Intelligent processing to optimize the benefits of hearing aids
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SUMMARY
Summary

In this thesis a few clinical studies have been described and the advantages of different methods to compensate hearing loss with hearing aids were investigated. One of the most important methods is to recover binaural hearing by fitting two hearing aids. The first part is devoted to the advantages of bilateral hearing aid fittings. Due to the introduction of digital hearing aids advanced signal processing became feasible, such as modulation-based noise reduction and directionality by dual microphone techniques. In the second part of this thesis three studies have been described which point out the added value of those algorithms.

Part 1:
The added value of bilateral hearing aid fitting (Chapters 3 - 5)

The purpose of the study
Possible changes in the system of the financial reimbursements for hearing aids require a solid underpinning of current clinical fitting practice for bilateral hearing aids. PACT (Platform for Audiological Clinical Testing) initiated a broad retrospective study in different audiological centres to evaluate the current fitting practices and the subjective advantages of a second hearing aid. Additionally, a prospective study was performed with the purpose to have better criteria for bilateral hearing aids. Therefore we investigated the objective and subjective parameters that correlated to a better stereophonic effect and to an advantage of a bilateral fitting compared to an unilateral fitting.
Methods of the study

The study consists of three parts: a literature review, a retrospective study, and a prospective study.

In the retrospective study 1000 clinical files of consecutive hearing aid approvals of one or two hearing aids were investigated. All patients involved in the investigation of the clinical files were asked to complete an extensive questionnaire, about two years after the hearing aid approval. Eventually, 505 questionnaires were returned. These questionnaires were used for the evaluation of the long-term effect. Different relations between anamnestic, audiological, and subjective aspects were investigated.

In the prospective study the subjects were selected from the regular clinical populations of eight audiological centres who started a trial with two hearing aids. Before the trial period diagnostic tests were conducted, to get more information about the binaural function and the critical S/N ratio per ear, because it is difficult to compose new criteria for reimbursement of a second hearing aid based on the standard audimetric data only. The diagnostic tests consist of BMLD-tests (Binaural Masking Level Difference), IATD-tests (Interaural Time Difference), and SRT-tests (Speech Reception Test) per ear. After the trial period, evaluation tests were conducted with one and with two hearing aids. The evaluation tests consisted of SRT-tests with spatially separated sound sources and localization tests with daily sounds. Also a questionnaire was used, in which the subjects were asked to answer questions about different situations without, with one, and with two hearing aids. Eventually, the results of 214 subjects were analysed.

Results

The systematic review of literature showed obviously an added value of the second hearing aid. The effect of auditory deprivation is a real risk for unilateral fittings. The results of the retrospective study gave detailed insights into current fitting practices. It showed that the bilaterally fitted group was more satisfied with the hearing aids than
the unilaterally fitted group. People with large hearing losses used the hearing aid more often, experienced a lower auditory functioning, experienced the same satisfaction and had a higher handicap score than people with smaller hearing losses. For digital hearing aids a significantly better auditory functioning and a slightly lower handicap score was found than for standard analogue hearing aids. It was difficult to predict hearing aid use and satisfaction on base of anamnestic and audiological data.

The prospective study showed that it was also difficult to predict the advantage of a second hearing aid by the results of the diagnostic tests used in this study. An obvious difference between both studies was that in the prospective study 93% of the subjects were fitted bilaterally in contrast to about 60% in the retrospective study. The evaluation tests showed an objective view of the advantage of the second hearing aid, both for speech intelligibility with spatially separated sound sources and for directional hearing. For the speech test in background noise with spatially separated sources positive effects were measured for the second hearing aid, for the larger part due to cancellation of the head shadow effect and for a smaller part due to a purely binaural effect. There was an obvious subjective bilateral advantage for detection, discrimination, speech intelligibility in quiet, in noise and for localization. However, the aversiveness of loud sounds is higher with two hearing aids than with one.

Part 2:
The added value of advanced signal processing (Chapters 6 - 8)

The purpose of the study
Since the introduction of digital hearing aids there were a lot of changes, both for the hearing aid user and for the hearing aid prescriber. The question was what the real effect is of different algorithms in hearing aids. Therefore different studies were conducted to measure the added value of:
Summary

- digital hearing aids with noise reduction compared to analogue hearing aids without noise reduction (Chapter 6),
- digital hearing aids with noise reduction and/or a dual microphones compared to the same hearing aids without noise reduction and omnidirectional microphones (Chapter 7),
- digital hearing aids with adaptive dual microphones compared to fixed dual microphones and omnidirectional microphones (Chapter 8).

