was tested over approximately 10 weeks in the sequence own aid(s)—ImpaCt(s)—own aid(s). Further details of the fitting and test procedures are provided below.

SUBJECTS

Three adults participated in the trial. Relevant information about them and their own hearing aids appears in Table 1, and their unaided hearing thresholds are reported in Table 2. Each subject's hearing loss was within the range suggested by the manufacturer to be suitable for a successful fitting of the ImpaCt aid. All subjects were experienced users of behind-the-ear hearing aids of different types (see Table 1). None had previous exposure to the

Table 1 Relevant Information About the Subjects Who Participated in the Trial

Subject	*Age (years)*	*Sex*	*Etiology*	*Own Hearing Aid(s)*	*Ear(s) Fitted*
S1	72	M	Noise exposure	Bernafon SB13	Binaural
S2	54	F	Osteogenesis imperfecta/Meniere's disease	Phonak SFPPSC	Left
S3	72	M	Mumps/noise exposure	Bernafon PB675	Right

Table 2 Pure-Tone Hearing Threshold Levels (dB HL) for the Aided Ear(s) of Each Subject

		Frequency (Hz)							
Subject	*Ear Fitted*	*250*	*500*	*750*	*1000*	*1500*	*2000*	*3000*	*4000*
S1	L	60	65	65	70	75	75	75	65
	R	65	60	60	70	75	70	70	70
S2	L	100	80	85	100	85	90	85	100
S3	R	75	70	80	80	100	115	105	115

TranSonic aid. Subjects were not paid for their participation in the trial, although expenses such as travel costs were reimbursed.

AID FITTING AND EXPERIMENTAL PROCEDURE

Because the main purpose of the study was to investigate the effects of the frequency transposition processing provided by the ImpaCt, an attempt was made to match the frequency gain response of the ImpaCt to the frequency gain response of each subject's own hearing aid(s) for frequencies up to 2.5 kHz. This was intended to facilitate the evaluation of the effects of the transposition while minimizing the confounding effects of any differences between the hearing aids in other electroacoustic characteristics. For frequencies below 2.5 kHz (at which transposition does not occur), the high-pass and low-pass filters of the ImpaCt were programmed using the CFE software to provide approximately the intended frequency response. For higher frequencies (at which transposition is enabled), the effective response of the ImpaCt aid is also affected by the DCB function. The settings of the two DCB controls were adjusted to produce comfortable loudness while subjects listened to pulsed narrowband noise through the ImpaCt aid(s). The center frequencies of the noises were 4.0 kHz for DCB1 and 2.5 kHz for DCB2. The intensities of the noises were chosen to approximate the long-term levels of speech signals in the ⅓-octave bands centered on the corresponding frequencies (Byrne et al, 1994). Those levels were 46 dB SPL at 4.0 kHz and 48 dB SPL at 2.5 kHz.

For each subject, the ImpaCt aid(s) were fitted to the same ear(s) as their own hearing aid(s). To assess the accuracy of the fitting, aided thresholds were measured for each subject with both their own aid(s) and with the ImpaCt aid(s). The aided thresholds were measured using narrowband noises presented in the sound field at frequencies from 250 to 4000 Hz. The volume controls on the hearing aids were first adjusted to settings judged by each subject as appropriate for listening to speech at a normal conversational level (approximately 65 dBA).

