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

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CHAPTER 6.

CLINICAL EVALUATION OF A FULL-DIGITAL IN-THE-EAR HEARING AID

This chapter has been published in Audiology (Boymans et al., 1999)
6. Clinical evaluation of a full-digital in-the-ear hearing aid

Summary
In this study we measured the efficacy of a digital hearing aid with compression and noise reduction in a well-controlled clinical field trial in two independent centres. The experiments focused on a number of aspects of the application of the digital hearing aids.

The study combines a field test of 2x4 weeks with laboratory experiments. We used objective measurements (speech perception tests in background noise, loudness scaling) and subjective assessments (questionnaires). The measurements were performed before and after the field test. The questionnaires were collected after each field test. The results of the digital hearing aids were compared to the results of similar tests with newly fitted analogue reference aids. The study involved 27 sensorineural hearing-impaired subjects, wearing new hearing aids. They comprised a representative sample of ITE-users. We used a crossover design in which the subjects used successively digital hearing aids and analogue reference aids in a randomized order.

On average, the subjective data are more positive than the objective data. In the end, 20 out of 27 subjects had an overall preference for the digital hearing aid. The financial implications were not taken into consideration. However, objective data do not support this strong subjective preference. A reason could be that the method of analysis (short sentences in a short-duration background noise) is not suited for the digital hearing aid; the testing procedure does not allow the noise-reduction algorithm to adapt to the background noise. There was a striking difference between the results for the two centres. This difference can, at least to a certain extent, be attributed to the timing of speech relative to the background noise in the objective tests. This illustrates that the testing conditions are critical in modern non-linear signal-processing hearing aids with long time constants. New evaluation techniques should be developed for this new generation of active non-linear hearing aids.
6.1. Introduction

Digital hearing aids have some specific features that may provide extra benefit for the hearing-impaired users (Verschuure and Dreschler, 1993). We tested this assumption on a population wearing a full digital in-the-ear hearing aid. The hearing aid was a three-channel device with compression and noise reduction in each of the frequency channels. The results of the digital aid were compared with the results for state-of-art, analogue in-the-ear hearing aids, fitted to the same subjects, using a crossover design. The experimental focus was on the tested performance of users under well-controlled laboratory conditions and subjective performance data obtained from questionnaires after a trial period.

There are only a few well-controlled clinical trials with digital hearing aids thus far. Arlinger et al. (1998) tested a seven-channel digital hearing aid with the subject's own analogue aids as a reference. They found superior performance for the digital aid, but the subjective data, gathered with the Abbreviated Profile of Hearing Aid Benefit (Cox et al., 1995) and the Gotheburg Profile, were more positive than the objectively measured improvements for speech perception in noise.

Hearing-impaired listeners often have problems with speech intelligibility in environments with background noise. For that reason we used different kinds of background noises in the laboratory experiments, continuous speech-shaped noise, speech-modulated speech-shaped noise and a car noise. We measured the critical signal-to-noise ratio of sentences in these noises. The noises represent conditions to which we are often exposed in daily life. The thresholds were measured in the laboratory under fully controlled experimental conditions. Other problems experienced by hearing-impaired listeners have to do with their reduced dynamic range. We performed loudness scaling
tests to investigate the effects of the compression in the digital hearing aids on the perceived dynamic range.

Finally, subjective judgements on listening performance in different conditions were obtained in a field test. Specific attention was given to general aspects of wearing comfort, ease of an automatic volume control, the cosmetic aspects, the feedback problems, and the internal noise. Preferences have been assessed comparing the digital aid and the analogue reference aid with respect to the sound quality, acoustic feedback, the automatic volume control, the perception of loud sounds and the overall judgement.

