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Unilateral Versus Bilateral Hearing Aid Fittings

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1. Introduction

This study is designed to assess the added value of fitting a second hearing aid: to evaluate the current fitting practices, to assess the effect on spatial hearing, to evaluate this objectively, and to predict a positive effect from diagnostic tests.
The reasons and/or criteria for fitting one or two hearing aids are not always obvious. Many considerations, as localization, seem to play a role both for the hearing-impaired person and for the audiologist. 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 section two 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? Section three describes some recent findings in the literature. Section four describes the effects on spatial hearing that can be assessed in the individual patient. Section five addresses the issue whether a successful bilateral fitting can be predicted from apriori tests.

2. What are the current fitting practices

In order to find current fitting practices a large retrospective study (Boymans et al.2006, 2009) was conducted. In this study case history data, audiometric, and rehabilitation data, and subjective fitting results were evaluated in a population of 1000 subjects using modern hearing aids, included from eight Audiological Centers in the Netherlands. All centers are members of the foundation PACT, the Platform for Audiological and Clinical Testing and they are representative for Audiological Centers in the Netherlands. PACT was established as a platform for independent clinical research related to the use of hearing aids. Each center selected 125 consecutively hearing aid fittings and analyzed the clinical files of these subjects.
An extensive questionnaire on long-term outcome measures was conducted. This questionnaire is called the AVETA (the Amsterdam questionnaire for unilateral and bilateral hearing aid fittings). 505 questionnaires were returned from 1000 files/subjects described above after at least two years of hearing aid use. The questionnaire consisted of different components. Besides some general questions 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),

Abreviated Profile of Hearing Aid Benefit (APHAB, Cox et al., 1995), and the 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). On the basis of 28 questions, 7 categories were composed in which auditory functioning was measured in the different situations: detection of sounds, discrimination or recognition of sounds, speech intelligibility in quiet, speech intelligibility in noise, speech intelligibility in reverberation, directional hearing or localization, and comfort of loud sounds. For each patient and each category the mean scores were calculated only when more than 50% of the questions were available. The total auditory function is the average result of all categories.
The subjective results of the populations with unilateral and bilateral hearing aids were compared with the case-history and audiometric data from the clinical files.

2.1 Percentage bilateral

In our sample of 1000 subjects, 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).

2.2 Effects of age

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.

2.3 Effects of hearing loss

Figure 1 shows the absolute numbers of unilateral and bilateral fittings as a function of the average hearing loss at the better ear. For small hearing losses relatively more unilateral fittings than bilateral fittings were found. For larger hearing losses more bilateral fittings were found, ranging from 40% to 69%.
There is a trend that patients with small hearing losses have a preference for unilateral fittings at the poorer ear, while patients with larger hearing losses have a preference for unilateral fittings at the better ear.

2.4 Effects of asymmetry

Figure 2 represents the absolute difference between both ears for the groups with unilateral and bilateral fittings. Most bilaterally fitted patients had a rather symmetric hearing loss (92% had inter aural differences up to 20 dB) 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 was 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 to the better ear.
There was a trend that a large asymmetry in pure-tone audiogram went along with a large asymmetry in maximum speech discrimination. But there was also a lot of scatter. Sometimes a small asymmetry in pure-tone audiogram went along with a large asymmetry

