Intelligent processing to optimize the benefits of hearing aids
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CHAPTER 9

FINAL DISCUSSION
9. Final discussion

In this chapter we will address some methodological issues that are related to the evaluation of hearing aid benefit or to the comparison between different hearing aids and/or different hearing aid settings. Then, we like to review the most important results from the studies described in this thesis. We will end with some recommendations for future research.

9.1. Methods for the assessment of benefit

It appears that small differences between hearing aids and or hearing aid settings are not always measurable with the mostly used “objective” clinical tests. For example, it is difficult to assess the benefit of modulation-based noise reduction in an objective way. However, the subjective difference between different types of processing or between different settings can be very important for the hearing-impaired. For some subjects the scores of questionnaires are more positive than the scores extracted from the clinical tests. On the other hand, larger differences like head shadow effect or the effect of a directional microphone could be captured more easily in objective outcome parameters.

Despite of the theoretically expected relation between headphone tests like IATD and BMLD and the benefit of bilateral fittings in speech intelligibility, no clear correlations were found in the clinical practice (except for correlations with the pure-tone audiogram). One reason can be that the IATD and the BMLD-test are too specific. For those tests we used only one frequency, while a relatively broad range of frequencies determines speech intelligibility. However, also the SRT-test per ear did not give predictive information either. An option might be to measure BMLD directly with speech material in future experiments on bilateral hearing aids.
Speech perception plays an important role in our communication. To evaluate hearing aids, different speech tests can be used. One of the most natural speech tests is an SRT-test with sentences in continuous background noise, as often used in the Netherlands. This is a standardized test with a high precision and an acceptable duration (it takes about 3 minutes per list). However, if many conditions have to be tested, it is too time-consuming. In addition, the speech stimuli cannot be used more than once, because there is a chance that the subject can remember the sentence or parts of the sentence.

For repeated measurements, there is need for a test that can be repeated endlessly, like the Oldenburger Satztest that is currently under development for the Netherlands (see Chapter 2.2). When many conditions have to be compared in a study, the JFC-test can be used. In this test also subjective factors play a role like listening comfort. Consequently, this test does not converge exactly to 50% speech intelligibility, and differences in the individually used criteria are likely. However, for comparative measurements the JFC-test has proven to be able to distinguish between different hearing aid settings, and takes considerably less time than the SRT-test. However, this test is less pronounced than the SRT-test and the SRT-test should be regarded as the "golden standard".

Another subjective test with sentences that can be applied to compare different hearing aid settings is a paired-comparison test. This test is used in Chapter 7. The results of the paired-comparison test provide a more qualitative judgement about specific aspects of the different settings (e.g. listening comfort or subjective intelligibility), and the test results show an ordinal order of preferred settings. As for the JFC-test, it is hard to obtain data of speech intelligibility only. Aspects of sound quality and listening effort may play a role.

For some studies we need a more sensitive test, to measure differences between settings. Why is one setting of the hearing aid more preferred than another? A questionnaire is an
important tool to get subjective information, but the results of a questionnaire can give a bias if the conditions are not blinded. Sound quality is related to speech intelligibility and to the listening effort it takes to understand speech. To measure subjective aspects in an objective way, we can also think about measurements that are related with effort. One possibility to is to add a measurement of reaction time. When it is more easy to understand speech with a specific hearing aid or with a specific hearing-aid setting, the subject will react faster than when the mental effort is higher to understand speech. Another test to collect data about listening effort is the measurement of pupil dilatation. There is a relation found between the pupil dilatation and the difficulty of speech perception in noise (Kramer et al., 1997). Pupil dilatation will increase for more difficult listening conditions (lower S/N ratios).

Because people communicate in different acoustical environments, we should invest in the use of more different background noises in speech tests. However, with all tests it is important to take into account the characteristics (for example the attack and release time) of the hearing aid. The test material can influence the results. The duration of the background noise should be long enough to activate different processing in the hearing aid.

In summary, the battery of tests that are available for comparative measurements should be extended in the future in order to be able to use objective evaluation tests also for the more subtle differences between hearing aids and hearing aid settings.