6.2. Method

The study was designed as a two-centre study of the Academic Medical Centre Amsterdam (AMC) and the Erasmus University Rotterdam (EUR) in order to compensate for bias due to local experience and/or preference in Amsterdam or in Rotterdam. Furthermore there is a long-standing tradition of co-operation between both Audiological Centres involved, which guarantees an optimal tuning of the assessment procedure, both for the objective measurement and for the subjective assessment. The study combines a field test of 2x4 weeks with laboratory experiments before and after the field test in order to get an indication of acclimatization (Gatehouse, 1992). The results of the digital hearing aid were compared with the results of similar tests with a reference analogue hearing aid. Laboratory experiments included measurements of speech perception in continuous speech noise, in speech-modulated speech noise, and in low-frequency car-noise. Loudness scaling with constant noise, speech- and car noise resulted in two parameters: the most comfortable level (MCL) and the slope of the loudness growth function. The subjective performance during field tests was assessed by means of extensive questionnaires.
6.2.1. Subjects

We selected 27 subjects from the clinic population seeking help for audiological problems in the AMC or the EUR, ensuring that the subjects comprised a representative sample of ITE-users. They were asked to participate in the study on a voluntary basis. There were no age restrictions, except that children (<16 years) were not included in the study. Selection criteria were that subjects should:

- be capable of assessing a hearing aid in a rational manner
- not have any language problems which may influence the speech tests
- choose to wear two in-the-ear hearing aids
- have a symmetrical sensorineural hearing loss (interaural differences < 15dB)
- have a PTA (0.5, 1 and 2 kHz) hearing loss between 30 and 75 dB(HL).

Participants in the study who expressed strong disappointment when they had to return the digital hearing aids after the test, were allowed to keep their digital hearing aids at the same cost as the analogue hearing aids. This was not known to them until after they had expressed their preference for either one of the hearing aids.

Table 6.1 shows the population statistics and the average hearing losses in the subgroups participating in AMC and EUR.

<table>
<thead>
<tr>
<th></th>
<th>AMC</th>
<th>EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of subjects</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>first-time users</td>
<td>9/15</td>
<td>12/12</td>
</tr>
<tr>
<td>Range of ages (years)</td>
<td>27 - 86</td>
<td>36 - 78</td>
</tr>
<tr>
<td>av. loss at 500 Hz (dBHL)</td>
<td>27 ± 13.4</td>
<td>35 ± 14.2</td>
</tr>
<tr>
<td>av. loss at 1000 Hz (dBHL)</td>
<td>38 ± 9.6</td>
<td>44 ± 14.0</td>
</tr>
<tr>
<td>av. loss at 2000 Hz (dBHL)</td>
<td>58 ± 6.8</td>
<td>49 ± 10.4</td>
</tr>
<tr>
<td>av. loss at 4000 Hz (dBHL)</td>
<td>69 ± 14.9</td>
<td>59 ± 11.9</td>
</tr>
</tbody>
</table>

Table 6.1. Subject characteristics and mean hearing losses.
Clinical evaluation of a full-digital in-the-ear hearing aid

