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Evaluation of a digital power hearing aid: SENSO P38[1]

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Introduction

Digital technology was introduced in headworn hearing aids in 1995 (Sandlin, 1996, Elberling, 1996) and several studies have reported a preference for these aids over analog hearing aids (Arlinger et al., 1998, Valente et al.,1998, Boymans et al., 1999). However, the first generation of digital hearing aids which were introduced to the market were not powerful enough for persons suffering from severe-to-profound hearing losses. The first digital hearing aids specifically intended for this group of persons became available in 1998 when Widex introduced a new series of digital hearing aids, the SENSO P series. The SENSO P series includes two extremely powerful models which are designed especially for severe-to-profound losses. Since persons with a severe-to-profound loss rely on their hearing aids to a great extent, it is of considerable interest to observe how experienced users in their daily environment as well as in a clinical test set-up evaluate these hearing aids.

At the Department of Audiology at Sahlgrenska University Hospital in Gothenburg, Sweden, several efforts have been made to become a suitable site for conducting evaluation studies of new hearing aids. The clinic has immediate access to the medical history and health status of the majority of hearing impaired citizens within the Gothenburg region, providing basic data on 26,000 subjects (1998). Specifically, several basic studies on severely hearing impaired subjects living in the area have been conducted. The clinic has close contact with more than 400 persons born between 1904 and 1974, who were characterised by a sensorineural hearing impairment exceeding 70 dB HL at 1.0 kHz in the better ear. This clinic was therefore chosen for the evaluation study.

In a clinical study, several irrelevant factors may influence the result. Especially when the expectations are very high, as is the case with digital hearing aids (Bille et al., 1999). An efficient tool for minimising a possible test bias is to use a crossover strategy in combination with a blinded test design. In this way, the test subjects will not know which hearing aid is the one being tested and which is the reference aid. Due to the construction of P38, practically all functions, including the volume control, are programmable and this study could therefore be carried out as a blind study without introducing any inconvenience for the users.

Digital technology permits solutions and gives opportunities which are not feasible (or sometimes not even possible) with analog technology. The reference aid in this study is programmed as a linear aid, but uses digital technology. We have no guarantee that such a linear aid will be equivalent to an analog linear hearing aid. In fact it is very possible that the three-band Vario Slope™ filter design, which allows precise adjustment of the frequency response, and the Direct Power Drive™ output stage, which is practically free of distortion, may give a sound reproduction preferable to that possible with analog hearing aids. It is therefore also of considerable interest to compare the performance of the digital hearing aids to the subjects' own analog hearing aids. However, one might fear that such a comparison will favour the newly fitted digital hearing aid as opposed to the subjects' own hearing aids which may have been fitted months or even years earlier. In order to minimise such influence, the subjects' own analog hearing aids in this study were refitted prior to the comparison.

Thus the aim of the study is:

1. To compare two specific types of digital linear and non-linear signal processing by programming Widex SENSO P38 according to a linear and a non-linear strategy in order to identify the signal processing preferred by the patients.

2. To compare the digital processing and fitting procedure of P38 with the analog signal processing of the subjects' own hearing aids.

[1] *This is a slightly expanded version of the article published in the March 2000 issue of Hearing Review on pages 59-62 & 64.*

Method

Test subjects

Twenty-five experienced adult hearing aid users with a post-lingually acquired sensorineural hearing impairment were used as test subjects. Their audiograms were within the fitting range of the hearing aid as shown in fig. 1. A random procedure was used to select the test subjects. A total of 28 patients were randomly selected among the 223 registered persons who fulfilled the inclusion criteria. Three patients who were not able to follow the instructions were excluded during the first fitting session. The remaining 25 served as test subjects. Their mean age was 63 years (SD=13.8 years, range 24-77 years). The mean speech recognition score of phonemically balanced Swedish words was 46% (SD= 28.4%, range 0-92%) for the right ear and 41% (SD= 25.2%, range 0-96%) for the left ear. Fifteen subjects had a sensorineural hearing loss of unknown origin. In nine subjects the aetiology was hereditary, and one subject had an acquired hearing loss. Noise trauma was also a component of the hearing loss for nine subjects.

