Intelligent processing to optimize the benefits of hearing aids
Boymans, M.

Citation for published version (APA):
Boymans, M. (2003). Intelligent processing to optimize the benefits of hearing aids

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
CHAPTER 4.

THE BENEFITS OF BILATERAL HEARING AIDS II:
A retrospective study

This chapter is submitted to Int.J.Aud. (Boymans et al., 2003a)
4. Retrospective analysis of the benefits of bilateral hearing aids

Summary
This study describes the outcomes of a retrospective analysis of the results for hearing aid prescription in eight Dutch Audiological Centres. In total 1000 clinical files of consecutive hearing aid approvals in 1998 have been investigated. Three categories of data have been collected from clinical files: anamnestic data, audiometric data, and rehabilitation data.

With respect to the fitting practices most bilateral fittings were found for rather symmetrical hearing losses, but also for asymmetries, up to 30-40 dB, bilateral fittings were applied. The percentage of bilateral fittings was 60% and this percentage proved to be almost independent of age and independent of hearing loss, except for small hearing losses in which the better ear was too good for fitting a hearing aid. More bilateral fittings were also found for the group of repeated fittings. However, there is a lot of scatter in the audiological data. So criteria for a successful provision of bilateral hearing aids cannot be derived from standard audiometric data only.

To investigate the benefits of one or two hearing aids after at least one year of practice all patients, involved in the investigation of the clinical files, were asked to fill in an extensive questionnaire. For this purpose a questionnaire was composed of parts of existing questionnaires, covering issues of detection, discrimination, speech intelligibility in quiet and in more difficult situations, localization, comfort of loud sounds, hearing aid use, auditory functioning, satisfaction, benefit, and handicap. 505 Questionnaires were returned and they have been used to evaluate the long-term effects. The subjective data of the questionnaires showed a clear benefit of the second hearing aid in the bilaterally fitted group for detection, localization, and for speech intelligibility in quiet. Even in more difficult situations with noise and/or reverberation significant benefits were found. The aversiveness of loud sounds was not significantly worse than for the situation with one hearing aid.
Finally, the relations between objective parameters from audiometric and anamnestic data, and the subjective outcome measures, were analysed. One of the most important conclusions is that the bilaterally fitted group was more satisfied with the hearing aids than the unilaterally fitted group and with regard to the degree of residual handicap the distributions of outcome measures were about the same for both groups. Another conclusion is that hearing aid fitting in subjects with a relatively good ear is not less effective than hearing aid fitting in subjects with higher hearing losses. Furthermore, the group with more severe losses showed about the same satisfaction as the group with mild hearing losses. The repeated fitting group has a higher hearing loss, shows more satisfaction but has a higher residual handicap score than the first fitting group. In 1998 only a few digital hearing aid models were available, but the scores for auditory functioning with digital hearing aids are relatively good.

4.1. Introduction

In the literature many advantages of a second hearing aid have been described (for more details see Chapter 3). Hawkins and Yacullo (1984) found a significant bilateral advantage independent of microphone type and reverberation time. The stimuli were played through earphones. Festen and Plomp (1986) found a better S/N ratio in subjects with two hearing aids than with one hearing aid for higher hearing losses (PTA \(_{5.1.2\, kHz}>60\, dB(HL))\). A significant improvement in midplane localization performance for a second hearing aid, was found by Punch et al. (1991). This was measured in laboratory conditions, and the outcome measures of the questionnaires in a real life situation were in agreement with the above-mentioned result.

More subjective comparisons, of unilateral and bilateral fittings, were studied by Erdman et al. (1981). They asked the subjects to report the differences between the two modes of amplification after a trial period of 9 days in total. In case of a bilateral fitting more advantages than disadvantages were reported. The mostly mentioned subjective advantages were improved speech clarity, stereophonic effect, and balance in hearing.
Mostly mentioned disadvantages for a bilateral fitting were: difficulties to balance volume controls, increased ambient noise, and cosmetic concerns. Stephens et al. (1991) concluded that persons with worse hearing levels showed a higher improvement for localization with bilateral fittings than persons with better hearing levels. The former group preferred bilateral fittings and made their choice predominantly for acoustical reasons (clarity, localization, loudness). The persons with milder hearing losses showed less benefit from a bilateral fitting and the reasons for their choice were more varied. Balfour et al. (1992) showed a bilateral preference for mild and/or moderate hearing losses in a paired comparison study with recorded material. Judgements were made on eight separate quality dimensions. The bilateral preferences were strongest for speech in quiet and for the dimension fullness and spaciousness. Clarity was ranked as the most important feature.

Furthermore, Silman et al. (1984) found an auditory deprivation effect for speech recognition, for the unfitted ears of subjects with unilateral fittings after 4-5 years of hearing aid use. Gelfand et al. (1987) found also a significant decrease in speech intelligibility scores after 4-17 years for the unaided ears of unilaterally fitted subjects, while there was no decrease in PB scores for their aided ears. Also no decrease in speech intelligibility was found for the bilaterally fitted group, or for the unaided group. Gelfand (1995) described in a case study the recovery of the auditory deprivation effect. For some subjects, in which the deprivation effect developed within two years, the effect recovered completely, for some subjects the effect did recover significantly but not completely, and for some subjects the deprivation effect took several years to develop and did not recover after several years of bilateral fitting.

Many statements about bilateral fittings are based on work of 10 or more years ago. In the mean time hearing aid technology improved. Therefore, the present study investigates retrospectively the current application of bilateral fittings in eight Dutch Audiological centres, using modern hearing aids. The focus of this study is threefold:

- An inventory was made of 1000 clinical files, with respect to current fitting practices of hearing aids in the Netherlands, because the reasons and/or criteria for
fitting one or two hearing aids are not always obvious. Many considerations seem to play a role both for the hearing-impaired person and for the hearing-aid prescriber. For example, a large asymmetry in hearing loss can be a contra indication for a bilateral fitting, but it is not clear to which limits. The key question in this part of the study is: What are current fitting practices in a large (multi-centre) clinical population and which are the audiometric characteristics of subjects fitted with one or two hearing aids?