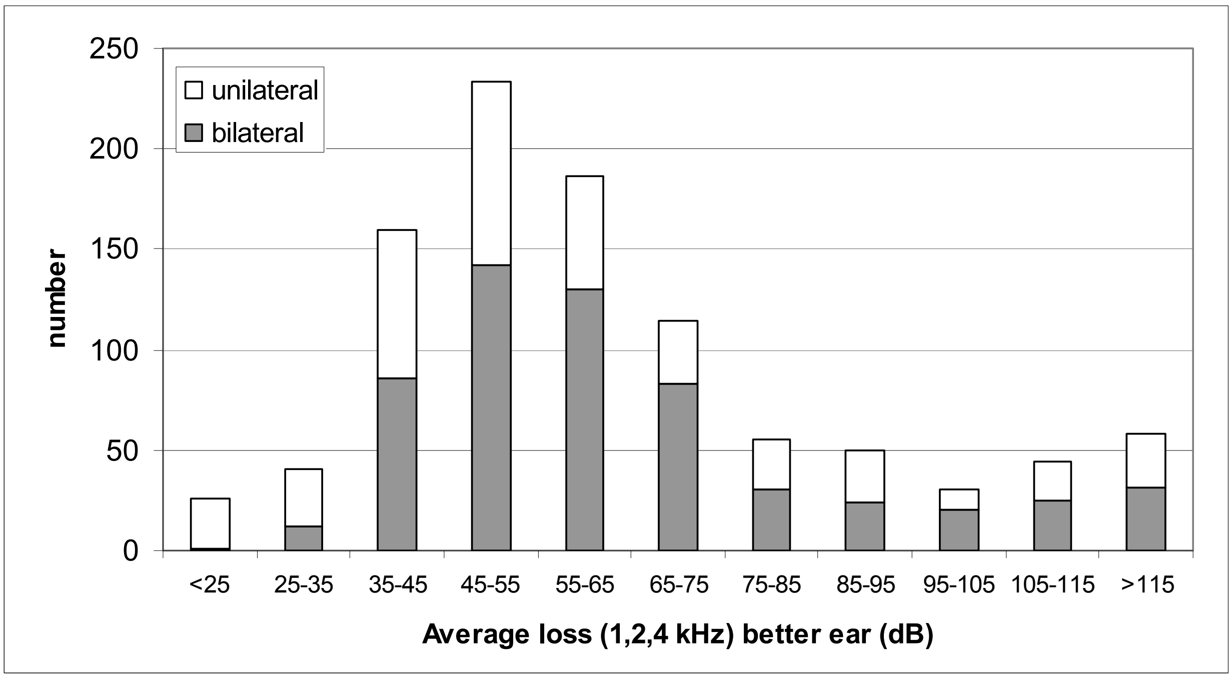

Fig. 1. Cumulative histogram for the numbers of unilateral and bilateral fittings for the total group for different hearing losses at the better ear (average 1,2,4 kHz).