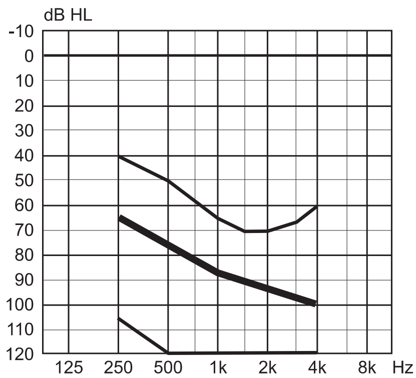

Fig. 1 Fitting range of the test-HA and the range of audiometric thresholds for the 25 test subjects

The subjects' mean experience with hearing loss was 34 years (SD=12.1 years, range 14-56 years). The subjects' mean hearing aid use was 23 years (SD=8 years, range 8-38 years). Fifteen subjects were binaurally fitted and 10 subjects were monaurally fitted. Audiometric tests included pure tone audiometry and speech audiometry without background noise. Bone conduction thresholds and tympanometry were measured if the status of the middle ear was not evident from the subject's files. The subjects were informed verbally and by written information. They were not paid for taking part in the study. The test design was approved by the Committee of Ethics at the hospital.

Experimental design

Each subject compared three hearing aids.

1. The experimental hearing aid (denoted exp-HA) was a Widex digital hearing aid, SENSO P38, programmed according to the manufacturer's specification.

2. The first reference hearing aid (ref-HA) was the digital hearing aid, SENSO P38, programmed as a linear hearing aid with a limiter type output AGC.

3. The second reference hearing aid (own-HA) was the subject's own hearing aid refitted according to the NAL fitting rule prior to the test.

A randomised crossover design was used when comparing the exp-HA and the ref-HA. The test design was in accordance with the "Nordic minimum requirements for clinical testing of hearing aids", Hagermann, 1999.

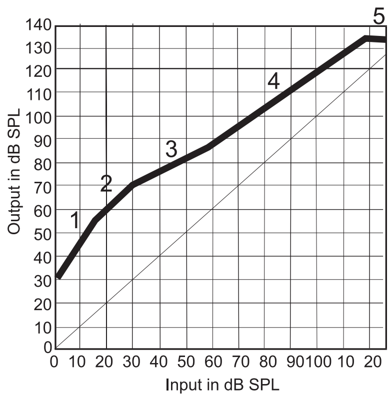

Fig. 2 Example of an input/output curve for the test-HA.

The exp-HA is a three-channel digital hearing aid. Each channel has a separate AGC with a multi-segmental I/O characteristic, and each segment is automatically adjusted during the fitting procedure according to the user's audiogram and according to a measurement of the acoustic properties of the earmould. The I/O characteristic consists of five segments of which three might be further adjusted during the fine tuning procedure. These segments are numbered 2, 3 and 4 in fig. 2. Thus, the compression ratio can be adjusted for high-level inputs (I/O segment 4 in fig. 2.) and for low-level inputs (I/O segment 3). Finally, the constant gain segment 2 is adjustable. Segment 2 represents the range of levels at which the instrument yields the highest gain for a particular setting of the instrument. This maximum gain is pre-set automatically. The latter measurement is carried out by the hearing aid itself by invoking a feedback manager during the fitting procedure. The automatic setting will provide the test instrument with a certain acoustic feedback margin. A manual adjustment possibility allows the gain of segment 2 to be set according to the degree to which the user wishes to listen to weak sounds. A Sound Stabilizer™ regulates the attack and release times of the instrument according to the characteristics of the input signal. Often, fast compression will create audible distortion products or 'pumping' artefacts. If this is foreseen, the Sound Stabilizer™ will slow down the speed of regulation. On the other hand, if it is predicted that fast acting compression can be used without audible artefacts, the regulation is automatically speeded up. The regulation speed (viz. the attack and release times) may very well differ between the bands. Furthermore, the exp-HA was equipped with a volume control with a range of 6 dB. This relatively small range was used since the exp-HA aid was equipped with an Enhanced Dynamic Range Compression AGC which operates over a wide range of input levels corresponding to segments 3 and 4 in fig. 2.

The ref-HA is physically identical to the exp-HA, but it is programmed as a linear hearing aid (i.e. in this case segments 3 and 4 on the

I/O curve fig. 2 are linear, CR=1). Thus, the ref-HA has a constant gain for practically all input levels (cf. fig. 3). This gain is programmed to approximate the NAL Modified Hearing Aid Selection Procedures for Severe/Profound Hearing Losses (Byrne et al., 1991). The range of the programmable volume control of the reference hearing aid was set to 18 dB. This relatively wide range was used since the compression at low and medium input levels was made inactive by being programmed as a linear instrument.

