Multi-Microphone Instruments, DSP and Hearing-in-Noise

sensorineural hearing loss poses the greatest hearing difficulty when an individual is trying to hear and communicate in noisy environments. Consequently, hearing-impaired people need hearing instruments that provide both audibility and an improved Signal-to-Noise Ratio (SNR). This means that hearing instruments should selectively amplify the signal that the person wants to hear more than any other signals existing at the same time.

Audibility is not enough. Even when audibility is provided, those with hair cell damage/loss still require a better SNR than normal hearers in order to perform as well on speech intelligibility tasks.[1,2,3] The relationship between speech intelligibility and SNR is estimated to be on the order of 8-10% improvement in speech intelligibility for every 1 dB improvement in SNR. Therefore, even seemingly small improvements in SNR are important. The better the SNR improvement achieved by any hearing device, the greater the help provided in multiple, everyday listening situations.

Individual requirements for SNR improvement vary. Typically, the greater the hearing loss the greater the required SNR improvement compared to normal-hearing individuals. For example, those with an average 40 dB hearing loss, require a SNR improvement of about 5 dB, while 70 dB losses require about 9 dB SNR improvement.[4,5] When discussing the selection of amplification for children, Ross & Seewald' suggest that a SNR of 6 dB in the surrounding environment will not seriously interfere with the speech comprehension of a normal-hearing child. A hearing-impaired child, on the other hand, requires a SNR in excess of 20 dB if his/her residual hearing is to be fully realized.

Studies of user satisfaction and use of hearing instruments have shown repeatedly that poor instrument performance in noise is identified strongly with:

- Non-ownership of hearing instruments by people with hearing impairment.[7,8]
- Failure to use hearing instru-ments often or regularly.[9]
- A low percentage of wearers who are satisfied with instrument performance in multiple listening environments.[7,8]
- Poor ratings given to the help received from instruments in noise.[7,8]

Furthermore:

- From 11 possible suggestions to hearing instrument manufacturers on ways hearing instruments should be improved, 87% of survey participants gave "improved speech intelligibility in noise as their top priority.[10]
- An extensive consumer satisfaction survey of nearly 5000 hearing instrument users of 13 high technology products from 10 manufacturers showed that, in order to achieve high levels of satisfaction, instruments must provide listening utility in multiple environments. That is, they must provide satisfactory help and improved speech intelligibility in situations important to the end user.[7,8]

Restored Audibility Is Not the Total Solution

People who have two normal functioning cochleae are able to hear remarkably well in competing noise. They are able to locate and selectively listen to one voice in a crowd of voices. This ability is dependent on good directional hearing derived from binaural integration of information from both ears, which in turn, relies on having normal psychoacoustic processing of the time, intensity and spectral information reaching two spatially separated cochieae.

A loss of inner and outer hair cell function in the cochlea results in both a loss of sensitivity and a loss psychoacoustic function. Making sounds audible is part of the solution and can be achieved for each individual with increasing precision using the latest developments in hearing instrument technology. Unfortunately, evidence [4,5,11] suggests that none of the currently avail able hearing instruments–including the digital /programmable models — are able to fully replace the necessary temporal, amplitude and spectral processing ability necessary for "normal" hearing in noise.

What is Noise?

Any signals other than what the hearing instrument user wishes to hear, at any given moment, can be defined as "noise"—particularly if it has the ability to interfere with hearing and understanding a desired signal. Noise, therefore, cannot be defined simply as a specific spectrum, nor has noise any specific, constant characteristic(s) which can be used to separate it physically from a desired signal. This is because what is a desired signal and what is noise is a moment-to-moment, qualitative, personal decision for everyone. Circuit solutions to the problem of hearing in noise have met with only modest success in improving *speech intelligibility*. Rather, these solutions have experienced much higher success in the important area of achieving *comfort* in noise.