- In addition, we investigated the subjective benefit of one and two hearing aids. For this purpose we applied an extensive questionnaire that was designed to focus on a variety of aspects related to disability and handicap due to hearing-impairment, and related to use, benefit, and residual handicap after fitting with one or two hearing aids. This study describes the subjective results obtained from a total of 505 returned questionnaires out of the same population of 1000 subjects described above. The key question is: what are the subjective outcome measures for the unilateral and bilateral fittings?

- Finally, we combined the subjective results of the populations with unilateral and bilateral hearing aids with the anamnestic and audiometric data from the clinical files. In this analysis we will focus on the differences for specific subgroups in order to answer the key question: How are the relations between subjective judgements on the one hand and anamnestic and audiological data on the other?

4.2. Method

4.2.1. Population

Eight Audiological Centres participated in this retrospective study regarding the fitting results of the hearing aid population in the Netherlands. They are representative for Audiological Centres in the Netherlands and all centres are members of the foundation PACT, the Platform for Audiological and Clinical Testing. PACT was established as a
platform for independent clinical research related to the use of hearing aids. As a representative sample of the hearing aid fittings, each audiological centre selected clinical files of 125 consecutive hearing aid approvals in 1998.

4.2.2. *Investigation of the clinical files*

To characterize the populations with unilateral and bilateral fittings, three categories of data have been extracted from the clinical files.

- Anamnestic data like gender, age, and hearing aid experience.
- Audiometric data like pure tone audiogram and speech audiogram. The speech discrimination as a function of level was measured with CVC-words according a standardized procedure used in the Netherlands. (Bosman, 1989).
- Rehabilitation data like type of hearing aid, unilateral/bilateral, and the duration of the trial period.

4.2.3. *Questionnaires*

To investigate the benefit of one or two hearing aids after at least one year of practice, all patients, involved in the investigation of the clinical files, were asked to fill in an extensive questionnaire. The questionnaire consisted of different components. First some general questions were asked, for example about the intensity of hearing aid use and about the communication intensity. Parts of existing questionnaires were included like the Hearing Handicap and Disability Inventory (HHDI, van den Brink, 1995), the Amsterdam Inventory of Auditory Disability and Handicap (AIADH, Kramer et al., 1995), questions about aversiveness of loud sounds and about situations with reverberation from the Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox et al., 1995), and the seven questions of the newly developed International Outcome Inventory for Hearing Aids (IOI-HA, Cox et al., 2000). In addition we asked about the reasons
why the patients used one or two hearing aids. The AIADH and APHAB questions were asked for the situation without a hearing aid, with one hearing aid, and with two hearing aids (if applicable). Unpaired T-tests were used to measure the significance between the differences of the unilaterally fitted group and the bilaterally fitted group. The significance of the differences between the subjective results with one and with two hearing aids in the same subjects was tested by paired T-tests.

4.2.4. Relations between data from clinical files and the subjective results

A nonparametric correlation technique (Spearman’s r) was used to calculate the correlations between the most important parameters from anamnestic and audiologic data, and from outcome measures of the questionnaires. To investigate the different relations between the results from the questionnaires and the data from the clinical files, we used a multiple linear regression technique to predict different outcome measures as dependent variables by a selected set of audiometric and anamnestic parameters as independent variables. In addition, subgroups have been defined in which the average values of input and output variables have been compared. The subgroup profiles indicate the deviations of each subgroup relative to other subgroups and to the total group regarding to age, the degree of hearing loss, and the percentage of bilateral fittings. The results profiles present the mean results per subgroup (as far as the data are available): an index for the use of the hearing aids, the total score of auditory functioning (AIADH and APHAB), the benefit of the second hearing aid (if applicable), the average satisfaction (based on IOI-factor 1), and the experienced handicap (based on HHHI). The significance of the differences between subgroups has been tested with unpaired T-tests.
4.3. Results

Clinical files of in total 1000 patients are investigated (508 men and 492 women). The patients were fitted with either one or two behind-the-ear (BTE) or in-the-ear (ITE) hearing aids. The average age was 64 years old. As expected, the age groups between 65 and 85 years are over-represented.

4.3.1. Fitting results, information from the clinical files.

587 Subjects were fitted with two hearing aids (bilaterally). 413 Subjects were fitted with one hearing aid, but in 7 of these subjects a CROS or biCROS fitting was applied. The latter fittings were regarded as unilateral fittings, because the sound presentation was to one ear only (in all of these subjects the hearing loss at the better ear was worse than 30 dB (HL)).

Anamnestic and rehabilitation data.
Age appeared not a factor of importance with respect to the distribution of bilateral and unilateral fittings: about 60% of every age decade was fitted bilaterally. In 36.5 % of the cases the fitting concerned a first fitting and in this subgroup about half of the patients were fitted unilaterally. For the group of experienced users, 36% of the unilaterally fitted users decided to change to two hearing aids. Most of the patients that were used to wear two hearing aids continued to do so. Only 12% of them changed from two to one hearing aid.

In our population BTE fittings were much more frequent than ITE-fittings (85% and 15%, respectively). To classify the different hearing aids three categories have been chosen: conventional analogue, advanced analogue (like multi-program hearing aids and multi channel compression aids), and digital hearing aids. In 1998 only a few types of digital aids were on the market. In the test population only 14% digital hearing aids
were prescribed, and 86% analogue hearing aids (69% conventional and 17% advanced).

The duration of the trial periods was typically between 2 to 4 months. Sometimes the duration was considerably longer. There were no clear differences between the duration of the trial periods for unilateral or bilateral fittings; on average 15.2 and 15.0 weeks, respectively.