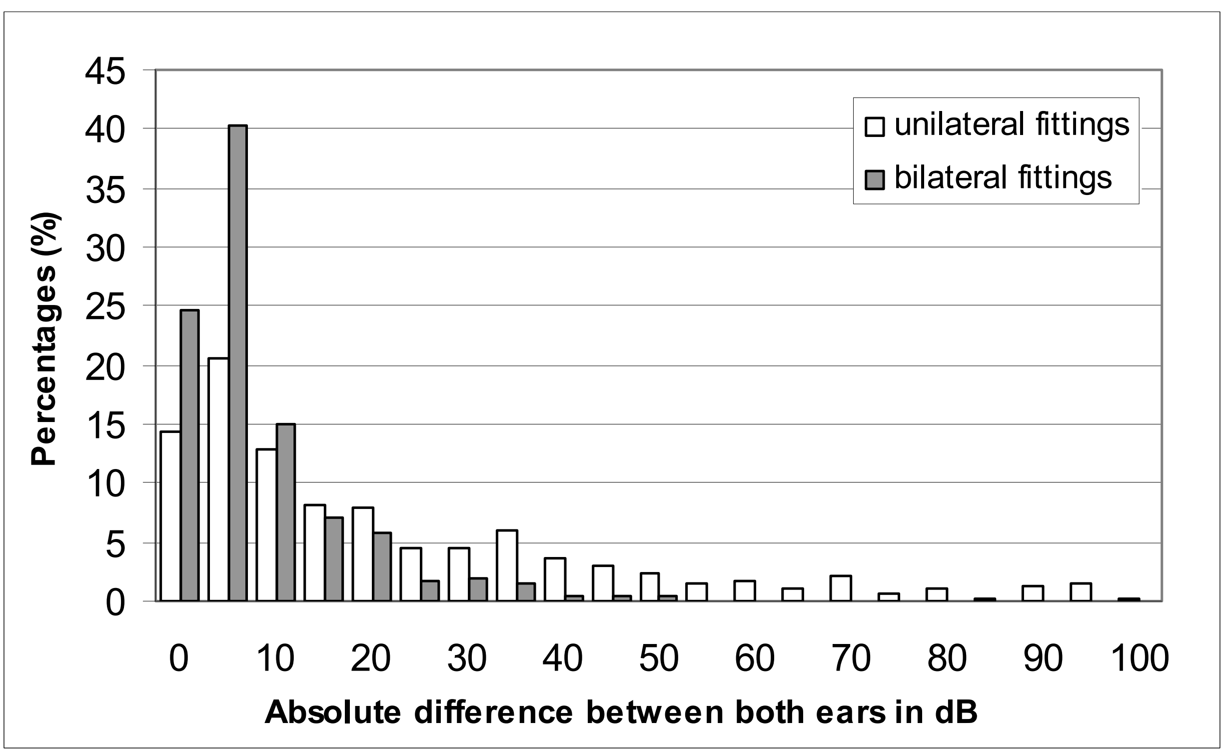

Fig. 2. The absolute difference between the PTA's (1,2,4 kHz) of both ears for the groups with unilateral and bilateral fittings.

in speech discrimination and vice versa. The trend that better-ear fittings were found for larger asymmetries, was predominantly dependent on the asymmetry of the speech discrimination.

In subgroups matched on gender, age, degree of hearing loss and audiometric asymmetry, no significant differences between unilaterally fitted and bilaterally fitted participants were found for hearing aid use, residual handicap, and satisfaction. However significant better results were found for the bilaterally fitted group than for the unilaterally fitted group for localization but also for detection and reverberation when the situation as fitted (bilateral or unilateral) was compared to the unaided situation.

Significantly higher scores for localization and speech in noise were found for the group with "high-end" hearing aids and they showed less residual handicap than the group with more basic hearing aids. However this does not influence the long-term effects of bilateral benefits.

The analysis of the relation between objective parameters from audiometric and case history data and the subjective outcome measures of different subgroups showed that the candidacy for bilateral fittings could not be predicted from age, maximum speech intelligibility, employment, exposure to background noise, and social activities.

2.5 Reasons for choosing bilateral

Part of the questionnaires was 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 was frequently based on the residual capacity of the other ear that was still relatively good (70x) or just worse (73x). Also using the telephone with the other ear could be a reason to choose for one hearing aid (43x), or problems with the own voice when fitted bilaterally (39x).

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 was mentioned as the most important reason (150x). Other reasons like better localization, the balance between ears, and listening to both sides occurred in about the same numbers (90x-110x). In only one case it was mentioned that two hearing aids are chosen to stop further deprivation.

3. Some issues on bilateral fitting in literature

3.1 Deprivation

Deprivation effect was frequently described in the literature. When the hearing organ is stimulated insufficiently, speech discrimination ability can deteriorate gradually. Hearing impaired subjects fitted unilaterally and who have bilateral hearing losses may develop a deprivation effect in the unaided ear.