All circuit solutions, including digital signal processing (DSP) strategies, filtering strategies, changes in compression characteristics and gain reduction in bands can only act on some defined physical characteristic(s) of the total signal when this input signal matches a certain physical criteria (e.g., level or spectral criteria). Because the total signal that has entered the hearing instrument consists of both the desired speech signal and the undesired noise, circuit processing typically affects both the signal and the noise equally, and the overall SNR often remains the same.

SNR improvements may be achieved if the noise is steady state or confined to a narrow band (e.g., only in the low frequencies). Most naturally occurring noises are broadband, however, and in the case of the most problematic background noise—competing speech—it also has the same time and spectral characteristics. In general, studies of available in-circuit solutions and DSP strategies have failed to confirm consistent,

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significant SNR improvements and significant average improvements in speech intelligibility in noise.[11,12]
for decades that standard directional microphones in hearing instruments can improve the SNR an average of 2-3 dB. With such microphones, signals arriving from behind the listener are reduced in level before they enter the signal processing path. The use of these instruments has remained low, however, for a number of reasons: directivity has been confined to the lower frequencies; the instruments reputed loss of directivity in highly reverberant environments; poorer low frequency sensitivity for desired signals arriving from the front of the instrument user compared to an omnidirectional microphone; the disadvantage of directional microphones in some situations (e.g., safety in traffic, hearing back-seat passengers in a car, listening to music, etc.) when the user cannot easily switch between directional and omnidirectional modes.

Studies of more recent applications of directional microphone systems in hearing instruments, specifically multi-microphone systems (or dual-microphone arrays), have shown significant average improvements in SNR compared to the improvements reported for standard, one-microphone directional instruments: Valente et al.[13] reported an average 8 dB SNR improvement, and Lurquin & Rafhay[3] reported an average 6.6 dB SNR improvement.

Evidence also suggests that the poorer the SNR in the test situation, the greater the relative improvement in percent correct on a speech intelligibility task when switching from omnidirectional to directional mode. Voss[14] reported 15% improvement at -10 dB SNR and 29% improvement at -15 dB SNR. Users of some multi-microphone instruments are reportedly able to switch easily between omnidirectional and directional performance, for access to the best mode for individual preferences in specific environments.[15]

The two studies that follow address the effectiveness of multi-microphone instruments (using the Phonak Piconet AudioZoom) and compare both objective and subjective measures in noise to that of high quality DSP instruments. The studies also address the questions of whether DSP alone can help solve the hearing-in-noise problem or if the application of directional microphone technologies in addition to advanced processing strategies is warranted.

Norwegian Study

This study, conducted in Bergen, Norway by co-author Asgaut Warland, MD, followed a study initiated by the advisory group for the Norwegian national insurance system (Rikstrygdeverket) which compared the participants' analog instruments to two brands of digital instruments. The analog instruments were described as modern, well-functioning and representing a variety of manufacturers and processing types, including non-linear products. The objective Speech-in-Noise test and subjective tests, as described for the study below, resuited in the finding that the digitals outperformed the analog instruments. (An overview of the study appears *in News from Oticon,* Jan. 1998.)

It was conceded, however, by those conducting the study that digital instruments may not be the best option for *everyone* and that some technologies that are not fully digital may be as effective. The study reported here was conducted to compare instruments with multi-microphones to the participants' currently worn digital instruments.

Usage Value	MMic	DSP
Very Good	10	4
Good	11	14
Moderate	1	4
Little	—	—
None	—	—

Table. 1. *Norwegian study participants' evaluation of the total usage value (benefit) of the multi-microphone (MMic) and DSP instruments.*

Performance rating	MMic	DSP
Significantly better	4	—
Better	12	5
Total people	16	5

Note: One person reported no difference

Table. 2. *Norwegian study participants' overall performance rating of the multi-microphone and DSP devices.*

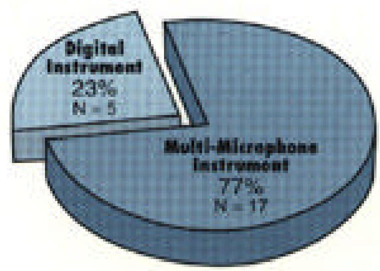

Fig. 1. *Number (and percentage) of participants who preferred either the multi-microphone or DSP instruments.*

Methodology: Twenty-two adults ranging in age from 42-77 (14 males and eight females) with an average age of 68 years were used as subjects. Average hearing loss between 0.5-4 kHz for the 26 test ears (4 people were binaural users) was 52 dB HL.