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Av.loss .5 - 4 kHz</th>
<th>analogue reference aid</th>
<th>IG re NAL .5 - 4 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>45</td>
<td>60</td>
<td>Danavox 161 K-Amp</td>
<td>4,5</td>
</tr>
<tr>
<td>2</td>
<td>78</td>
<td>49</td>
<td>Dahlberg Invisa +</td>
<td>3,7</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>41</td>
<td>Danavox 161 K-Amp</td>
<td>5,8</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>45</td>
<td>Oticon 155-Micro</td>
<td>2,1</td>
</tr>
<tr>
<td>5</td>
<td>46</td>
<td>48</td>
<td>Oticon 155-Micro</td>
<td>1,8</td>
</tr>
<tr>
<td>6</td>
<td>70</td>
<td>44</td>
<td>Widex LX</td>
<td>2,6</td>
</tr>
<tr>
<td>7</td>
<td>48</td>
<td>61</td>
<td>Oticon I-22P</td>
<td>0,7</td>
</tr>
<tr>
<td>8</td>
<td>86</td>
<td>46</td>
<td>Oticon Logic Communicare</td>
<td>4,1</td>
</tr>
<tr>
<td>9</td>
<td>26</td>
<td>38</td>
<td>Philips M60-O(H)</td>
<td>4,3</td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>53</td>
<td>Siemens Cosmea CM 122</td>
<td>7,1</td>
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<tr>
<td>11</td>
<td>72</td>
<td>55</td>
<td>Oticon 155</td>
<td>3,7</td>
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<td>12</td>
<td>52</td>
<td>39</td>
<td>Danavox 161 K-Amp</td>
<td>2,5</td>
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<tr>
<td>13</td>
<td>40</td>
<td>41</td>
<td>Oticon 154</td>
<td>1,3</td>
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<tr>
<td>14</td>
<td>66</td>
<td>44</td>
<td>Philips M60-O(F)</td>
<td>2,1</td>
</tr>
<tr>
<td>15</td>
<td>42</td>
<td>55</td>
<td>Oticon 155 mini</td>
<td>1,2</td>
</tr>
<tr>
<td>EUR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>59</td>
<td>55</td>
<td>Danavox 131</td>
<td>7,3</td>
</tr>
<tr>
<td>22</td>
<td>51</td>
<td>38</td>
<td>Danavox 131</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>67</td>
<td>53</td>
<td>Philips M60-O</td>
<td>3,7</td>
</tr>
<tr>
<td>24</td>
<td>76</td>
<td>41</td>
<td>Beltone Invisa +</td>
<td>5,9</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
<td>56</td>
<td>Oticon Prima Focus</td>
<td>6,6</td>
</tr>
<tr>
<td>26</td>
<td>79</td>
<td>39</td>
<td>Oticon 154</td>
<td>7</td>
</tr>
<tr>
<td>27</td>
<td>59</td>
<td>36</td>
<td>Beltone Invisa +</td>
<td>5,6</td>
</tr>
<tr>
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<td>43</td>
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<td>7,6</td>
</tr>
<tr>
<td>30</td>
<td>56</td>
<td>58</td>
<td>Danavox 161CD</td>
<td>4,1</td>
</tr>
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<td>31</td>
<td>37</td>
<td>59</td>
<td>Danavox 161CD</td>
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</tr>
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<td>32</td>
<td>68</td>
<td>40</td>
<td>Danavox 151 premier</td>
<td>8,6</td>
</tr>
<tr>
<td>33</td>
<td>68</td>
<td>43</td>
<td>Philips M20</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 6.2. Summary of individual data of age and average hearing loss (.5 - 4 kHz). For each subject the analogue reference aid is indicated, as well as the rms-value of differences between the IG-responses and the NAL-targets (.5 - 4 kHz)(after corrections for the setting of the volume wheel).
6.2.2. Hearing aids

Half of the subjects started the experiment by using the digital hearing aids and the other half by using the analogue hearing aids. The type of hearing aid (digital or analogue) was switched over after half the trial period. It was impossible to use a blinded protocol, but the order of the trial period over digital and analogue hearing aids was randomized.

The reference hearing aid was a newly fitted analogue in-the-ear hearing aid. We used many different brands for the reference hearing aids, see Table 6.2. Concha in-the-ear hearing aids and CIC aids (completely-in-the-channel) were not used as reference aids, nor were multi-program in-the-ear hearing aids, with a remote control. All reference aids had volume controls.

6.2.3. The fitting procedure of the conventional hearing aid

The reference hearing aid always was a new analogue in-the-ear hearing aid. The conventional aid was fitted according to the standard clinical selection method and checked by insertion-gain measurement. We tried to achieve a frequency characteristic according or close to the NAL-r prescription rule (Byrne & Dillon, 1986). Table 6.2 also presents the rms-values of the differences between the measured insertion gains and the NAL-predictions. The maximum output power was limited according to the subject's uncomfortable loudness level.
6.2.4. The fitting procedure of the digital hearing aid

The digital hearing aid in this study was a Widex Senso. We used the LP2 Programmer for the fitting of the digital hearing aid using the manufacturer-designed integrated in-situ fitting procedure. A feedback-reduction system is incorporated in the hearing aid and it was programmed according to the standard procedure prescribed by the manufacturer using the LP2 Programmer. The frequency crossover points between low-, mid-, and high-frequency channels were chosen according to the recommendations of the fitting procedure. We selected one out of three filter settings according to the audiogram. In all cases the standard filter setting could be used, except for subject 3.