Gelfand et al. (1987) described long-term effects of unilateral, bilateral or no amplification in subjects with bilateral sensorineural hearing losses. They compared audiometric thresholds and speech scores for phonetically balanced (PB) words with results obtained 4-17 years later. Speech recognition scores were not significantly different in both ears for the bilaterally fitted subjects and for the subjects not wearing hearing aids. However, in adults with a unilateral hearing aid fitting, speech recognition performance for the unaided ear was decreased significantly. This might be attributed to the deprivation effect. Silman et al. (1984) also used the deprivation effect as starting point for their research. They investigated

whether deprivation occurs and if it can be found after a long-term follow-up. 44 Adults with bilateral sensorineural hearing losses were fitted unilaterally with hearing aids and 23 with bilateral aids. For all of these subjects data about auditory functioning were obtained prior to the hearing aid evaluation, at the time of the hearing aid evaluation, and 4-5 years after the evaluation. The most important result is that there were significant differences between initial and follow-up speech-recognition scores only for the unaided ears of the unilaterally fitted group. The authors indicate that this is an auditory deprivation effect that was not found in the bilaterally fitted group. Age and hearing sensitivity factors were partial led out. So, these factors could not have influenced the conclusions. A third study is the work of Silman et al. (1993), who investigated both auditory deprivation and acclimatisation. To investigate both aspects, 19 adult subjects were fitted unilaterally, 28 bilaterally and there were 19 matched control subjects. All of them had a bilaterally symmetrical sensorineural hearing impairment. Their speech recognition ability was tested by three different tests (W-22 CID, nonsense syllable test (NST), speech-reception-in-noise (SRT)). They were initially tested six to twelve weeks following the hearing aid fitting. After one year, the follow-up test was performed. The results of the latter test showed a slight improvement in speech perception in the aided ear, in comparison with the initial test, and a larger decrement in the unaided ear. This was visible in the W-22 test as well as in the NST test. The improvements in the aided ear can be regarded as acclimatisation to amplification at the aided ear; the decrements can be ascribed to auditory deprivation in the unaided ear. The difference in magnitude suggests that more time is needed for a significant acclimatisation effect in the aided ears of both the unilaterally and bilaterally aided groups than for an auditory deprivation effect in the unaided ears of the unilaterally aided group.
The occurrence of deprivation is a reason to choose for two hearing aids. Hurley (1999) found that word recognition scores deteriorated in the unaided ear after 5 years of hearing aid use for 25% of the unilaterally fitted subjects. Although there can be some recovery from deprivation, there are also cases known where the auditory deprivation effect is not reversible (Gelfand, 1995). In contrast to other investigators, Jauhiainen (2001) found no indications for the onset of auditory deprivation in unaided ears.

3.2 Horizontal localization

Improved localization is an advantage often mentioned in literature. It means that subjects with two hearing aids are better capable of determining from what direction a sound arrives. Punch et al. (1991) presented objective data of this advantage. Although their research is focused on bilateral fitting strategies, they found that localization with bilateral hearing aids was significantly superior to localization with unilateral hearing aids. Besides this objective advantage, Stephens et al. (1991) found that an improvement of localization was one of the reasons for people to choose for two hearing aids. Dreschler and Boymans (1994) tested localization ability with one and two hearing aids in the same subjects. They found that the localization ability was significantly better with two aids than with one. The results of Byrne et al. (1992) showed that the bilateral advantage was also applicable for subjects with moderate to severe hearing losses. In the experiments of Köbler et al. (2002) the subjects had to repeat sentences and indicate the side where the sentence came from. The results for localization were almost the same for the condition without hearing aids and with two hearing aids. A worse result was found for the condition with only one hearing aid.

In contrast with other studies, Vaughum-Jones et al. (1993) found that the localization ability with two hearing aids was worse than with one hearing aid in some subjects. Their conclusion was that subjects initially should be aided unilaterally and, if necessary, two aids could be considered. Nabelek et al. (1980) investigated the effect of asymmetry in sound pressure levels produced by signals coming from two loudspeakers. By changing the sound pressure level (when the sound level at one side was increased by a certain amount of dB's (ΔL), the sound level at the other side was decreased by the same amount) the position of the sound image in a lateralization experiment varied. In normal-hearing subjects, for sound imagines on the midline, ΔL was zero. In unfitted hearing-impaired subjects with bilateral hearing losses, ΔL was within the normal range. However, in aided balanced (equal gains) and/or unbalanced conditions (10 dB disparity in gains) ΔL for midline images was outside the normal range for some bilaterally fitted subjects. Based on these results, the authors concluded that bilateral hearing aids could give a bias in the symmetry of the presentation levels between both ears.