The test persons' own hearing aids served as a second reference hearing aid. These were behind-the-ear analog hearing aids representing several manufacturers.

Fitting procedure

The digital aids were programmed according to the manufacturers' recommendation using the Widex Compass software with a HI-PRO interface. Monaural or binaural fitting of exp. and ref. HAs was done according to the type of fitting of their own HA. The acoustic performance of the hearing aids was checked before and after the study. The subjects were randomly assigned to two groups of approximately same size.

When refitting the subjects' own hearing aids, insertion gain was measured using a composite signal at an input level of 60 dB.

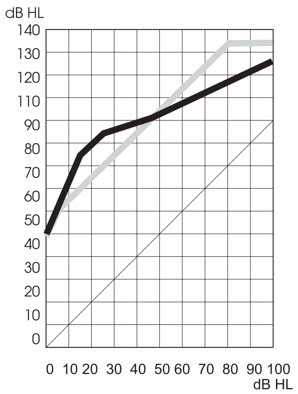

Fig. 3 I/O curves at 500 Hz for the test-HA (black) and for the ref-HA (gray).

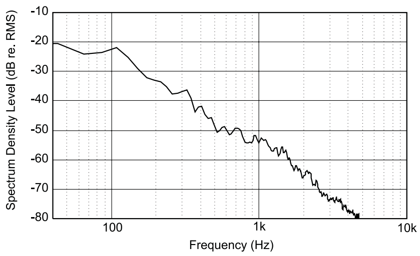

Fig. 4 Spectrum of car noise.

Test protocol

Session 1
The test subjects met at the clinic for pure tone audiometry and confirmation of the medical diagnoses. The fitting of the subject's own HA was re-evaluated by insertion gain measurements and interview. Refitting was decided if the response did not compare to the NAL RP recommendation, or if the user complained about its function. New ear impressions were taken for all aided ears. A questionnaire and a dairy were explained and handed out to the subjects.

Session 2
Speech recognition tests were performed with own HA in quiet, in car noise (see fig. 4) and in two levels of babble noise (see fig. 5). Then hearing aid 1 (HA1) was fitted. Depending on a randomisation, HA1 was either exp-HA or ref-HA.

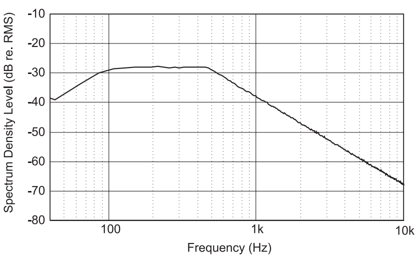

Fig. 5 Spectrum of ICRA babble noise.

Session 3
HA1 was fine tuned after two to five days based on a diary filled out by the subject and based on the subject's comments. The subjects were encouraged to meet at the clinic for subsequent fine tuning if they were not fully satisfied with the fitting. After session 3 there were approximately four weeks of field-tests.

Session 4
Speech recognition tests with HA1 as described under session 2. Questionnaires were filled out at the end of the test period and examined by the audiologist who subsequently summarised the interviews of each session in a protocol. Then HA2 was fitted.

Session 5
Fine tuning as described for session 3. After session 5 there were approximately four weeks of field-tests.

Session 6
Speech recognition tests with HA2 as described under session 2. Questionnaires were filled out using the same form as that used with own HA and HA1. In this way, the subject could make sure that the relative judgements of the three hearing aids were consistent. Insertion gain measurement and acoustical control measurement of the hearing aid were made.

The study also included a session where the exp-HA, the ref-HA and own-HA were compared in pairs in various sound environments. This session was primarily intended for developing a test procedure based on paired comparison and the results will be reported elsewhere.

Evaluation

Speech recognition scores were determined with the standard Swedish phonemically balanced (SPB) 50-word lists (Lidén, 1954) presented at 58 dB SPL in quiet or at 68 dB SPL in two different noise backgrounds. One noise signal was a synthetic six-person babble with idealised speech spectrum, representative of normal vocal effort (ICRA, 1997). The other noise signal was "In a car" (car noise) from the CD: "Real-life Environment Sound Examples" (Widex, 1995). It is a low-frequency noise whose long-term spectrum falls at about 20 dB per octave in the range 60-10000 Hz. The speech and noise materials were digitally pre-mixed and recorded on a compact disc. The speech-to-noise ratio with the ICRA noise was set to +8 dB. Based on a pilot experiment, the speech-to-noise ratio with the car noise was set to -9 dB, which was found to yield approximately the same average score as the ICRA noise at +8 dB S/N. Figs. 3 and 4 show the long-term-average spectra of the two noise signals.