We first fitted the hearing aid on the data from the normal pure-tone audiogram (in the HTL mode). For the standard filter setting, the HTL-values for the three channels were derived from the audiometric losses at 500, 1000 and 3000 Hz respectively. In the HTL-mode acoustical properties of the hearing aid shell, and the residual volume of the ear canal were not taken into account. Next the standardized audiogram-based in-situ fitting procedure was used. Tones were generated by the hearing aid, and we measured a hearing level for each of the three frequency bands (low, middle and high). This procedure was not affected by the aid in the other ear. After the aid had been fitted according to the two methods the feedback test was conducted. The subject was then asked to chew and the feedback test was repeated. When the value for one of the bands (low, middle or high) was below -10 a new impression of the ear canal was made in order to achieve a tighter fit of the hearing aid in the ear canal. The values of the UCL-mode (uncomfortable level) were recorded. The subject was asked to report on the sound quality and the loudness of both hearing aids. This resulted in readjustments of the fitting in a number of cases.
6.2.5. Objective evaluation with speech

The pre-trial testing was done in weeks 0 and 4, the post-trial testing was done in week 4 and 8. It was expected that testing with isolated words was not appropriate for the given digital aid in view of the relatively long time constant of the noise reduction algorithm. For that reason we used speech-reception thresholds (SRTs) for sentences as described by Plomp and Mimpen (1979) in a number of background noises. This test reflects better daily-life situations.

The SRT threshold was determined for a continuous speech-shaped noise, for a speech-modulated speech-shaped noise and for a low-frequency car-noise. The speech-shaped noises had the same long-term spectrum of the speaker (according to Plomp and Mimpen) and we used the modulated noise as described by Festen and Plomp (1990). For every situation we used a male and a female speaker.

Testing was conducted with ten lists of sentences with an adaptive up-down procedure. This test has been proven to be accurate (test-retest standard deviation between 0.9 to 1.5 dB) and fast. The order of the lists was randomized. The noise level was set at 64 dB(A). The noise started 5 seconds before the speech, which we initially thought to be early enough to activate the automatic processing of the digital hearing aid.

In an evaluation discussion the manufacturer provided additional information about the time constants of the noise reduction scheme. Because of a time-lag between the two centres the EUR-group then decided to produce a CD with each test sentence preceded by another sentence in noise to present noise and speech long enough for the noise-reduction algorithm to be activated. In order to distinguish the target sentence from the leading adaptation sentence, the leading sentence was a sentence played backwards. There was no gap between the leading sentence and the test sentence. The same inverse sentence was used for all test sentences. The CD was used for the testing of all EUR
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subjects. This implies that the testing procedure differed somewhat between the two institutes in this respect.

6.2.6. Laboratory experiments on loudness scaling

We obtained data on loudness perception by means of loudness scaling. In Amsterdam the method of the Würzburger Hörfeld Skalierung (Hellbrück and Moser, 1985) was applied based on a 50-point scale. Loudness scaling was measured for each individual and each of the following types of noise: fragments of constant speech noise, single-speaker speech and car noise. The ranges of output levels were 30-80, 30-90, and 30-900 dB(A), respectively. The noises were presented for 5 seconds. This was long enough to reach a steady state response of the automatic loudness processing of the digital hearing aid, although the noise reduction was not yet fully activated. The subjects were asked to judge the loudness of the sounds presented on a 50-point scale ranging from “not heard” to “too loud”. They were instructed to judge loudness at the end of each fragment. In the EUR-group a similar procedure was applied, based on a 10-point scale according to Pascoe (1986). In Rotterdam loudness scaling was measured for narrow-band noises for the centre frequencies 500, 1000, and 2000 Hz.