3.3 Speech perception

Speech intelligibility is one of the most important aspects for the hearing-impaired (if not the most important). Most studies concentrate on the speech perception in noise and in reverberation, because these are the most critical listening situations. The fitting of bilateral hearing aids introduces two sources of improvement: the binaural squelch effect and the removal of head-shadow effect. The squelch effect is the true binaural component and can be described as the difference (in dB) in the critical signal-to-noise ratio (S/N ratio) between monaural and binaural listening. However, the benefits of bilateral fittings for speech intelligibility appear to be related primarily to the compensation of head-shadow effect. When listening with two hearing aids, the difference (in dB) of the critical S/N ratio between near-ear and far-ear listening is about 6-7 dB smaller than for listening with one aid (Markides, 1982). Köbler et al. (2002) used a fixed S/N ratio of + 4dB, and they found a statistically significant advantage of 5% in speech intelligibility when the subjects were fitted bilaterally.

Festen and Plomp (1986) investigated the speech-reception threshold (SRT) in noise with one and with two hearing aids in a group of 24 hearing-aid users. All subjects had a nearly symmetrical hearing loss. The critical S/N ratio measured (the S/N ratio at 50 % speech perception) proved to be hardly better with two hearing aids than with one hearing aid for subjects with moderate hearing losses when speech and noise came from the frontal direction. However, a significant benefit for bilaterally fitted hearing aids was present in subjects with a pure tone average $PTA_{(.5,1,2\ kHz)}$ larger than 60 dB, and when the speech and noise sources were spatially separated. Day et al. (1988) also concluded that subjects with severe hearing losses experience more benefit from two hearing aids than from one. They used a free field audiovisual sentence-in-noise test (FASIN) in a reflection-free room.

Bronkhorst and Plomp (1989) showed that the binaural advantage due to head shadow effect decreased when the hearing loss at high frequencies was more severe. So, the binaural advantage depends on the audiometric configuration of the hearing loss. Also, Bronkhorst and Plomp (1990) found that the binaural advantage due to a spatial separation of speech and noise was smaller for small hearing losses than for large hearing losses. In contrast to this study, Moore et al. (1992) showed a binaural advantage for almost all hearing losses when speech and noise were separated. However, in Moore's test design one ear was blocked for the unilateral situation. This suggests that contribution of the unaided ear was mainly responsible for the fact that the benefit from bilateral fitting depends on the degree of hearing loss.

Hawkins and Yacullo (1984) determined the S/N ratio necessary for a constant performance level of word recognition for normal hearing and for hearing-impaired listeners with bilaterally symmetrical mild-to-moderate sloping sensorineural hearing losses. The showed a bilateral advantage (2-3 dB) and this appeared to be independent of microphone type and reverberation time. In addition, there was a directionality advantage for the conditions with directional microphones compared to the same conditions with omni-directional microphones. These two advantages appeared to be additive (at least at the two shorter reverberation times) because no interaction between the two was found. The results indicated that the optimum performance in noise was achieved when hearing-impaired subjects weared bilateral hearing aids with directional microphones in rooms with short reverberation times.

Nabelek et al. (1981) measured the effects of unilateral and bilateral fittings for 15 subjects with bilateral sensorineural hearing losses in noise and in reverberation. Word recognition scores were significantly higher in bilateral listening modes. The advantage of bilateral listening did not depend strongly on reverberation time or the use of hearing aids. The scores improved by 7 % for a reverberation time of 0.1 s and 3.4 % for a reverberation time of 0.5 s.