The trial commenced with an evaluation of each subject's performance with their own hearing aids. Aided thresholds were measured, and speech recognition was assessed using three types of test. In the first test, two lists of 50 monosyllabic words, similar to the consonant-vowel nucleus-consonant (CNC) words described by Peterson and Lehiste (1962), were presented, and subjects were asked to identify each word. Subjects' responses were recorded as the proportion of phonemes correctly identified. The second test evaluated subjects' recognition of consonants. The test comprised three tokens of each of 16 consonants contained in an /a/-consonant-/a/ context and presented in a random order. Subjects were asked to identify each consonant, and their responses were recorded as the proportion of consonants correctly identified. They indicated their responses by pointing on a printed list showing all of the alternatives. The third test assessed subjects' perception of speech in competing noise. Two lists of sentences were presented, and subjects were asked to repeat verbally as many words as they could at the completion of each sentence. Each list contained approximately 100 words, and subjects' responses were recorded as the proportion of words correctly identified. In all tests, the speech material was presented at an average level of 65 dBA from sound recordings via a loudspeaker located approximately 1.5 m directly in front of the listener's position. The word and consonant material was recorded by a female speaker, whereas the sentence material was recorded by a male speaker. For the test using sentences, the competing noise was multitalker speech babble, and the signal-to-noise ratio (SNR) was 10 dB. No list of words or sentences was presented to any subject more than once throughout the trial. Subjects were tested individually in a medium-sized sound-attenuating booth.

After the initial tests using the subjects' own hearing aids, the ImpaCt aids were fitted. As mentioned above, the frequency response of the ImpaCt was adjusted to approximate that of each subject's own hearing aid(s) for frequencies up to 2.5 kHz. The starting parameter values for the frequency transposition processing were those recommended for each subject by the version of the CFE software that was made available by AVR at the time of the experiment. These settings were programmed into one memory (P1) of the ImpaCt aids. A second memory (P2) was programmed to provide settings deemed appropriate by the CFE software for listening in noisy situations. Each subject was asked to use the ImpaCt in place of their own hearing aid(s) for approximately 2 weeks. At the end of that time, each subject received the speech recognition tests described above. The P2 program was selected for the tests of sentence comprehension in noise, whereas the P1 program was used for the other two tests. Following the tests, minor adjustments were made to the programs in the ImpaCt aids based on the subjects' comments and suggestions. Because of these changes, the results of the initial tests with the ImpaCt aids were excluded from the final analysis. The values of the transposition parameters for each subject after the initial adjustments are listed in Table 3.

Table 3 Settings of the Frequency Transposition Parameters in the ImpaCt Hearing Aid(s) for Each Subject

Subject	*Ear Fitted*	*FCVL*	*DCB1 (dB)*	*DCB2 (dB)*
S1	L	1.75	1.0	0.0
	R	1.75	1.0	0.0
S2	L	1.75	3.0	3.0
S3	R	1.5	6.0	3.0

FCVL = frequency compression for voiceless sounds, DCB = dynamic consonant boost.

Each subject was asked to continue using the ImpaCt aids over approximately the next 6 weeks. At the end of each 2-week interval, the speech recognition tests described above were conducted. Therefore, at the conclusion of the 6-week trial period, scores had been obtained for six lists of CNC words, three lists of consonants, and six lists of sentences. These scores were averaged for each subject. In addition, aided thresholds were measured at the commencement of the trial period with the ImpaCt aids on the P1 program, and the volume controls were set to each subject's preferred setting.

Subsequently, subjects were asked to revert to using their own hearing aids exclusively. After a further 2 weeks, their speech recognition with their own aids was evaluated again with the above tests. To obtain the same number of scores on each test for their own aids as for the ImpaCts, the tests comprised four lists of CNC words, two lists of consonants, and four lists of sentences. The scores from these tests were combined with the scores from the tests conducted before the ImpaCts were fitted (described above) and averaged for each subject.

RESULTS

The aided thresholds, measured for each subject using both their own hearing aids and the ImpaCt aids, are shown in Figure 1. For frequencies below 2.5 kHz (at which transposition would not have occurred during the threshold measurements), the data for the ImpaCt aids are generally close to, or better (lower) than, the corresponding data for each subject's own aids. At higher frequencies, the thresholds with the ImpaCt aid (in transposing mode) are about 30 dB better for S3 and about 10 dB better for S2 than for their own aids. However, the thresholds are slightly worse with the ImpaCt aids for S1.

The sequence of trial periods and timing of speech recognition assessments were designed to minimize the confounding effects of familiarization with the ImpaCt and practice with the test procedures on the overall comparison of scores. Furthermore, inspection of each subject's scores obtained throughout the experiment indicated that no consistent increase or decrease in the scores with each aid had occurred. Therefore, the results reported below and shown in Figures 2 to 4 are averages over all scores obtained by each subject with each type of aid.