Loudness scaling was done before and after the trial periods with the different hearing aids. The data points were fitted by straight lines and the parameters of loudness growth were based on the fit in order to reduce measurement error. Two parameters were calculated from the fit: the level at which a loudness level of 50% of the scale was reached (called “MCL”) and the slope of the loudness growth function. The former is related to the amount of hearing loss, the latter to the amount of recruitment.
6.2.7. **Subjective assessment**

The trial period gave each subject the opportunity to become accustomed to the sound of each pair of the hearing aids, and to make possible a subjective assessment of the subject’s performance with the hearing aids. After a trial period each subject came to the Audiological Centre for a debriefing and for the laboratory experiments. The debriefing gave the experimenter at the Audiological Centre the opportunity to confirm and complement the subjective assessment of the hearing aid.

In week 4 and 8 the subjects completed a questionnaire on their experiences with the hearing aids. The subject had no access to their previous responses. The questionnaire used a visual analogue scale. All indications were performed on unmarked lines with end markings such as:

```
bad __________________________ good.
```

The subjects were asked to make a mark on each scale corresponding to their subjective rating of their performance in that condition. Questions were asked about the hearing aid in general (sound quality, functioning, frequency of use etc.) and rated speech intelligibility with the hearing aid in a number of situations. Situations were divided into a number of categories such as at home, outside and at work. They were also asked to indicate how often the described situation occurred and how important that situation was for the subject (all using visual analogue scales).

At the end of the study each subject completed a final questionnaire in which they were asked to rank the two hearing aids in a number of important situations. The results determined the relative subjective differences between the two kinds of hearing aids.
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Total-results (n=27)

AMC-results (n=15)

EUR-results (n=12)
6.3. Results

We present the results in four categories: critical S/N ratios in different background noises, loudness scaling for different noises, subjective data from the questionnaires, and the overall preference after two trial periods.

It can be seen from Table 6.1 that the subjects in the AMC-group had on average greater and more sloping hearing losses than those in the EUR-group. In the AMC-group there was a mix of experienced and first-time users, while the EUR-group consisted entirely of first-time users. We ordered new ear moulds in 17% of the cases. The decision to do so was based on the results of the feedback test. We found this test to be very helpful in detecting malfunctioning ear moulds, although in individual cases there have been some complaints about acoustical feedback in spite of a good result in the feedback test.

6.3.1. Data on speech perception in noise

Figure 6.1a shows the results of the SRT-test for the total group (n=27). The medians and 25 and 75 percentile points are represented for the differences in critical S/N ratios between the digital hearing aid and the conventional hearing aid in a number of conditions. When the value represented by the diamond is positive it indicates that the speech perception threshold with the digital hearing aid was better than with the conventional hearing aid, in that situation. The left diamond represents the difference in

Fig. 6.1. Panel a-c: The medians and the 25 and 75 percentile points for differences in the critical S/N ratios (in dB) between the digital hearing aid and the analogue hearing aid for the total group (6.1a) and for the subgroups AMC and EUR (6.1b-c). Positive diamonds corresponds for better speech perception for the digital hearing aid. S=continuous noise, F=fluctuating noise, C=car noise.
the S/N ratio in continuous noise (S), the diamond in the middle represents the
difference in S/N ratio in fluctuating noise (F) and the right diamond represents the
difference in S/N ratio in car noise (C). The first set shows the results obtained with the
female voice, the second set with the male voice, the third set is measured after the
hearing aid fitting (pre-trial) and the fourth set is measured four weeks after the hearing
aid fitting (post-trial). The last set shows the combined result for male voice and female
voice and pre- and post-trial testing. The differences, between the pre- and post-trial
scores were not significant. This implies that we did not find measurable effects of
acclimatization in our experimental set-up. In the subgroups of AMC and EUR (Fig.
6.1b and 6.1c, respectively) significant but opposite effects appear to be present. In the
AMC-results the digital hearing aid performed clearly worse (p<0.01 for the continuous
and fluctuating noises and p<0.05 for the car noise). In the EUR-results the digital
hearing aid performed significantly better in the continuous noise and in the car noise
(p<0.05). For the interpretation it is important to realize the difference in speech
material (EUR: extra time to allow switch-on of noise-reduction algorithm) between the
centres and the differences in the patient characteristics.