![Histogram of Hearing Losses and Fittings](image)

**Fig. 4.1. Cumulative histogram for the numbers of unilateral and bilateral fittings for the total group for different hearing losses at the better ear (average 1,2,4 kHz).**

**Audiometric data**

Figure 4.1 shows the absolute numbers of unilateral and bilateral fittings as a function of the average hearing loss at the better ear. For mild hearing losses relatively more unilateral fittings than bilateral fittings are found. For larger hearing losses more bilateral fittings were found, ranging from 40% to 69%.
Figure 4.2 represents the absolute difference between both ears for the groups with unilateral and bilateral fittings. Most bilaterally fitted patients have a rather symmetric hearing loss, but bilateral fittings were also found for asymmetrical losses with interaural differences up to 30-40 dB. The average asymmetry between both ears for unilateral fittings is 22.2 dB (±23.0) and for the bilateral fittings 8.0 dB (±8.7).

In the unilateral fitted group 44 % of the hearing losses was symmetrical (± 10dB), and in 65% of the remaining cases the hearing aid was fitted on the better ear.

![Absolute difference between both ears in dB](image)

**Fig. 4.2. The absolute difference between the PTA’s (1,2,4 kHz) of both ears for the groups with unilateral and bilateral fittings.**

For the unilaterally fitted subjects the average hearing loss (.5, 1, 2, 4 kHz) of the right ear (x-axis) is plotted against the average hearing loss of the left ear (y-axis) in Figure 4.3a and 4.3b (for right-ear-fittings and left-ear-fittings, respectively). In both figures a clear asymmetry is shown.
Fig. 4.3. Scatter plots of the average hearing losses (.5, 1, 2, 4 kHz) on the right ear (x-axis) and the left ear (y-axis) for subjects with right-ear-fittings (Panel a) and left-ear-fittings (Panel b).

The figures show a preference for unilateral fittings at the better ear for large hearing losses (panel a: upper triangle, panel b: right-hand triangle), but for small and moderate hearing losses also unilateral fittings have been realized at the poorer ear (panel a: lower triangle, panel b: left-hand triangle). However there is a lot of scatter in the individual data. The diagonal lines will be discussed in the Discussion Section.

In Figure 4.4 the asymmetry in tone audiogram (in dB) is compared with the asymmetry in maximum speech discrimination loss (in %). On the horizontal axis the tone-audiometric differences of the right and the left ear are plotted (average hearing losses at 1, 2, and 4 kHz). On the vertical axis the differences of the right and the left ear are plotted for loss in maximum speech discrimination. In Figure 4.4a the results are shown for the unilaterally fitted group (circles for the right fitted ear, crosses for the left fitted ear) and in Figure 4.4b for the bilaterally fitted group (triangles).
Figure 4.4a shows a trend that a large asymmetry in pure-tone audiogram goes along with a large asymmetry in maximum speech discrimination. But there is also a lot of scatter. Sometimes a small asymmetry in pure-tone audiogram goes along with a large asymmetry in speech discrimination and vice versa. Figure 4.4a confirms the trend that better-ear fittings are found for larger asymmetries, and the figure also shows that this is predominantly dependent on the asymmetry of the speech discrimination. Figure 4.4b shows that most bilaterally fitted patients had relatively symmetrical hearing losses.

![Scatter plots of the differences of the right and the left ear for the average pure-tone hearing loss (1, 2, and 4 kHz) in dB (x-axis), versus the differences of the right and the left ear for the loss in maximum speech discrimination in % (y-axis). Panel A: for the unilaterally fitted group (circles for the right fitted ear, crosses for the left fitted ear) and panel b: for the bilaterally fitted group (triangles).](image)

In our population most hearing losses have a sensorineural origin (75 %). In 25 % of the cases a conductive component is present, usually resulting in mixed hearing losses. The choice between a unilateral or bilateral fitting was clearly influenced by the kind of hearing loss. For purely sensorineural hearing losses the percentage bilateral fittings is 63%. When there is conductive component at least at one ear, this percentage decreased to 48%.
4.3.2. Subjective results / questionnaires

An extended questionnaire has been sent to the group of 1000 patients described before. 505 Returned questionnaires were applicable for processing (50.5% response).

Figure 4.5a shows the distributions of age over different age decades for the total group (n=1000) and for the response group (n=505). There are relatively fewer responses in the group 20-30 years and the group 90 – 100 years than in the middle group. But the distribution of age over the different age decades is not significantly different between the total group and the response group.

Figure 4.5b shows the same trend for both groups with respect to the distribution of the average hearing loss at the better ear. Only the patients with a severe hearing loss are relatively less well represented in the response group than in the total group. This leads to a small but significant (p<0.001) difference for the average hearing losses in both groups (59 dB for the response group and 62 dB for the total group). However, both figures suggest that the response group is a representative sample of the total group with respect to age and hearing loss. Also the distributions of unilaterally and bilaterally fitted patients are in agreement. In the total group 59% of the patients were fitted bilaterally and 41% unilaterally versus 58% bilateral and 42% unilateral fittings in the response group.

Part of the questionnaires is devoted to reasons why the patient himself/herself chose for one or two hearing aids. This was partly an open question. In the group of 210 unilaterally fitted patients 410 times a reason was mentioned to choose for a unilateral fitting. The choice of one hearing aid is frequently based on the residual capacity of the other ear that is still relatively good (70x) or just worse (73x). Also using the telephone with the other ear can be a reason to choose for one hearing aid (43x), or problems with the own voice when fitted bilaterally (39x).
Retrospective analysis of the benefits of bilateral hearing aids

Fig. 4.5. Panel a: the distributions of different age decades for the total group and the response group. Panel b: the distributions of the average hearing loss at the better ear for the total group and the response group.
In the group of 295 bilaterally fitted patients 690 times a reason was mentioned to choose for a bilateral fitting. Obviously, the quality of sound is mentioned as the most important reason (150x). Other reasons like the balance between ears, better localization, and listening to both sides occur in about the same numbers (90x-110x). In only one case it is mentioned that two hearing aids are chosen to stop further deprivation.