Leeuw and Dreschler (1991) found better critical S/N ratios for speech intelligibility in noise (SRT-test) tested by normal-hearing listeners using two BTE hearing aids compared to one BTE hearing aid (mean difference 2.5 dB). This implied a significant advantage of bilateral over unilateral amplification, which proved to be dependent on the type of microphone (omni-directional or directional) and the azimuth of the noise source, except for 0^0. Contrary to the results of Hawkins and Yacullo (1984), the bilateral advantage in speech intelligibility was highest with directional microphones.

Dreschler and Boymans (1994) measured SRTs in noise with a spatial separation between speech and noise in 12 hearing-impaired subjects. The results showed better SRT's for the subjects using bilateral hearing aids. Bilaterally fitted subjects made better use of the spatial separation between speech and noise sources, resulting in 5dB better SRT thresholds. In addition, they applied a dichotic discrimination task, where 3-syllable words and 4-syllable numbers were presented simultaneously from $+45^0$ and -45^0 azimuths. Results only showed a clear bilateral improvement in speech discrimination for the speech material that was presented from the (unilaterally) unaided side. For words and for numbers, this effect was statistically significant.

Not all studies support the findings of improved speech intelligibility. Allen et al. (2000) found a significant evidence of binaural interference for 2 out of 48 elderly subjects ($p<0.05$). Although the small number could easily be explained by normal variability in differences between speech scores, this finding may indicate that for some individuals speech intelligibility scores with two ears could be poorer than with the better ear alone. Bodden (1997) argued that the binaural function of the ears should be restored by hearing aids. When hearing loss deteriorates the binaural function, signal processing should be used as compensation.

Markides (1982) found a difference of 2-3 dB as the bilateral advantage of two hearing aids. His experiments confirm that the effect of the head-shadow compensation are more important than the effect of binaural squelch.

4. What are the effects on spatial hearing objectively and subjectively?

In the literature many advantages of bilateral hearing aid fittings, relative to unilateral fittings, were shown, but it is difficult to obtain hard evidence about the benefits because of methodological limitations. For the correct interpretation one has to keep in mind that blinding was not possible, and that the selection of subjects in these studies partly determined the findings.

In the retrospective study described in section 2 no clear information could be found about the objective outcome measures. Therefore a prospective study was conducted. In that study (Boymans et al 2006, 2008) the same Audiological centers participated. 214 Subjects who were willing to start a trial period with bilateral hearing aids were included, 113 men and 101 women with an average age of 66 years (range: 18-88). For 133 subjects the fitting concerned a first fitting (62%). Most hearing losses were sensorineural hearing losses (79%). The average hearing loss (500 - 4000 Hz) was 47 dB for the right ears as well as for the left ears. After the trial period 200 subjects opted for a bilateral fitting (93%) and 14 subjects (7%) for a unilateral fitting. The small unilateral group was not distinguishable from the bilateral group on base of the asymmetry between both ears.

After the trial period that was long enough to decide between unilateral or bilateral fitting, (trial durations vary individually from 4 weeks to several months), the evaluation tests were conducted in order to evaluate the benefits of a second hearing aid, objectively.

To measure the effect of a second hearing aid a localization test was used as well as a Speech Reception Threshold Test (SRT-test) with spatially separated sound sources. To perform well on the latter test good localization ability was needed. Both measurements were conducted with unilateral and bilateral conditions for all subjects. The ear of the unilaterally fitted hearing aid was based on the preference of the individual subject.

4.1 Localization test

For the localization test 5 loudspeakers were used (-90º, -45º, 0º, +45º, +90º) at 75 cm from the subject. Mixed sounds were randomly presented from different loudspeakers, for example: music, children laughing, dogs barking. All sounds were presented at an average level of 65 dB(A) with adequate roving. Every 0.7 seconds a new sound was generated randomly from the sounds that were not active at that time. The duration of the signals varied between 2.2 and 3.5 seconds. So, during the test three to five signals were presented simultaneously at each moment. There was one target sound: the telephone bell. The subject had to indicate where the target sound came from. The duration between the answer and the next stimuli varied between 4 and 10 seconds. The order of presentations was randomized, in total six measurements for each loudspeaker box. The test was performed with one and with two hearing aids.