6.3.2. Data on loudness scaling

Loudness scaling was performed before and after the trial periods. There are no
systematic effects of acclimatization on loudness perception, at least not within the 4-
weeks duration of the trial period. For that reason the presented results have been
averaged over tests before and after the trial period.

For the AMC-group we assumed that the dynamic range to be used for speech ranges
from the levels scaled as 'soft' (Categorical Loudness Units, CLU =10) to the levels
scaled as 'too loud' (CLU=50). We calculated the dynamic ranges from the loudness
slopes. For the EUR-group a similar approach was followed using the Pascoe scores,
averaged over 500, 1000 and 2000 Hz.
Compression may be expected to reduce the slope of the loudness curve, which is increased in the majority of sensorineural hearing-impaired subjects. If compression is effective this would show up as a difference in the loudness curve (a lower slope value and a higher dynamic range) for the compression digital hearing aid relative to the linear reference aid. We compared the results on loudness scaling for the 22 subjects who used a linear reference aid. In 23% of the cases (AMC n=3, EUR n=2) the calculated dynamic range in the digital aid was more than 10 dB higher than in the linear analogue aid. In the majority of the cases (16) the difference was less than 10 dB, while in one case the dynamic range was more than 10 dB higher in the analogue aid. We concluded that the effects of compression do not clearly influence the average dynamic range.

The correlation between the slopes of the "aided" loudness curves for the analogue and digital hearing aids is shown in Fig. 6.2 for a number of different sounds. For the AMC-group no clear effect of compression is present.

Fig. 6.2. Panel a and b: The relations between "aided" loudness slopes for the linear analogue and compression digital hearing aids for different noises for AMC and EUR, respectively.
For the EUR-group a slight trend can only be found for lower loudness slopes for the digital aid. The range of slopes is larger for the AMC-group than for the EUR-group. It is difficult to interpret these differences due to the different noises used in AMC and EUR. There were lower loudness slope values for single speaker noise and higher slopes for the other noises. No systematic differences were found between different frequencies.

6.3.3. Subjective data from the field test questionnaires

The questionnaires were very comprehensive, and therefore we constructed composite ratings summarising six important groups of acoustical situations: in quiet, in noise, in a car, on a telephone, watching TV or being in a theatre, and listening to music.

Figure 6.3a and b present composite scores on the speech intelligibility ratings for respectively the AMC-group and the EUR-group. The left white bars represent the scores of the analogue hearing aid and the right grey bars those of the digital hearing aid. In most of the cases we see a better rating for the digital hearing aid except for TV/theatre (AMC) and telephone (AMC and EUR).

The translation of individual field test data into absolute percentages can only be done after the application of a criterion value. As we computed the data from questionnaires with 4.2-cm long analogue-visual scales, we used as criterion that for a better score the rating should be in the "best" third part of the scale. This means that the judgement should be more than 2.8 points from the negative end of the scale or less than 1.4 points from the positive end of the scale.

The subjects were also asked about the frequency of occurrence and the individual relevance of each situation. These data have been used to weigh the intelligibility scores according to the perceptual relevance. There is no systematic difference between the
weighed scores for use and importance and the unweighted scores. For almost all conditions we see a better score for the digital hearing aid.
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Absolute scores are important because they are not related to an unknown reference like the old hearing aid. On the other hand, they are clearly influenced by the expectations of what should be "ideal" and there is no single hearing aid, which approaches the ideal situation. Therefore, additional information can be obtained from the relative data, especially when care is taken to select a good reference. In this study we investigated thoroughly in this reference condition by performing a completely new binaural fitting with state-of-the-art analogue aids. It is our opinion that these relative data reflect well the benefit of this type of digital hearing aid over an analogue reference aid used in the study.