The results of the CNC word tests are shown in Figure 2. For each subject, there was little difference in performance between the ImpaCt aid(s) and that subject's own aid(s). This was confirmed by a two-way analysis of variance (ANOVA), with factors of aid type and subject. The ANOVA showed that the effect of processing condition was not significant ($p = .382$). Although the effect of the subject factor was highly significant ($p < .0001$), as would be expected given the differences in hearing impair-

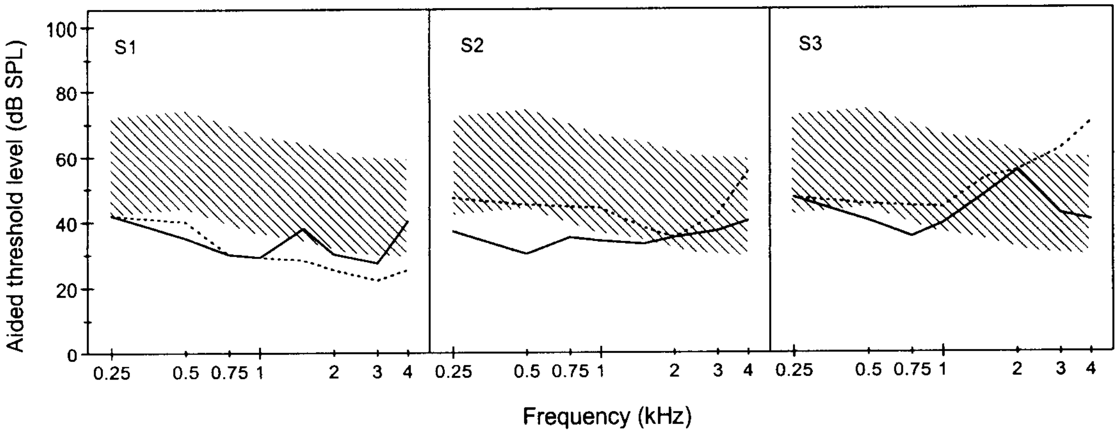

Figure 1 Aided audiograms for each subject, measured using narrowband noise. In each panel, the dotted line shows the thresholds for the subject's own conventional hearing aid(s), and the solid line shows the thresholds for the ImpaCt hearing aid(s). The hatched area indicates the approximate range of typical speech spectra.

ments among the subjects, the interaction between the subject and condition factors was not significant (p = .088).

A similar pattern of results was obtained from the consonant tests, as shown in Figure 3. A two-way ANOVA confirmed that the effect of processing condition was not significant (p = .588). Although the effect of the subject factor was highly significant (p < .0001), the interaction between the subject and condition factors was not significant (p = .600).

In contrast, each subject obtained a lower score for the sentences test in noise when using the ImpaCt aid(s) than when using their own hearing aid(s), as shown in Figure 4. This observation was confirmed by a two-way ANOVA, which showed that the effect of processing condition was significant (p = .026). Once again, the effect of the subject factor was highly significant (p < .0001), whereas the interaction between the subject and condition factors was not significant (p = .093). Possible explanations for these results are discussed below.

DISCUSSION

The aided thresholds shown in Figure 1 confirm that the shape of the frequency response for the ImpaCt aid(s) was broadly similar to that of each subject's own aid(s), at least for frequencies below 2.5 kHz. For higher frequencies, the aided thresholds for the ImpaCt aids would have been affected by the settings of