Methods of the study
Field tests of 2 x 4 weeks, with laboratory tests at two audiological centres, were used to determine the added value of the noise reduction in a first-generation digital hearing aids. 27 Hearing-impaired subjects with sensorineural hearing losses were conducted in field tests with digital in-the-ear hearing aids (with noise reduction) and with a newly fitted analogue in-the-ear hearing aid (without noise reduction). The order of field tests was randomized. At the start and at the end of each field test, objective measurements were conducted (loudness scaling and speech intelligibility in continuous speech-shaped noise, speech-modulated speech-shaped noise, and car noise, with speech and noise at $0^\circ$ azimuth). At the end of each field test the subjects completed a questionnaire. The results of both hearing aids were compared.

Different algorithms within one hearing aid were used to determine the added value of a dual microphone. 16 Hearing aid users participated in three field tests, each of four weeks. For four weeks the hearing aids were fitted without noise reduction, for four weeks the hearing aids were fitted with noise reduction (based on spectral and temporal differences) and for four weeks the hearing aids were fitted with a dual microphone. The order of fittings was randomized. Both ‘objective’ measurements (SRT-test with a male voice and a female voice at $0^\circ$ azimuth, in cocktail noise or car noise coming from $-90^\circ$, $+90^\circ$ and $180^\circ$), and ‘subjective’ measurements (paired comparisons and questionnaires) were conducted. SRT-tests were conducted both before and after each
field test. In weeks 4 and 12 paired comparisons were conducted with 4 different hearing aid settings (also the setting with both noise reduction and dual microphone activated). The questionnaires were completed after each field test. In the last week SRT-tests were also conducted for the setting with both noise reduction and dual microphone activated.

The effect of the adaptive dual microphone is compared to the omnidirectional microphone and the fixed dual microphone (within the same hearing aid). Localization tests with 13 loudspeaker boxes in a horizontal plane from -90° to +90° were performed first. JFC-tests (Just Follow Conversation) with different sound sources were performed to measure the effects on speech intelligibility. The speech was always presented in front of the subject (0°) and the continuous noise was presented from different (fixed) spatial locations: 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°, 360°. The measurements were repeated with an extra noise from -90° or 90°, respectively. The noise was presented at a constant level, the subject was asked to adjust the level of the speech until he/she could just follow the sentences. SRT tests were performed with the noise from the front, from the left- and the right-hand side, and from the back. Nine subjects with two in-the-ear hearing aids and nine subjects with two behind-the-ear hearing aids were measured.

Results
In general, there were subjective preferences for digital hearing aids above newly fitted analogue hearing aids. However, this was not confirmed by the results of the SRT-test in the free field, and the results of loudness scaling. There was also a difference between the results of both centres. For the SRT-test the choice of background noise proved to be a determinant for results of evaluation. In one centre the noise was activated 5 - 6 seconds before the speech, while in the other centre the noise was activated about 10 seconds before the speech. Therefore more time was left to activate the noise reduction in the hearing aid. In the subjective evaluation large differences were shown and we
have to realize that ‘bias’ of personal preferences of the hearing-impaired subjects could be an important factor (halo effect).

The advantage of testing different algorithms within the same hearing aid is the possibility of blinding the experiment, such that there is no bias by personal preferences of the subjects. The effects of the dual microphone are clearly positive, especially for the SRT-test and the paired comparisons. The objective and subjective results were in agreement. The effect of noise reduction was obviously smaller than the effect of the dual microphone. However, noise reduction reduced the aversiveness of loud sounds significantly. There is no difference between the benefits of the dual microphone per se and the effects of the combination of dual microphone and noise reduction.

Compared to other settings, the adaptive directional microphone had no negative effect on localization of noises (especially for in-the-ear hearing aids). The dual microphone, both fixed and adaptive, showed a better result in speech intelligibility with spatially separated noise sources than the omnidirectional microphone. The behind-the-ear hearing aid with adaptive directional microphones had a clearly added value for noise conditions with two spatially separated noises.