**Frequency of use of the hearing aid(s)**

The patients were asked questions about the frequency of use for the right and the left hearing aids separately. 488 of the 505 patients answered these questions. Therefore, it was possible to assess the frequency of use in three groups: patients fitted unilaterally (n=199), patients fitted bilaterally wearing both hearing aids equally frequent (n=242), and patients fitted bilaterally but wearing one hearing aid more frequently than the other (n=47).

The use of hearing aids for bilaterally fitted patients is slightly higher than for unilaterally fitted patients. 74% Of the bilaterally fitted patients, wearing both hearing aids equally frequent, are wearing the hearing aids for 8 hours or more versus 62% of the unilaterally fitted patients.

In the group of 47 bilaterally fitted patients wearing one hearing aid more frequently than the other, 74% wear only one hearing aid for 8 hours or more, but the use of the second hearing aid is obviously lower.

Twelve hearing-impaired patients (9 unilaterally and 3 bilaterally fitted patients) indicated not to wear the hearing aids at all. Besides, 16 bilaterally fitted patients did not wear the second hearing aid complementary to the first hearing aid. So 31 hearing aids were not used; this is 4% of the total of 777 prescribed hearing aids in the response group. We could not find a systematic relationship between the degree of the hearing loss and the non-use of the hearing aid. Likewise, it can be calculated that 27 hearing
aids were used for less than 1 hour a day. This, however, should not be interpreted as inefficient use because selective use can be of great value in specific situations.

**Handicap and satisfaction**

Ten questions about the degree of handicap according the HHDI (van den Brink, 1995) were part of the questionnaire. The parameter derived from these questions reflects the degree of handicap experienced with hearing aids, ranging from 0 to 3 (lower scores are more favourable). The differences between unilaterally fitted and bilaterally fitted patients were not significant.

<table>
<thead>
<tr>
<th></th>
<th>Unilaterally fitted subjects</th>
<th>Bilaterally fitted subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHDI-score for Handicap</td>
<td>1.14 ± 0.69</td>
<td>1.10 ± 0.68</td>
</tr>
<tr>
<td>(on a scale from 0 - 3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IOI-factor 2</td>
<td>3.62 ± 1.00</td>
<td>3.74 ± 0.87</td>
</tr>
<tr>
<td>(reverse score for Residual Handicap; scale from 1 - 5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IOI-factor 1</td>
<td>3.23 ± 1.14</td>
<td>3.44 ± 1.07*</td>
</tr>
<tr>
<td>(Satisfaction; scale from 1 - 5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p<0.05  ** p<0.01  ***p<0.001

**Table 4.1.** Average scores (± st.dev) for handicap and satisfaction indices in two subgroups: patients with a unilateral fitting (n=194) and patients with a bilateral fitting (n=289). The indices presented are the HHDI scores for handicap and the IOI-subscores: IOI-factor 2 (the reverse of the residual handicap) and IOI-factor 1 (for satisfaction). For HHDI a lower value indicates a better result, while for IOI factors lower scores indicate a worse result. The significance of the differences between the groups is indicated by asterisks (unpaired T-tests).

To measure the residual handicap of the hearing aid user, also three questions of the IOI-questionnaire (Cox et al., 2000) have been used. The results of the IOI-factor 2
correspond closely to the results of the HHDI described above, but for the IOI-factor 2
the scale ranges from 1 to 5 and higher scores are associated with less residual handicap
(more favourable). Three other questions are related to the benefit or satisfaction of the
hearing aid and are combined in the IOI-factor 1 (on a scale from 1 to 5; see also
Kramer et al., 2002). The bilaterally fitted group is significantly more satisfied with the
hearing aids than the unilaterally fitted group (p<0.05). In Table 4.1 the results have
been summarized.

Auditory disabilities
To investigate the subjective judgements of functioning without a hearing aid, with one
hearing aid, and with two hearing aids, subscales of AIADH (Kramer, 1995) and
APHAB (Cox et al., 1995) have been applied. On the basis of 28 questions, 7 categories
were composed in which auditory functioning was measured in the next situations:
detection of sounds (5 questions), discrimination or recognition of sounds (1 question),
speech intelligibility in quiet (5 questions), speech intelligibility in noise (5 questions),
speech intelligibility in reverberation (1 question), directional hearing or localization (5
questions), and comfort of loud sounds (6 questions). For each patient and each
category the mean scores were calculated only when more than 50% of the questions
in that particular category had been answered. All scales range from 1 to 4. The results
of the subjective judgements are presented in Figure 4.6 for all seven categories. The
average results of unilaterally fitted patients (n=210) and bilaterally fitted patients
(n=295) are plotted separately. Higher values always correspond with a better result.

In the group of 210 unilaterally fitted patients (Figure 4.6a) the benefit of a hearing aid
can be derived from the difference between the bars without hearing aid and with one
hearing aid. Higher grey bars indicate a positive effect of the hearing aid. This is for all
categories clearly present, except for the comfort of loud sounds (last two bars). It is
remarkable that clear benefits are also found for difficult listening situations (noise and
reverberation). The benefit of one hearing aid for localization is only marginal and
wearing a hearing aid causes clearly more aversiveness for loud sounds.
Retrospective analysis of the benefits of bilateral hearing aids