Test condition	Exp-HA	Ref-HA	Own-HA
Speech level 58 dB No noise	40.2	30.7	33.8
Speech level 68 dB ICRA noise, level 60 dB	37.6	36.2	27.0
Speech level 78 dB ICRA noise, level 70 dB	38.1	35.8	28.5
Speech level 68 dB Car noise, level 77dB	32.9	31.5	24.3

Table 1. Average speech recognition scores in per cent recorded with exp-HA, ref-HA and own-HA in the four test conditions.

Test condition	Exp-HA versus Ref-HA	Exp-HA versus Own-HA	Ref-HA versus Own-HA
Speech level 58 dB No noise	(**)	(*)	()
Speech level 68 dB ICRA noise, level 60 dB	()	(***)	(*)
Speech level 78 dB ICRA noise, level 70 dB	()	(**)	(*)
Speech level 68 dB Car noise, level 77dB	()	(*)	(*)

Table 2. Significance levels of differences between speech recognition scores listed in table 1. Paired t-tests were used. The level of significance is indicated by asterisks: (***), (**), (*) and () indicate $p \leq 0.001$, $p \leq 0.01$, $p \leq 0.05$ and not significant (i.e $p>0.05$), respectively.

Questionnaires

Three questionnaires were used. The first one was an integral part of the Nordic minimum requirements for clinical testing of hearing aids. It contains questions related to the outcome and benefit of the hearing aid in various situations. In the second questionnaire, the subject has to rate seven aspects related to sound quality on a 7-point scale (viz. loudness, noisiness, softness etc). In the third questionnaire, the subject should rate the function of the hearing aid in six different common user situations on a 7-point scale.

Results

Speech recognition in quiet and in noise

When speech was presented at a moderate level of 58 dB in a quiet background, the exp-HA provided a better score than both reference hearing aids. In all three situations with background noise, speech recognition was better with either type of digital hearing aid than with the subjects' own analog hearing aids. In these situations, however, there was no significant difference between the scores obtained with the exp. HA and the ref-HA.

Answers given to the questionnaires

The main results obtained with questionnaire 1 (from Nordic minimum requirements for clinical testing of hearing aids) were:
The vast majority of the subjects (23 of the 25 subjects) used their hearing aids for more than eight hours a day. On average, the subjects had used their own hearing aid in 8.4 out of 10 common listening situations while they had used the exp-HA and the ref-HA in 7.2 and 7.3 situations respectively. The difference between exp-HA and ref-HA versus own-HA is highly significant ($P \leq 0.001$). This indicates that the test period of four weeks was not sufficient to experience all listening situations. Using the Wilcoxon Signed Rank Test, several significant differences were found. In all cases where significance was found, the exp-HA or ref-HA performed better than own-HA. These are listed in table 3. No significant differences between exp-HA and ref-HA were registered in these situtions. When asked about their overall preference, the exp-HA was preferred by 14 subjects, the ref-HA by 6 subjects and own HA by 5 subjects. At the end of the study when the subjects were asked about their final preference, some of the subjects had changed their opinion. As the final preference, 17 subjects chose the exp-HA, 5 subjects chose the ref-HA, and 3 subjects preferred own-HA. The subjects indicated on a scale from 0 to 10 how sure they were about their choice of hearing aid, 10 being absolutely sure. The mean value was between 6.6 and 6.9 for all three possibilities of preference.

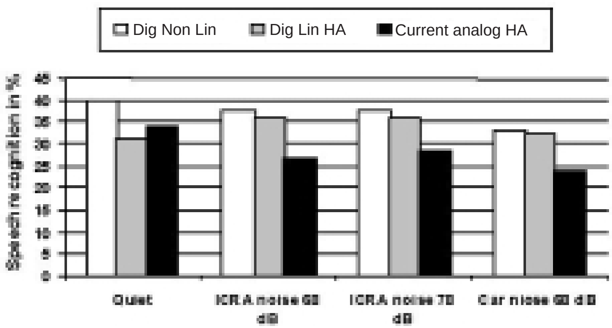

Fig. 6 Speech recognition scores obtained in four listening situations with each of the three types of hearing aid: test-HA (white), ref-HA (gray), and own-HA (black).