For the relative data we used the comparative ratings for the two hearing aids given in the questionnaire in week 8. Table 6.3 shows the subjective results related to the differences between the analogue and the digital aid. Here we did not differentiate between significant and small but possibly insignificant differences. Some differences are only marginal. However, others are large and certainly significant.

<table>
<thead>
<tr>
<th>Subjects with improved sound quality in the digital aid</th>
<th>AMC</th>
<th>EUR</th>
<th>Overall %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects with less acoustic feedback with the digital aid</td>
<td>9/5</td>
<td>10/12</td>
<td>70%</td>
</tr>
<tr>
<td>Subjects with greater ease of handling due to automatic volume control</td>
<td>6/15</td>
<td>7/12</td>
<td>48%</td>
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<tr>
<td>Subjects with improved comfort of loud sounds in the digital aid</td>
<td>8/15</td>
<td>12/12</td>
<td>74%</td>
</tr>
<tr>
<td>Subjects with higher overall preference for the digital aid</td>
<td>9/15</td>
<td>9/12</td>
<td>67%</td>
</tr>
<tr>
<td>Subjects with higher overall preference for the digital aid</td>
<td>10/15</td>
<td>10/12</td>
<td>74%</td>
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</tbody>
</table>

Table 6.3. Subjective results regarding the preferences for analogue or digital aids

Figure 6.4 a-b represents the relative ratings on general aspects of the hearing aid and about intelligibility ratings for AMC (black bars) and EUR (grey bars). For most of the considered conditions the subjects prefer the digital hearing aid, except for power consumption, visibility, intelligibility during a meeting and telephone at work for the AMC-group and wearing comfort and visibility for the EUR-group.
Fig. 6.4. Panel a - b: relative ratings for AMC (black bars) and EUR (grey bars) on general aspects of the hearing aid and on intelligibility aspects.
Figure 6.5 a-b shows the results for the total group. The statistical significance for the preferences in the total group has been indicated by the shading of the bars (black for p<0.01, grey for p<0.05). When we look at the total-group we see no significantly better scores for the analogue aid. Eleven aspects are significantly better (at 1% level) for the digital hearing aid, including the total score.
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Figure 6.5. Panel a - b: relative ratings for the total group. The level of significance is indicated by the shading of the bars (black for $p<0.01$ and grey for $p<0.05$).
6.3.4. *Overall preference after two trial periods*

In the AMC-group 5 out of 15 subjects (subjects 3, 5, 10, 11, and 13) had an overall preference for the analogue hearing aid, in the EUR-group 2 out of 12 (subjects 25 and 26). This group of 7 subjects consisted of four first-time and three experienced hearing-aid users. This is reasonably in agreement with the ratios in the total population. The analogue hearing aids that were preferred above the digital aids can be derived from Table 6.2.

![AMC+EUR (analogue aid preferred)](image)

*Fig. 6.6. Intelligibility ratings composed from answers to questions on different acoustical situations for the analogue and digital aids, for the subjects who had an overall preference for the analogue hearing aid (AMC and EUR).*

We could not detect a systematic effect to explain the overall preference. The reasons for choosing the analogue hearing aid differed from individual to individual. The composite scores of the subgroup choosing the analogue aid do not show a clear preference for the analogue aid, but the results are less supportive for the digital aid than the data for the total group (see Fig. 6.6 relative to Fig. 6.3).
6.4. Discussion

A number of aspects of our results favour the digital hearing aid, in other aspects the digital hearing aid is not superior to a well-fitted analogue hearing aid. The results in the EUR-group are more favourable than in the AMC-group, both in the speech intelligibility data and in the subjective ratings. The audiological difference between the two groups is that the EUR-group consists entirely of first-time hearing-aid users and that their losses were relatively mild and less sloping. It has been hypothesised that the results of the analogue reference aids may be relatively good, because they are completely adapted to conventionally amplified sounds. However, we found no experimental evidence in our data that the experienced users in the AMC-group performed better with the analogue hearing aid than the first-time users.