Fig. 4.6. Panel a: the average results of the subjective judgements (according AIADH and APHAB), without and with one hearing aid, for all 7 categories for the unilaterally fitted patients (n=210). Panel b: the average results of the subjective judgements (according AIADH and APHAB), without, with one, and with two hearing aids, for all 7 categories for the bilaterally fitted patients (n=295). All scales range from 1 to 4. The higher the bars, the more positive the result.
For the group of 295 bilaterally fitted patients the results are presented similarly in Figure 4.6b. Again, the benefits of a hearing aid can be derived from the differences between the bars without (open) and with one hearing aid (grey). Although different populations are involved the average effects for the unilaterally and bilaterally fitted patients are in close agreement. In this study, the effect of a second hearing aid is especially important. For this purpose the differences between the scores with one (grey bars) and two hearing aids (black bars) in the group of 295 bilaterally fitted patients can be compared. Despite the fact that some individual scores for specific situations were worse for two than for one hearing aid, the mean results for the whole group (including the patients with bad experiences) show a predominantly positive effect. Improvements of the mean scores were found for all categories except for comfort of loud sounds. The disadvantage of wearing a second hearing aid is that the comfort of loud sounds is somewhat worse for two hearing aids than for one hearing aid. This effect is obviously smaller than the effect of the first hearing aid compared to the situation without a hearing aid.

Only a minority of the patients answered all questions for the situations without, with one, and with two hearing aids. This means that the group results are based on varying numbers of subjects. Consequently, the trends may not be representative for the average effects in the individual hearing-impaired subject. That is the reason why a separate analysis was done on a subset of respondents who did answer all questions. This concerns 75 unilaterally fitted patients and 49 bilaterally fitted patients. In each of these groups paired t-tests were used to investigate the significance of the differences. For both groups the scores with one hearing aid were significantly higher than without a hearing aid (p<0.001) for all categories except for comfort of loud sounds for which significantly lower scores were found (p<0.001). This implies that a hearing aids leads to significant improvements in six out of seven categories.

In addition, we found significant improvements with two hearing aids relative to one hearing aid in the bilaterally fitted group with respect to detection (p<0.001), speech in
quiet (p<0.01), speech in noise (p<0.001), speech in reverberation (p<0.001) and localization (p<0.01). Again the comfort of loud sounds was significantly lower (p<0.001).

Finally, the results of the unilaterally fitted group and the bilaterally fitted group are compared to one another using unpaired t-tests. For the comparable condition with one hearing aid the bilaterally fitted group rated significantly lower scores than the unilaterally fitted group with respect to detection (p<0.05), discrimination of sounds (p<0.001), and speech intelligibility in quiet (p<0.01). However, a comparison of the final fitting results shows that the group of bilaterally fitted subjects scored significantly better with two hearing aids than the group of unilaterally fitted subjects with one hearing aid with respect to detection (p<0.05), localization (P<0.001), and speech in noise (p<0.05). This was accompanied by slightly lower scores for the comfort of loud sounds (p<0.05) for the bilaterally fitted group. Together these data explain partly why the satisfaction, as measured with IOI-factor 1, was significantly higher in the bilaterally fitted group than in the unilaterally fitted group (p<0.05, see Table 4.1).

4.3.3. Relation between subjective results and anamnestic and audiological data

In this section we will describe different relations between the clinical files and the questionnaires. Because the results are partly based on the questionnaires, this analysis includes only the group of 505 hearing-impaired in the response group.

First we investigated the correlations between the most important parameters from anamnestic and audiologic data and from outcome measures. In the total response group the following significant correlations were found:
- The frequency of hearing aid use is lower at higher age (p<0.01) and higher for larger hearing losses (p<0.01).
A higher hearing aid use goes along with more satisfaction (IOI-factor 1, p<0.01) and more benefit of the second hearing aid (p<0.01).

The benefit of the second hearing aid is positively correlated with the satisfaction (p<0.01).

Average scores for auditory functioning are lower for higher hearing losses (p<0.01).

Better auditory functioning goes along with less handicap (p<0.01) and more benefit of the second hearing aid (p<0.01).

Higher handicap scores are found at higher ages (p<0.05) and higher hearing losses (p<0.01).

As indicated in the Methods section, we applied a multiple linear regression technique to predict different outcome measures as dependent variables by a selected set of audiometric and anamnestic parameters as independent variables. The following outcome measures were predicted: degree of hearing aid use, average auditory functioning, IOI factor 1 (related to benefit and satisfaction), and average handicap (HHDI). As independent variables we only included parameters that were not too closely interrelated with the other parameters in the set (r<0.50, i.e. less than 25% shared variance). The set consisted of the 10 parameters listed in the columns of Table 4.2. The results of a stepwise multiple linear regression are presented as rows in Table 4.2. For each of the outcome measures the rows show the (multiple) correlation coefficients and the independent variables included for the prediction. The +/- signs indicate the direction of the relationship and the *-symbols the significance.

Hearing aid use can be predicted to a very limited degree (r=0.286) by the independent variables and is mainly related to the factor first/repeated fitting and the degree of hearing loss at the better ear. The average score for auditory functioning is mainly determined by the degree of hearing loss at the better ear (r=0.457), but the prediction can be refined up to r=0.552 by adding five other variables. The IOI-factor 1 (related to benefit and satisfaction) does not show high correlations with the set of independent variables and consequently, it is hard to predict the benefit/satisfaction from anamnestic
Retrospective analysis of the benefits of bilateral hearing aids

and audiological data. Finally, the handicap index HHI is related to the intensity of communication, the degree of hearing loss at the better ear, age, and the asymmetry of the hearing loss (multiple r=0.448).

Table 4.2. The results of a stepwise multiple linear regression for the response group to predict different outcome measures (dependent variables, first column) and the independent variables (predictors on the horizontal axis). For each of the outcome measures the rows show the (multiple) correlation coefficients (second column) and the independent variables included for the prediction. The +/- signs indicate the direction of the relationship and the asterisks the significance.

In addition, we analysed the effects for specific subgroups. For this purpose we defined so-called profiles, consisting of characteristic data about the hearing-impaired subjects in a specific subgroup (subgroup-profile) and the results obtained (results profile).
The subgroup profiles indicate the deviations of each subgroup relative to other subgroups and relative to the total group. The results profiles present the mean outcome parameters per subgroup (as far as the data are available).