Question	Exp-HA preferred	Ref-HA preferred
Conversation with one person in quiet.	(*)	(*)
Conversation in a large group in noise.	(*)	(*)
Conversation with one person, travelling in a car or a bus.	()	(*)
How often can you determine where sound comes from, using the hearing aid?	(*)	()
How is it to put the HA on the ear?	(**)	(**)
How is it to adjust the controls of the hearing aid, e.g. the volume control or the M-T switch?	(*)	(**)
How is it to change the hearing aid battery?	(*)	()

Table 3. Question and level of significance when comparing exp. and ref. with own HA (Wilcoxon Signed Rank Test). (**), (*) and () indicate p = 0.01, p=0.05 and not significant (i.e p>0.05), respectively.

Question	Exp-HA	Ref-HA	Own-HA
Loudness	3.5 (**)	3.4 (**)	2.7
Clearness	3.4 ()	3.6 (*)	2.9
Softness	3.4 ()	3.6 (**)	3.0
Fullness	3.6 (*)	3.5 (*)	3.1

Table 4. Rating of various parameters on a scale ranging from 0 to 6 and level of significance when comparing with own HA (Wilcoxon Signed Rank Test).

Question	Exp-HA	Ref-HA	Own-HA
How do you rate the ability of the hearing aid to catch sounds from a distance, e. g. singing birds or playing children?	3.8 (***)	3.1 (*)	2.3
How do you rate the ability of the hearing aid to amplify weak sounds, e. g. when you are listening to a person speaking in a weak voice or from a long distance?	3.0 (**)	2.7 (***)	1.7
How do you rate the ability of the hearing aid in situations where the level of sound is frequently fluctuating?	3.2 (*)	2.8 ()	2.5

Table 5. Rating of the benefit of the three types of hearing aids in various situations. Minimum and maximum benefit corresponds to rate 0 and 6 respectively. Level of significance when comparing Exp-HA and Ref-HA with own HA is also shown (Wilcoxon Signed Rank Test).

Questionnaire 2 addressing the sound quality of the hearing aids revealed a number of significant differences between exp-HA/ref-HA and own-HA (table 4). However, no significant differences were found between exp-HA and ref-HA (Wilcoxon Signed Rank Test).

Questionnaire 3: When comparing exp-HA with ref-HA, significant differences were found in favour of exp-HA on two questions. "How do you rate the ability of the hearing aid to catch sounds from a distance, e.g. singing birds or playing children?" and "How do you rate the hearing aid in situations with strong sounds e.g. when children are shouting or from crowds of people." The level of significance was 0.01 and 0.03 respectively.
When comparing the exp-HA or ref-HA with own HA, a number of significant differences were found (table 5).

Final choice of hearing aid

Before being informed about the type of hearing aid, four subjects changed their response to question 18: "Which of the hearing aids you have tried do you prefer?" Two subjects who originally had preferred own HA changed their opinion: one subject in favour of the exp-HA and one in favour of the ref-HA. Two subjects changed their preference from the ref-HA to the exp-HA. Thus, the final overall preference was that the exp-HA was selected by 17 subjects, the ref-HA by 5 subjects and own-HA by 3 subjects.

Discussion

The exp-HA was selected by 17 subjects, the ref-HA by 5, and the own-HA by 3 subjects. The finding that 22 subjects chose digital signal processing is consistent with the results of the speech recognition tests where several significant differences were registered in favour of digital hearing aids over own analog HAs. At a first glance this may seem surprising, since all three types of hearing aids had a frequency response close to NAL RP. One possible explanation is that programming of the digital aids was more accurate than that of the analog aids. E.g. with the VarioSlope™ filters the target frequency response could be approximated very closely, and by using the feedback manager the gain at high frequencies could be set close to the feedback limit without influencing the response at lower frequencies, both of which are so important for this group of listeners. Also, it is evident that the distortion of digital aids is considerably lower than the distortion in most analog aids. In our earlier studies we found that severely hearing impaired persons experienced the highest benefit of their hearing aid in favourable listening situations with negligible background noise. Thus, the finding that the exp-HA gave higher speech recognition scores in quiet may explain why a majority of the test subjects preferred the exp-HA over the ref-HA. Note that this preference was made while the identity of the hearing aids was masked. Therefore, the subject's choice was not influenced by prior knowledge of the type of hearing aid or by whether analog or digital technology was used. Also in the paired comparison tests, the exp-HA was preferred in a quiet background in all three ratings: overall rating, rating of speech, and rating of sound quality.