Compression may be expected to reduce the loudness slopes, which are steeper for the majority of sensorineural hearing-impaired subjects. In our data no clear evidence was found to support this assumption, although there is a slight tendency in the EUR-data for a reduced loudness slope with the digital compression aid.

The critical signal-to-noise ratio for the digital hearing aid was found to be better than the critical signal-to-noise ratio for the analogue aid in the EUR-group, but not in the AMC-group. The difference between the results in the subgroups shows that this is a substantial effect, possibly related to the differences in the testing procedures used. A possible explanation can be that in the experimental set-up at the AMC the stimulus condition at the beginning of the test sentence changes from noise only to speech in noise. This may degrade the perception of the test sentence, at least temporarily. In the EUR-approach the stimulus condition is acoustically the same at the beginning of the test sentence. Only the time-scale of the speech signal is reversed. Thus, the acoustical contrast (the difference between the background noise and the test sentence) at the beginning of the test sentence.
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is minimal. However, we were rather surprised about the amount of improvement in the critical signal-to-noise ratios found. The possibility that differences in the fitting procedure of the reference aid influence the differences found, cannot be excluded.

The differences in the results in the speech testing data between the centres underline the problems associated with the validation of the effects of non-linear compression and noise-reduction hearing aids with long time constants. One may argue that the test procedure should be chosen in a way optimized for the signal processor, but one can also argue that sudden changes in the acoustical background are an inevitable part of daily life and should be included in laboratory testing to give it face validity. The time constant of the noise-reduction algorithm can be up to 20 seconds, which is considerably longer than most clinicians realize. Therefore, the question arises how we can perform speech testing relevant for daily-life situations.

The subjective scores are not always in agreement with the objective scores. In Figure 6.7 the differences in the total composite scores (see Fig. 6.3) have been plotted against the differences of the overall SRT-results (averages for total scores for continuous, fluctuating, and car noises in Fig. 6.1) for each individual subject. Positive values point to better results for the digital hearing instrument. The objective and subjective scores appear to be hardly correlated. Fig. 6.7 also shows that the subjective scores are more positive for the digital hearing aid than the objective results.
Fig. 6.7. The difference in the total composite scores (subjective scores) against the difference of the overall SRT-values (objective scores, averages for total scores for continuous, fluctuating and car noise.

One reason can be that small changes cannot always be measured objectively due to measurement accuracy. On the other hand, a subjective bias may be present. Although we tried to rule out subjective preferences as far as possible, the study design could not be blinded. The information about digital hearing aids in the media and in advertisements may have played a role resulting in a halo effect for digital. On the other hand, the profile of the subjective outcomes are quite realistic in our opinion, indicating that there are also disadvantages with the digital aid such as the visibility, the power consumption, and its use with the telephone at work. The trend of our data is in agreement with the results of Arlinger et al. (1998), who also found clearer benefits for the subjective data than for the objective results.
6.5. Conclusions

From this study the following conclusions can be drawn:

- The subjective data show clear benefits for the digital hearing aid.
- The objective data are less clear. The results in the EUR-group are clearly better than those in the AMC-group. These differences are too large to be explained by relatively small differences between the populations, the audiometric differences, or the differences in fitting procedures. In our opinion, the main difference is in the way the digital hearing aid is able to adapt to the test signal before the actual testing starts.
- The compression used in the digital hearing aids did not affect the results of the loudness scaling tests.
- In the end, 20 out of 27 subjects had an overall preference for the digital hearing aid. Halo effects cannot be excluded.