9.2. Comparisons between hearing aids

In Chapter 6 we compared modulation-based noise reduction hearing aids with the own analogue hearing aids of each subject. This was the only way to make direct comparisons because the hearing aid under test had only one program, and it was not
possible to switch off the noise reduction. There is some risk to use the own hearing aid as a reference, because now the test cannot be blinded. The subjects can think that the new hearing aid is better, because it is more expensive, it is digital, or they heard it from the commercials, etc. (e.g. Bentler et al., 2003). This can give a bias, especially for the questionnaires. In Chapter 7 we investigated a hearing aid, which had more than one hearing aid program, and we could switch off the noise reduction and/or the dual microphone. The subjects were not told which program was activated. This is a more objective way, because of blinding. Now the own hearing aid was also tested, just as a case of control. An even better approach is double blinding, but this requires different test leader to program the hearing aids and to conduct the evaluation methods.

Besides blinding, another reason for using one hearing aid is the fact that it is essential to have identical hearing aid characteristics. For a correct comparison of settings it is important to change only one parameter of the hearing aid. For that reason it is obvious that there has to be detailed knowledge about the hearing aid specifications. Sometimes certain characteristics are linked to other characteristics. This cannot always be seen from the specifications of the hearing aid or from the fitting software of the manufacturer.

To control the hearing aid settings in an objective way, an insertion gain measured with speech noise is recommended. In our opinion, it is the only way to see what is happening at the eardrum, taken into account the ear canal and the acoustical properties of the ear mould. The noise reduction should be switched off. When this is not possible ICRA noise can be used (Dreschler et al., 2001) at least for modulation-based noise reduction algorithms. There is an option to select a single-speaker (male or female) speech noise. With that noise the noise reduction will not be activated, and it is possible to see what the output is as a function of different frequencies.
One of the negative components of hearing aids is the aversiveness of loud sounds, as we encountered most clearly in Chapters 4 and 5. With two hearing aids this becomes even worse. To optimize speech intelligibility it is important to use the complete (residual) dynamic range of the impaired ear. However, the maximum output of the hearing aid should be selected with great care in order to avoid negative effects in terms of sound quality and overexposure.

9.3. The benefits of bilateral hearing aids

As mentioned in this thesis, hearing-impaired people do often complain about speech intelligibility in background noise. This plays an important role in the studies on the benefit of a unilateral or bilateral fitting and/or the effect of different signal processing in hearing aids.

The advantages of two ears above one ear, are better localization and better speech intelligibility in background noise. For hearing-impaired people, a logical consequence or a “natural way” to rehabilitate, is to choose for a bilateral fitting instead of an unilateral fitting. When sounds are arriving at both ears the intelligent processing of the brain can be exploited. However, not every subject derives benefit from two hearing aids, and not every subject wants to have two hearing aids. Different reasons could play a role, like medical aspects, the amount of hearing loss, the symmetry of hearing loss, and the cosmetic aspects.

In the retrospective study (Chapter 4) 60% was fitted bilaterally. And in the unilaterally fitted group, even 44 % of the subjects had a symmetrical hearing loss (± 10dB). The bilaterally fitted group was more satisfied with a hearing aid than the unilaterally fitted group.
In the prospective study (Chapter 5), the subjects were asked to start a trial period with two hearing aids. After the trial period 93% opted for a bilateral fitting. Although this skewed distribution resulted in a relatively small group of subjects with a unilateral fitting (and thus in some problems with regard to the interpretation of the results), the high percentage per se clearly indicated that subjects who once experienced the benefits of bilateral hearing aids do not want to give up these benefits. In this respect it is important to note that most subjects pay part of the hearing aid costs themselves. So, they were also willing to invest in a bilateral fitting.

In the prospective group, all subjects have been measured unilaterally and bilaterally and evaluation tests showed clearly better results when subjects were fitted bilaterally. This advantage is measured for the speech reception test with separated sound sources as well as for the horizontal localization test. The largest effects originate in the elimination of the head shadow. Also the questionnaires show convincing evidence of the subjective benefit of a bilateral fitting above a unilateral fitting. Except for the comfort of loud sounds. After an appropriate correction for age and hearing loss, the bilaterally fitted group showed a higher hearing aid use and a higher hearing aid benefit.