<table>
<thead>
<tr>
<th>Sub-group profile</th>
<th>Total</th>
<th>unilateral</th>
<th>(bi)CROS</th>
<th>bilateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>N of subjects</td>
<td>505</td>
<td>204</td>
<td>6</td>
<td>295</td>
</tr>
<tr>
<td>Avg. Age</td>
<td>64</td>
<td>64</td>
<td>66</td>
<td>65</td>
</tr>
<tr>
<td>PTA better</td>
<td>59</td>
<td>57</td>
<td>42</td>
<td>61*</td>
</tr>
<tr>
<td>% Bilateral</td>
<td>58%</td>
<td>0%</td>
<td>-</td>
<td>100%</td>
</tr>
</tbody>
</table>

| Results profile   |       |            |          |           |
| Index for ha use  | 3.34  | 3.24       | 3.7      | 3.4       |
| Avg. Aud. Functioning | 2.96 | 2.9        | 2.73     | 3         |
| Benefit 2nd ha    | 0.27  | -          | -        | 0.28      |
| IOI-factor 1 (avg. satisfaction) | 3.35 | 3.23       | 3.22     | 3.44*     |
| Avg. Handicap score (HHDI)   | 1.12  | 1.13       | 1.33     | 1.1       |

* p<0.05  ** p<0.01  *** p<0.001

Table 4.3. Average values of the general parameters for the total group (n=505) and for the subgroups with a unilateral, a (bi)CROS, or a bilateral fitting. The unilateral group is compared with the bilateral group. The significance of the differences between the groups, is indicated by asterisks (unpaired T-tests).

The average values of the total group are presented in the second column of Table 4.3. In the next three columns of Table 4.3 similar profiles have been presented for the subgroups of subjects with a unilateral, a (bi)CROS, and a bilateral fitting, respectively. Given the small number of subjects, we tested only the inter-group differences for bilaterally fitted subjects relative to unilaterally fitted subjects. In the bilaterally fitted group the average hearing loss is slightly higher (p<0.05) and the satisfaction scores are higher (p<0.05). The trend towards a higher use in the bilateral group (see Section 4.3.2) is only significant at p<0.10.
## Table 4.4. Average values of the general parameters for the different subgroups based on anamnestic and audiometric parameters (Communication intensity, Hearing loss ‘mild’: PTA < 35 dB, ‘moderate’: 35 ≤ PTA ≤ 80, ‘severe’: > 80 dB, Speech audiogram). The group with a moderate hearing loss is compared with the group with a mild hearing loss, and with the group with a severe hearing loss. The significance of the differences between the groups is indicated by asterisks (unpaired T-tests).

<table>
<thead>
<tr>
<th>Sub-group profile</th>
<th>Communication Intensity</th>
<th>Hearing loss</th>
<th>Max. speech discr. score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>high</td>
<td>low</td>
<td>mild</td>
</tr>
<tr>
<td>N of subjects</td>
<td>364</td>
<td>141</td>
<td>37</td>
</tr>
<tr>
<td>Avg. Age</td>
<td>62</td>
<td>71</td>
<td>62</td>
</tr>
<tr>
<td>PTA better</td>
<td>58</td>
<td>62</td>
<td>26</td>
</tr>
<tr>
<td>% Bilateral</td>
<td>59%</td>
<td>58%</td>
<td>22%</td>
</tr>
<tr>
<td>Results profile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index for ha use</td>
<td>3.38</td>
<td>3.24</td>
<td>3.04</td>
</tr>
<tr>
<td>Avg. Aud. Functioning</td>
<td>3.02</td>
<td>2.78**</td>
<td>3.13</td>
</tr>
<tr>
<td>Benefit 2nd ha</td>
<td>0.29</td>
<td>0.23</td>
<td>0.29</td>
</tr>
<tr>
<td>IOI-factor 1 (avg. satisfaction)</td>
<td>3.4</td>
<td>3.24</td>
<td>3.11</td>
</tr>
<tr>
<td>Avg. Handicap score (HHDI)</td>
<td>0.98</td>
<td>1.49***</td>
<td>0.98</td>
</tr>
</tbody>
</table>

* p<0.05  ** p<0.01  *** p<0.001

**Anamnestic data**

We investigated differences in the result profiles for hearing-impaired patients with full-time or part-time *employments* (n=134) and hearing-impaired patients without a job or retired (n=354) (not shown in a table). There were hardly any differences between both groups. Patients without a job have slightly higher handicap scores (p<0.01) and – as expected - a clearly higher age (p<0.001).

The 2<sup>nd</sup> and 3<sup>rd</sup> columns of Table 4.4 show the profiles for the subgroups according to the intensity of verbal communication in daily life. The first group (high communication
intensity) consists of patients with much verbal communication and/or patients who indicated to be active members of a club or a union. Patients in the second group (low communication intensity) are less involved in verbal communication situations. The subgroup profile shows that the group with less intensive communication has a higher age ($p<0.001$). The results profile indicates that subjects with less intense communication have more problems in auditory functioning ($p<0.01$), and they show higher handicap scores ($p<0.001$).

**Audiological data**

In the 4th, 5th, and 6th column of Table 4.4 the effects of the *degree of hearing loss* are shown. The categories are based on the average loss at 1, 2 and 4 kHz for the better ear: mild (losses up to 35 dB, n=37), moderate (losses between 35 and 80 dB, n=385), and severe (losses higher than 80 dB, n=83), respectively.

The effect of a hearing aid for the hearing-impaired with a mild hearing loss is demonstrated by comparing the first group and the second group. In the group of mild losses the percentage of bilateral fittings is significantly lower ($p<0.001$). As a consequence the number of bilateral fittings was too small to assess the effect of the second hearing aid.