Nineteen participants were current users of one type of digital instrument and three participants were current users of another type of digital instrument. At the beginning of the study the majority of the participants reported they were satisfied or very satisfied with their digital hearing instruments. All test instruments were BTEs.

Before being fitted with the multi-microphone instrument, the participants were re-evaluated with their current digital instruments:

- Speech in noise test (monosyllables);
- Subjective evaluations: a) A rating of total usage value; b) A benefit comparison for the different types of instruments; c) Preference for hearing instrument.

Subjects were tested with the Speech-in-Noise test. Speech (monosyllables presented at 65 dBA) and noise were presented from the same speaker 1 m in front of the participant. The broadband noise from the audiometer was adjusted in level until participants scored 40%-50% correct with their digital instrument. Participants were then fit with the multi-microphone instrument, and after wearing it for eight weeks, the same SNR (average +8 dB) was used to repeat the speech test.

Results: Of 20 people tested, 16 achieved better speech-in-noise results with the multi-microphone instrument; three did better with their digital and one did equally well with both instruments. The majority of the participants (80%) achieved better speech-in-noise results with multi-microphone instruments, even though the speech and the noise were presented from the front, from the same speaker—a test protocol which is not considered favorable for evaluating the benefit from multi-microphone/directional technology.

Subjective evaluations: After eight weeks experience with the multi-microphone instrument, the participants were asked to subjectively evaluate it against their digital instrument. Participants were asked to rate the overall benefit/value of their current digital and the multi-microphone instrument on a 5-point scale from "very good" to "none." The multi-microphone instrument was rated "very good" by 46%, and digitals by 18% (Table 1).

Participants were asked whether the multi-microphone instrument was "Significantly better, better, no different, worse or much worse" than their digital instrument (Table 2). Results show that 73% rated the multi-microphone instrument as "significantly better" or "better" than the digital instrument. Five (23%) rated the digital instrument better than the

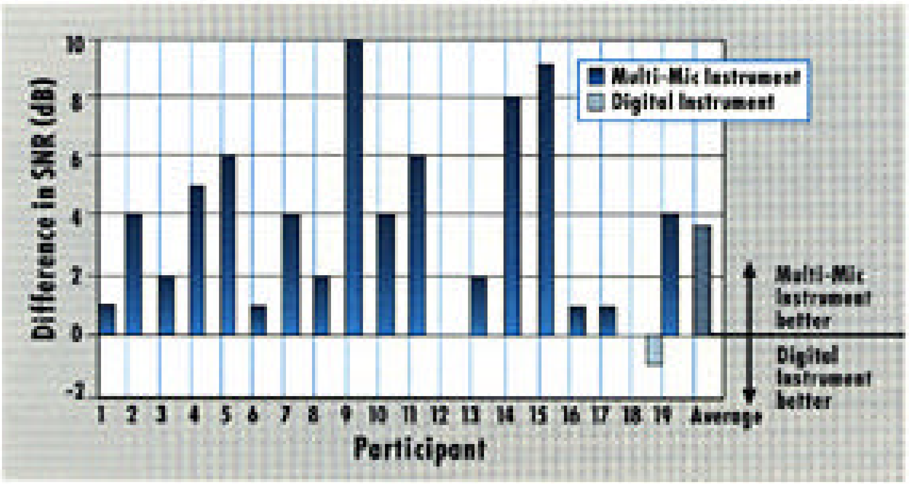

Fig. 2. *Difference in SNR for 50% correct (Dantale speech test) between digital and multi-microphone instruments in the Danish Study, with positive differences indicating better performance with multi-microphone instruments and negative differences indicating better results with digital instruments.*