It would have been nice if we could predict the effect of a unilateral or bilateral fitting for each individual on the basis of a-priori testing. Then an individual advice could be given more exactly. One of the outcomes of Chapters 4 and 5 is that a bilateral fitting is better, but not for all, and this is difficult to predict. The most important factor to predict is the PTA at the better ear. When hearing-impaired listeners can experience the effect of two hearing aids, they become motivated to choose for a bilateral fitting, especially for subjects with symmetrical hearing losses. This will cost at least one ear mould, but then each individual subject can experience the benefits of a bilateral fitting himself or herself. Hearing-impaired people who start with one hearing aid will not experience the advantages of the second hearing aid at that moment.
In addition, Chapter 3 summarises experimental evidence that the deprivation effect of the unfitted ear exists and this is a hidden danger of an unilateral fitting. Given the evidence about deprivation, the hearing aid fitter should seriously consider if a trial period with bilateral hearing aids should not be promoted. If there are some hesitations, based on lack of acceptance or for cosmetical reasons, the hearing-impaired subject should be persuaded at least to try two hearing aids in a trial period. Some additional counselling should be considered.

9.4. The benefits of digital signal processing

The studies in this thesis show that – within currently available technologies – the most effective signal processing within hearing aids is directivity. With a fixed directional (or an adaptive directional microphone), significant advantages relative to an omnidirectional microphone have been found, especially for speech intelligibility in background noise with separated sources of speech and noise (see Chapters 7 and 8). The subjective experiences with directivity are in agreement with the “objective” SRT-results (see Chapter 7).

For modulation-based noise reduction, no clear effects are measured for speech intelligibility in background noise (see Chapters 6 and 7). However, subjective experiences are also important. By means of questionnaires or paired comparisons, subjective experiences have been investigated. In Chapters 6 and 7 subjective advantages have been found for modulation-based noise reduction relative to the own hearing aid, and to the same hearing aid without noise reduction, respectively.

From the studies described in this thesis, it is clear that modern technology made important steps forward to reduce the problem of speech perception in noise. However,
the benefits are only found in selected areas (e.g. with the direct sound field and/or in listening comfort) and even high-end digital hearing aids do not yet provide an overall solution for the "speech-in-noise problem".

9.5. Some remarks about future research

To compare different hearing aid settings in an objective way, we need more sensitive test material. As mentioned before, this could be a test with special attention for the listening effort, like tests on reaction times or tests with the measurement of pupil dilatation. The test material has to be realistic, fast and reproducible. Also, there should be a possibility to measure many conditions. The test set up should be standardized to make different studies more directly comparable.

To compare settings or even different hearing aids, a standardized and precise fitting method should be developed. The use of generic fitting rules instead of manufacturer-specific fitting rules is important. The actual amplification of the hearing aids should be checked by means of insertion-gain measurements with appropriate test signals. When hearing aids are fitted and tested, there should be detailed knowledge about the hearing aid characteristics, not only what is seen on the screen of the fitting software.

We experienced that a close co-operation between the researcher and the manufacturer is an essential condition for this kind of research. We have to verify if the test conditions are appropriate (for example we need to know what the attack and release times are). Sometimes different programs proved to be coupled: when one parameter is changed in the first program, the algorithm is also changing in other programs. If this is not desirable for the purpose of the research, special precautions should be taken or special versions of the hearing aids should be produced. When the hearing aid is fine-tuned by means of the insertion gain, it is effective to make a copy of that specific hearing aid setting, and then change only the algorithm under test. When this is not
possible in a custom hearing aid it would facilitate to use non-standard hearing aids especially for research.

One of the goals of field-testing is to verify the benefits of new hearing aids and/or new algorithms in real-world conditions and to find indications for further improvements. Independent feedback to the manufacturer about problems with the hearing aid, software bugs or critical remarks, in an early stage of development has also proven to be very useful.

Another goal is that we need independent data on the benefits of specific hearing aids and hearing-aid options to provide hearing-impaired consumers with objective and independent information about modern hearing aids. This information should be based on independent research. Given the high number of innovations in digital hearing aids that are ahead of us, the high costs that are required for these innovations (and consequently the high prices that hearing-impaired consumers have to pay) and the high expectations that are raised by commercial brochures and advertisements, we need objective data and objective tests. Therefore, it is important to continue independent research in this area.

Unfortunately, the results of this thesis show that the “speech-in-noise problem” has not been solved yet, even if we use high-end digital hearing aids and we use them bilaterally. There is ample room for further improvements before most hearing-impaired listeners can participate without limitations in acoustically difficult situations.