None of the subjects were familiar with the use of extended dynamic range HAs and the subjective comments suggested that the high amplification of sounds having a moderate input level was not acknowledged by all subjects. In fact, at the paired comparison test, many of the subjects preferred linear amplification for listening to speech in a relatively weak background noise. This result, which was obtained using multichannel compression is consistent with Dillon's (1998) results using single channel compression. Dillon observed a preference for a high compression threshold of 66 dB SPL compared to a lower one of 50 dB SPL. Thus Dillon (1998) also observed a tendency for preferring linear amplification at low input levels. At a later follow-up in the present study, we experienced a sign of acclimatisation, namely that a majority of the subjects now appreciated being able to detect weak sounds. Another sign of a significant acclimatisation process was that the subjects' speech intelligibility had improved at the follow-up relative to that registered in the main experiment. This could mean that a low kneepoint is not immediately acceptable to many previous users of linear hearing aids, but may be appreciated after a period of use. We feel that it is important to explain to the user the possible advantages of a low compression threshold.

It is known that the group of severely hearing impaired persons relies very much on visual cues when trying to understand speech, especially in noisy surroundings. Several of the subjects reported that they found it difficult to evaluate speech intelligibility without having the visual cues available. These statements are consistent with the finding that they used an unusually long time to decide on a rating in the paired comparison tests. This may have an impact on the design of future studies with this clientele.

Conclusions

The results of both the field test and the tests performed in the laboratory showed a significant preference for the digital hearing aids compared to the analog. The 25 severe-to-profoundly hearing impaired subjects reported better ability to understand speech and superior comfort with the digital hearing aids. When considering the two digital hearing aids, the experimental aid, Widex SENSO P38, yielded better speech intelligibility in quiet and was preferred by a significant majority of the subjects over the digital linear reference. It was also preferred over their own analog hearing aids. During the study, many signs of an acclimatisation process in favour of the experimental hearing aid were registered. This indicates that preference for the experimental aid would be even more conspicuous after a period of use.

Appendix

At the end of the study, it appeared that several test subjects had criticised the function of the VC of the digital hearing aids. A possible reason for this was that the test program we used in the experiment in some situations

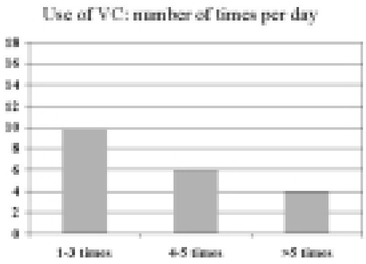

Fig. 7 Use of volume control: Number of subjects who used the VC the indicated number of times per day.

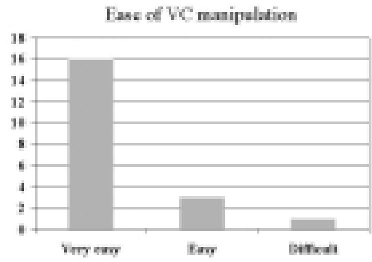

Fig. 8 Manipulation of the digital volume control: Number of subjects who rated the ease of manipulation as indicated.

erroneously had disabled the beep-tone indicator which signals operation of the digital VC. Another reason could be that it takes some practice to get used to a new type of VC. In order to test these hypotheses, a special questionnaire was designed in which the satisfaction with the VC was explored. At the end of the study those subjects who wanted to continue with the exp-HA/ref-HA were offered an opportunity to keep that hearing aid[1]. These hearing aids were fitted according to the procedure used for the exp-HA which is the standard procedure recommended by the manufacturer. After a month of daily use the questionnaire was administered and gave the following results. It appears from the figures that the subjects used their VC only a few times per day and that they, in general, found it very easy to manipulate. We concluded that the combined effect of beep-tone indications and training made the digital type of VC very appealing to the users.

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[1] Since the experimental hearing aids were prototypes, these were replaced with similar hearing aids from the normal production (cf. Andersen et al., 1998).

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