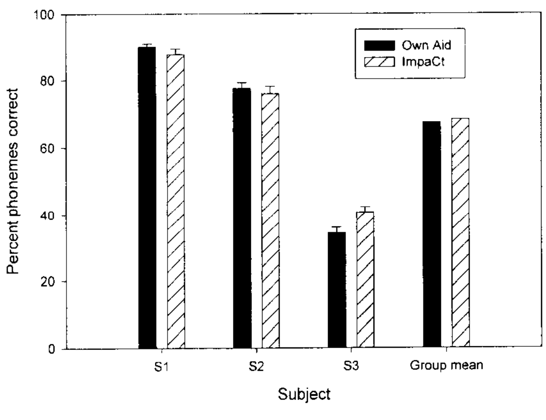

Figure 2 Results of the tests using CNC monosyllabic words. For each subject, the percentage of phonemes identified correctly is shown for the subject's own aid(s) (solid columns) and for the ImpaCt aid(s) (hatched columns). Error bars indicate one standard error of the mean. Average scores for the group are shown at the right.

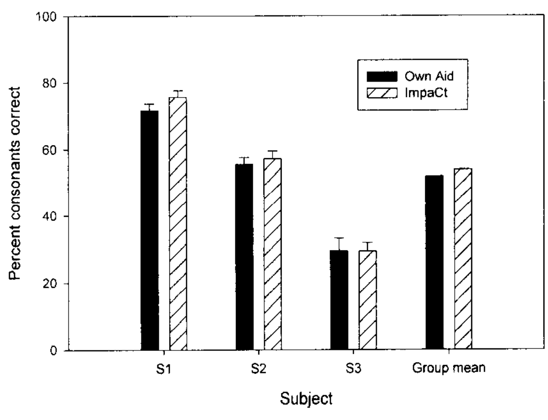

Figure 3 Results of the consonant tests. For each subject, the percentage of consonants identified correctly is shown for the subject's own aid(s) (solid columns) and for the ImpaCt aid(s) (hatched columns). Error bars indicate one standard error of the mean. Average scores for the group are shown at the right.

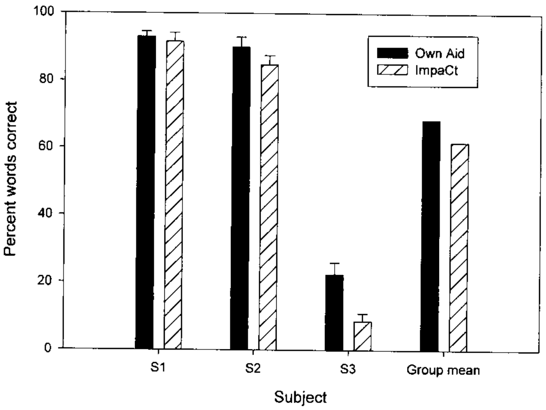

Figure 4 Results of the tests using sentences presented in noise. For each subject, the percentage of words identified correctly is shown for the subject's own aid(s) (solid columns) and for the ImpaCt aid(s) (hatched columns). Error bars indicate one standard error of the mean. Average scores for the group are shown at the right.

the transposition parameters (see Table 3). For example, of the three subjects, S3 had both the highest settings for DCB1 and DCB2 and the largest decline in unaided hearing thresholds with increasing frequency (see Table 2). Thus, when transposition was enabled by signals above 2.5 kHz, the transposition would have shifted those signals to lower frequencies, where S3's hearing sensitivity was better, and the DCB function would also have increased the level of the signals. The combination of these effects explains the observation that S3's aided thresholds improved with increasing frequency beyond 2.5 kHz (see Fig. 1). In contrast, both S1 and S2 had flatter unaided audiograms and smaller DCB values.

The aided threshold data for S1 and S2 indicate that most speech sounds were audible with both the ImpaCt and the subject's own aid(s), with S1 obtaining slightly better audibility across frequencies, on average, than S2. This is consistent with the results of the speech recognition tests (Figs. 2–4), which show that both S1 and S2 achieved high scores on all tests and that S1 performed somewhat better than S2. The much lower scores attained by S3 on each test may be explained by the poorer audibility he obtained with both the ImpaCt aid and his own aid, especially for frequencies around 2 kHz, which are particularly important for speech perception (Henry et al, 1998).