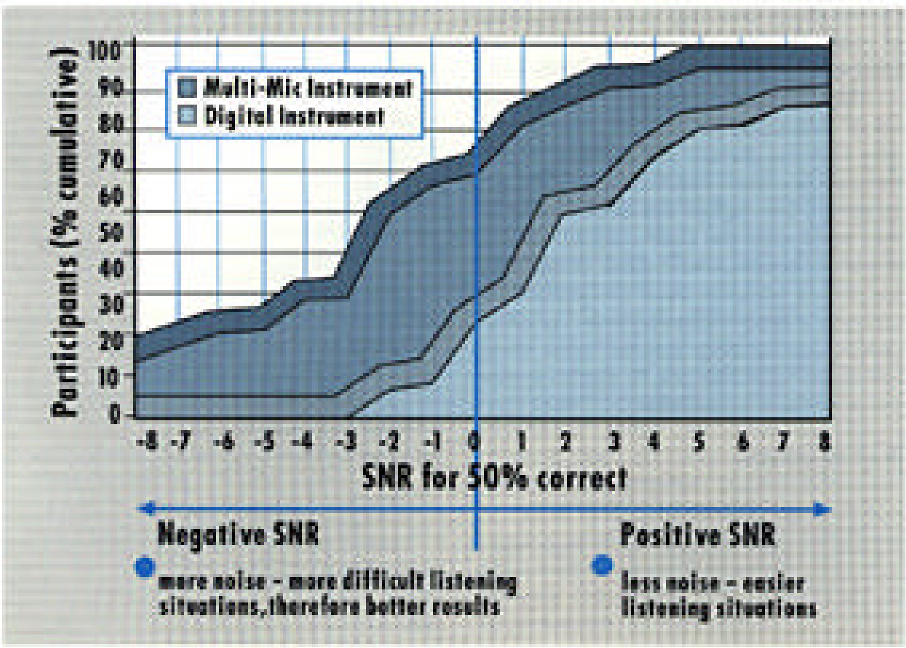

Fig. 3. *Percentage of Danish Study participants scoring 50% on the Dantale test at each SNR or at a worse SNR. With multi-microphone instruments, most participants scored 50% correct in negative SNRs (68% at 0 dB SNR*

multi-microphone instrument, and one participant reported no difference between the devices.

Participants were asked which instrument they preferred (Fig. 1). Seventeen of the 22 participants (77%) preferred the multi-microphone instrument. Five (23%) preferred the digital instrument.

Conclusion: For improvement in speech intelligibility in noise, better results were achieved with multi-microphone instruments than with fully digital instruments. The majority of people who
used and compared both technologies in real-life situations expressed a preference for the multi-microphone system.

However, the experimenters state that the main reason given for this preference was the ability to adjust the instruments. The multi-microphone instrument has a remote control for binaural switching between programs with either omnidirectional or directional microphone modes, whereas the DSP instruments are automatic and self-adjusting (i.e., no remote control). It is the intention of the experimenters to offer those participants who chose the multi-microphone instrument the opportunity to compare a digital product with a standard directional microphone.

Danish Study

The aim of this study, which was conducted at the Audiology Department of Viborg Hospital,

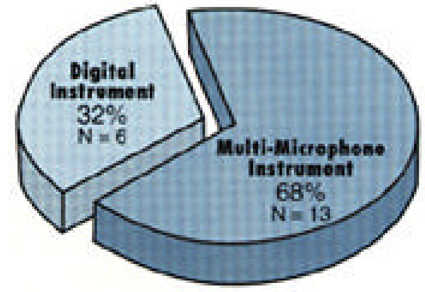

Fig. 4. *Number (and percentage) of participants who preferred either the multi-microphone or DSP instruments.*

Denmark, by co-author Claus Brenner Larsen, MD, and colleagues, was to compare the results achieved with one digital instrument brand and a digitally programmable multi-microphone instrument (Phonak Piconet2 P2 AZ-AudioZoom) using a speech-in-noise test and subjective evaluations. The study protocol was developed in collaboration with the instrument manufacturers and all evaluations were conducted in the presence of the manufacturers' representatives. The following summary is based on a presentation by Dr. Larsen at the 1998 Annual Meeting of the Swedish Technical/Audiological Society."