The effects of a hearing aid for patients with a severe hearing loss (higher than 80 dB) are demonstrated by comparing the second group and the third group. For the group with severe losses the average age is significantly lower, probably due to the participation of the Institute of the deaf as one of the Audiological centres. Although the hearing losses are (per definition) quite different, the percentage of bilateral fittings is about the same (see also Fig. 4.1). Subjects with severe hearing losses use their hearing aids significantly more frequently ($p<0.01$), their auditory functioning is significantly lower ($p<0.001$) and their handicap scores are significantly higher ($p<0.001$).
Subgroups have also been composed according *maximum speech discrimination scores* (7\textsuperscript{th} and 8\textsuperscript{th} columns in Table 4.4). The results of the analysis based on the speech audiogram are in agreement with the results based on the pure-tone audiogram. The average hearing loss for the group with poor speech discrimination (≤ 90\%) is significantly higher than for the group with better discrimination scores (> 90\%) and they are fitted more frequently bilaterally (p<0.01). The group with poor speech discrimination shows a significantly higher use of the hearing aids (p<0.01), a worse auditory functioning (p<0.001), and a higher handicap score (p<0.001).

<table>
<thead>
<tr>
<th>Sub-group profile</th>
<th>Fitting</th>
<th>Hearing aid</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First</td>
<td>Repeated</td>
<td>BTE</td>
</tr>
<tr>
<td>N of subjects</td>
<td>176</td>
<td>329</td>
<td>411</td>
</tr>
<tr>
<td>Avg. Age</td>
<td>67</td>
<td>63**</td>
<td>65</td>
</tr>
<tr>
<td>PTA better</td>
<td>47</td>
<td>66***</td>
<td>62</td>
</tr>
<tr>
<td>% Bilateral</td>
<td>49%</td>
<td>64%***</td>
<td>59%</td>
</tr>
<tr>
<td>Results profile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index for ha use</td>
<td>2.96</td>
<td>3.55***</td>
<td>3.37</td>
</tr>
<tr>
<td>Avg. Aud. Functioning</td>
<td>3.24</td>
<td>2.80***</td>
<td>2.9</td>
</tr>
<tr>
<td>Benefit 2nd ha</td>
<td>0.22</td>
<td>0.28</td>
<td>0.26</td>
</tr>
<tr>
<td>IOI-factor 1 (avg. satisfaction)</td>
<td>3.18</td>
<td>3.45*</td>
<td>3.39</td>
</tr>
<tr>
<td>Avg. Handicap score (HHDI)</td>
<td>0.95</td>
<td>1.20***</td>
<td>1.15</td>
</tr>
</tbody>
</table>

* p<0.05 ** p<0.01 *** p<0.001

Table 4.5. Average values of the results profile for different subgroups based on fitting parameters (first/repeated fitting, hearing aid type, and hearing aid technology: 'Conventional analogue', 'Advanced analogue', 'Digital'). The conventional analogue group is compared with the advanced analogue group, and with the digital group. The significance of the differences between the groups is indicated by asterisks (unpaired T-tests).
**Fitting results**

In Table 4.5, three types of categorizations in subgroups based on fitting results have been applied. In the 2nd and 3rd columns the differences between patients with a *first* (first group) and a *repeated fitting* (second group) are shown. The average age for the repeated fitting group is lower than for the first-fitting group (p<0.01). Hearing aid users with a repeated fitting have a higher hearing loss (p<0.001), use their hearing aids more frequently (p<0.001), show lower scores for auditory functioning (p<0.001) and have higher handicap scores (p<0.001), but they obtain a higher satisfaction (p<0.05) and are fitted more frequently with two hearing aids (p<0.001) than firstly fitted subjects.

The next two columns divide the subgroups according to the *kind of hearing aid*. ITE-users have less hearing loss (p<0.001), show higher scores for auditory functioning (p<0.001), and have lower handicap scores (p<0.05) than BTE-users.

Finally, the group has been categorized according the *technology level of the hearing aids* (6th, 7th, and 8th columns for conventional analogue, advanced analogue, and digital, respectively). The differences of the subgroups with advanced analogue aids and with digital aids have been tested relative to the relatively large group using conventional analogue hearing aids.

There are no significant differences between the different “subgroup profiles”. Nevertheless for the digitals (8th column) a significantly better auditory functioning is found (p<0.001) and a slightly lower handicap score (p<0.05) than for the standard analogue hearing aids (6th column). In the subgroup of advanced analogue hearing aids the benefit from the second hearing aid proved to be significantly higher (p<0.05).
4.4. Discussion

This retrospective study provides a thorough analysis of the fitting practice in eight Dutch Audiological Centres using state-of-the-art hearing aids. Special attention is given to the use of bilaterally fitted hearing aids. An inventory was made of 1000 clinical files, with respect to current fitting practices of hearing aids in the Netherlands. About 60% of every age decade was fitted bilaterally and 63.5% of the total group was a repeated fitting.

Current fitting practices show that the degree of hearing loss at the better ear appears to be relatively unimportant for the choice of unilateral or bilateral fittings (see Fig. 4.1), except for mild hearing losses (see Table 4.4). The most plausible reason is that in the mildly hearing-impaired subjects the better ear is too good for fitting a hearing aid. This is in agreement with the results of Stephens et al. (1991) who found that people with hearing levels higher than 45 dB prefer bilateral fittings.

For purely sensorineural hearing losses more bilateral fittings were prescribed. This reflects the fact that some conductive hearing losses can give medical contra-indications for wearing a hearing aid and it seems also to be connected to a larger chance of asymmetry in case of conductive components. Furthermore, the data show that bilateral fittings are usually not applied in case of more than 40 dB asymmetry between both ears.