The average scores on the tests in which speech was presented in quiet show little difference in performance between the ImpaCt aids and the subjects' own hearing aids. This suggests that the transposition failed to provide substantial benefit to the subjects during those tests. This is not surprising, considering that in a previous study with the TranSonic aid, only two of the five subjects appeared to gain additional speech information specifically from the transposition (McDermott et al, 1999). Furthermore, the transposition factors that seemed to be beneficial with the TranSonic (1.9 and higher) were all larger than those used in the present study (see Table 3). Although it appears possible that transposition factors larger than 1.75 might have been beneficial, the preferences expressed by the subjects during the initial fitting and adjustment of the ImpaCt aids indicated that larger factors may not have been tolerated, mainly because of distortion perceived with some high-frequency signals. In addition, the subjects in the TranSonic study had audiograms that were generally more steeply sloping than those of the subjects in the ImpaCt trial. This may have contributed to the ImpaCt subjects' preference for smaller transposition factors. Further research would be required to determine the optimum transposition parameter settings for each user of the ImpaCt instrument.

The average scores for the tests with competing noise show that the ImpaCt aid performed significantly more poorly for these subjects than did their own aids. Those tests were conducted with the ImpaCt aids set to the P2 program, which had been created by the CFE software based on the contents of the P1 program in each aid. Specifically, for P2 compared with P1, the cutoff frequency of the HPF was increased by two steps, the cutoff frequency of the LPF was decreased by one step, and the release time of the AGC was longer. The reduction in bandwidth of the hearing aid caused by the changes in the two filters is the most likely reason for the aid's poorer performance in the sentences test. In their anecdotal comments, S1 and S2 reported that they found the noise reduction of the P2 program effective, although S1 also noticed that P2 reduced speech intelligibility.

At the conclusion of the trial, subjects were permitted to keep the ImpaCt aids (for no charge) if they wished. All three subjects chose to keep the ImpaCt aids. S1 has reported some benefit from using one ImpaCt aid and one of his own aids as a binaural fitting, and S2 prefers the ImpaCt on program P2 to her own aid in noisy situations. However, S3 generally prefers his own aid to the ImpaCt aid and tends not to use the ImpaCt in noisy conditions.

CONCLUSION

This preliminary study of the performance of the AVR ImpaCt DSR675 hearing aid focused on the effects of the frequency transposition processing implemented in that aid. Unfortunately, no benefits attributable to the transposition were identified for the three subjects who participated in the trial. It is possible that subjects would have learned to obtain more information about speech from the transposed signals had they been able to gain experience with the ImpaCt aids for a longer time. Furthermore, at least two of the subjects (S1 and S2) had audiograms that were relatively flat, and it is plausible that hearing-aid users with a more steeply sloping hearing impairment would be more likely to find frequency transposition beneficial. Another factor that might have contributed to the disappointing outcome is the age of the subjects. It is possible that younger hearing-aid users would learn to make use of transposed signals more rapidly or more effectively than older people. For example, at least one published study reported positive outcomes for use of the TranSonic aid by four hearing-impaired children (Davis-Penn and Ross, 1993). Because it is difficult to generalize the results from subject groups that are so small, more research would be needed to help identify which hearing-aid users would be most suitable for a transposing instrument and to determine optimum settings for the transposition parameters. In the present study, those parameters were adjusted based on initial reactions from the ImpaCt users, rather than maintaining the settings recommended by the CFE software throughout the trial. It is possible that use of the recommended settings would have led to a better outcome on the speech perception tests, provided that the sound quality was still considered acceptable by the subjects.

The relatively poor results for the ImpaCt aid in the listening condition with competing noise suggest that simple noise reduction techniques (such as bandwidth limitation) may adversely affect speech intelligibility even though the subjective sound quality may be improved. More sophisticated techniques for noise reduction are needed to ensure that intelligibility is maintained or enhanced when background noise is attenuated. For example, the use of directional microphones has been shown to provide improved perception of speech in noise for some hearing-aid users, at least when the speech signals and noise are spatially separate (Vanden Berghe and Wouters, 1998).

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