Methodology: Nineteen adults were used as subjects, 14 males and 5 females with an average age of 64 years (age range 57-75 years). All were experienced, binaural hearing instrument users. Fifteen subjects previously wore BTEs; four previously wore ITEs. The three-frequency average hearing loss for the 38 test ears was 43 dB HL.

All test instruments were BTEs that were fit binaurally. Half the participants were fit first with the digital instruments, half were fit with the multi-microphone instruments. All manufacturer identification was removed from the test instruments to help avoid participant bias. The instruments were fit according to the manufacturer's recommended procedure for the digital instrument and to NAL targets for the multi-microphone instruments. After 14 days, the instruments were fine-tuned as required.

After two months, the following objective and subjective tests were performed:

1. Signal-to-Noise Ratio (SNR) for 50% correct, using the Dantale (Danish monosyllable) speech test and the ICRA recorded noise. The ICRA (International Colloquium of Rehabilitative Audiology) noise has a spectrum equal to the average speech spectrum for normal vocal effort and the same temporal variations as natural speech. Speech was presented from the front at 0^{o} azimuth; noise from four speakers at 45°, 135°, 225 ° and 315 ° azimuth.

2 A Viborg questionnaire was designed for the study. It comprised 12 questions on understanding or comfort in quiet and noisy situations and was completed after two months. Answers were recorded by marking a line labeled with the scale "very good-good-very bad."

3 The APHAB questionnaire for subjective evaluation of hearing instrument benefit was completed after two months experience with each instrument.

Participants were then re-fit with the other instrument which also was fine-tuned after 14 days. After two months, the objective and subjective tests were repeated. After all tests were completed, the participants were asked to indicate which instrument they preferred.

Results: For the Speech-in-Noise test, the average SNR for 50% correct on the Dantale test was 3.6 dB better with the multi-microphone instrument than with the digital instrument (Fig. 2). The Wilcoxon Matched-Pairs Signed-Ranks Test (2-tailed test) found the difference highly significant (p=.OOO3). The poorer the SNR for 50% correct, the better the result. That is, scores obtained at a negative SNR (e.g., -2 dB SNR) are a better result than those requiring a positive SNR (e.g., 2 dB SNR) (Fig. 3).

The results for each participant with both instruments are seen in Fig. 2. Seventeen of the 19 participants (90%) performed better with the multi-microphone instrument. For these subjects, the range of SNR improvement over the digital instrument was 1-10 dB. One person performed equally well with either instrument, and one person performed 1 dB better with the digital.

Subjective Evaluations: Neither the APHAB nor the Viborg questionnaire showed significant average differences between the instruments. Thirteen (68%) of the participants preferred the multi-microphone instrument; six (32%) preferred the digital instrument (Fig. 4).

Conclusion: Most subjects achieved better SNR improvement with the multi-microphone instrument than with the digital instrument and most expressed a preference for the multi-microphone instrument. The participants were not asked to explain their preferences, but it is quite possible that the difference is due to higher speech intelligibility in noise (i.e., 1 dB SNR can equate to 8-10% improvement in speech intelligibility scores). As six people expressed a preference for the digital instrument but only one person achieved better speech intelligibility with it, other aspects of a particular product may have high importance for a smaller number of individuals.

Summary

In these studies involving both digital and multi-microphone technology, a majority of participants achieved better speech intelligibility in noise and expressed a preference for the multi-microphone instruments. It is also likely they achieved satisfactory hearing in a wider range of real-life situations using the evaluated multi-microphone instruments.

These results are consistent with studies of consumer satisfaction which indicate that the greater the number of environments where satisfactory hearing is achieved, the higher the overall satisfaction level with the instruments.' Results are also consistent with other recent studies which indicate that the problem of adverse effects of background noise on speech intelligibility has not been totally overcome with the use of digital instruments presently available.""[2,7] •

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