For unilaterally fittings Dillon (2001) advocates to use the following rule-of-thumb: “Fit the ear that has the four-frequency average (4FA) threshold closer to 60 dB (HL)”. The audiometric data of our unilaterally fitted population have been analysed according to this rule-of-thumb. The diagonal lines in Figure 4.3 indicate positions with equal ‘distance’ to the average hearing loss of 60 dB (HL). Right ear fittings are expected in the upper and lower triangles while left ear fittings are expected in the left-hand and
right-hand triangles. Figure 4.3 shows that the rule-of-thumb, described above, is valid in the majority of cases.

Because of the fact that one of the participating audiological centres is an institute for the deaf with relatively young patients and relatively severe losses, the average age for the total group with severe hearing losses is significantly lower. However, the percentage of bilateral fittings is hardly dependent on age.

In addition, we investigated the subjective benefit of one and two hearing aids. The drop out rate of the questionnaires is about 50%. This seems to be a high percentage but the persons received the questionnaires two years after the last visit at the audiological centre, which is of course unfavourable for the response rate. The mean age of the subjects is high, so it is possible that they were ill, or not able to answer all those questions. In the response group the patients with a severe hearing loss are less well represented than in the total group. The reason could be that part of the questions was judged to be irrelevant for people with such a worse hearing.

The hearing aid use for the bilaterally fitted group is higher than for the unilaterally fitted group (12%). In addition, the bilaterally fitted group is more satisfied with the hearing aids and there is no significant difference in degree of residual handicap between both groups. For the bilaterally fitted subjects that filled in the questions both for 1 and 2 hearing aids, the subjective improvements of bilateral fittings were clearly present (a significant improvement for detection, speech in quiet, speech in noise, speech in reverberation, and localization), but also the comfort of loud sounds decreased significantly. So it is important to pay extra attention to the comfort of loud sounds, as well for the unilateral fittings as for the bilateral fittings. The results of the partly open question: ‘why people prefer two hearing aids’ are in agreement with the results of Erdman et al. (1981). The most important advantage for a bilaterally fitting was: a better quality of sound and a better balance between ears. The reason to choose one hearing aid was mostly based on the residual capacity of the other ear in our study. In the
clinical practice the subjects’ preference is a very important component of the decision. That may be the reason that only a few hearing aids are lying in the drawer.

We also combined the subjective results of the questionnaire with the anamnestic and audiometric data from the clinical files. In the multiple linear regression analysis we found that on basis of anamnestic and audiologic data, the average auditory functioning can be predicted the best, followed by the average handicap. It is hard to predict the hearing aid use and the satisfaction. As expected, the audiogram gives a lot of information: the higher the hearing loss the lower the auditory functioning, and the higher the average handicap. The asymmetry can give information about the average auditory functioning: the higher the asymmetry the lower the auditory functioning. So it is important to compensate for the asymmetry. The average handicap is also related to the intensity of communication. People with a high intensity of communication show less average handicap, or the other way around: people who show a high average handicap do not communicate much. This can be due to an isolated life style in which the hearing loss can play a role.

Finally we analysed the relationships between subjective judgements at one hand and anamnestic and audiological data at the other for specific subgroups. In the first instance there seems to be no striking differences between the unilateral and bilateral fitted groups because there were only two significant differences between both groups. The most important subjective factor is that the bilaterally fitted group was more satisfied with the hearing aids than the unilateral fitted group. An audiological factor is that they had a slightly higher hearing loss (4 dB). This is related to other factors. It happens that out of the other subgroups, people with a severe hearing loss have a higher hearing aid use, a lower auditory functioning and a higher handicap score. This is related to the maximum speech discrimination. The repeated fittings and the BTE-fittings have also a significant higher hearing loss. The small but significant age effect for the repeated fittings is unexpected and could not be explained. The kind of hearing aid appears not to have a large influence on the results. The fact that ITE hearing aids (and first fittings)
gave better results for auditory functioning and lower handicap scores, is undoubtedly influenced by the smaller hearing losses of the ITE users (and the first fittings). Although in 1998 only a few digital hearing aid models were available, it is remarkable that the scores for auditory functioning with digital hearing aids are relatively good.

It would be effective if one can predict whether a hearing-impaired listener is more satisfied by one or by two hearing aids. This study shows that the anamnestic data and audiological data used in this investigation are not able to predict the degree of hearing aid benefit accurately. Therefore, we decided to develop a test battery with other psychoacoustical tests. This will be investigated in a separate study. In that study also the fittings will be evaluated in an objective manner to provide firm evidence for the ultimate choice after a trial period with one or two hearing aids.

4.5. Conclusions

In our population bilateral fittings were found in relatively symmetric hearing losses (interaural differences up to 30-40 dB) and those fittings were slightly more frequently on sensorineural hearing losses than on conductive hearing losses. In the unilateral fitted group 44 % of the hearing losses was symmetrical (± 10dB), and in 65 % of the remaining cases the hearing aid was fitted on the better ear. The percentage bilateral fittings was hardly influenced by the average hearing loss (except for small losses) and proved to be independent of age. Hearing aid fitting on subjects with a relatively good ear is not less effective than hearing aid fitting on subjects with higher hearing losses at the better ear. Subjects with two hearing aids (who answered the questions for one and two hearing aids) showed significant subjective benefit for the second hearing aid in the categories: detection, speech in quiet, speech in noise, speech in reverberation, and localization, except for the comfort of loud sounds.
The analysis of relations between objective parameters from audiometric and anamnestic data and the subjective outcome measures of different subgroups showed the following trends:

- Large asymmetry in tone audiogram is associated with a low average auditory functioning.
- The bilaterally fitted group is more satisfied with a hearing aid than the unilaterally fitted group.
- More severe losses show a higher use, lower auditory functioning, and about the same satisfaction, and a higher handicap score.
- For the digital hearing aids a significantly better auditory functioning is found and a bit lower handicap score than for the standard analogue hearing aids.
- It is difficult to predict the hearing aid use and the satisfaction from anamnestic and audiological data.