In table 1 the results of the unilateral condition (average for the right and the left side) and the bilateral condition are shown. Localization was significantly better for the bilateral condition than for the unilateral condition. Most errors were made within 45°. There was a reduction of errors when a second hearing aid was added, for all degrees of errors (< 45^0, 45^0- 90^0, >90^0): a bilateral improvement of about 10% for the situation within 45 degrees and 13% for all situations together.

The benefit of a second hearing aid for localization proved to be rather independent of the other data, but showed a small but significant correlation with total auditory functioning (result derived from the AVETA questionnaire ($r = 0.18$; $p < 0.05$)).

	Percentage of errors	
	Unilateral (avg R/L)	Bilateral
< 45 degrees	38,3	28,3
45 - 90 degrees	7,2	5,1
> 90 degrees	2,5	1,3
Total	48,0	34,7

Table 1. The percentage of errors (within 45 degrees, between 45-90 degrees, more than 90 degrees and the total errors) of the localization test, for the unilateral condition (2nd column) and the bilateral condition (3rd column).

4.2 Speech intelligibility with spatially separated sound sources

A test with separated sound sources is a good simulation of daily conversations in real life. Localization plays an important role during this test. Two loudspeakers were positioned in front of the subject. The left loudspeaker was placed at -45 degrees and the right loudspeaker at + 45 degrees at 75 cm from the subject. For both sides a Speech Reception Threshold test was performed. The noise was an interfering (time-reversed) signal of the other gender. In conditions with speech from the left-hand side, the interfering signal came from the right-hand side and vice versa. The sentences (VU98, see Versfeld et.al., 2000) were presented randomly from the left and the right hand side, however, the male and the female speaker did not change from position during one list. So the subjects had to concentrate on where the normal speech came from and had to repeat the sentence. The interfering noise was presented at 65 dB(A).

	Critical S/N ratio in dB	
	Ipsi lateral side	Contra lateral side
Unilateral	-4,6 dB	-1,6 dB
Bilateral	-5,0 dB	-4,9 dB

Table 2. Average critical S/N ratio for the condition with the unilateral hearing aid at the speech side (ipsi-lateral, 2nd column) and the hearing aid at the noise side (contra-lateral, 3rd column) and for the bilateral condition (n=214). Lower values indicate better results.

In table 2 the average critical signal to noise ratios are presented for the ipsi- and contra-lateral condition, lower values represent better results. In this table the results with a female and a male voice have been averaged.

The ipsi-lateral condition (second column) is the condition with the unilaterally fitted hearing aid at the speech side; this is the most favorable condition. In the bilateral condition the second hearing aid is added to the noise side. Nevertheless, an improvement of 0.4 dB is shown. This is a purely binaural effect (binaural squelch effect).

The contra-lateral condition (third column) is the most difficult condition, with the unilaterally fitted hearing aid at the noise side. In the bilateral condition the second hearing aid is added to the speech side. An improvement of 3.3 dB is shown, due to the combined effect of elimination of the head shadow and the effect of binaural squelch. Participants

with more severe hearing losses showed a higher bilateral benefit for the SRT test with spatially separated sources, than did participants with milder hearing losses.
The benefit in speech perception with spatially separated sound sources is related to localization ($r = 0.19$; $p<0.01$).

4.3 Questionnaire

In the prospective study the AVETA questionnaire was used as well. The subjects were asked to complete the questionnaire for the condition without a hearing aid, with one hearing aid and with two hearing aids.
The average results of the group who preferred a unilateral fitting (n=13) showed a significant benefit for one hearing aid compared with the condition without hearing aid, for all categories (detection, discrimination, speech in quiet, speech in noise, localization, and aversiveness of loud sounds) ($p< 0.01$) except for the comfort of loud sounds. For loud sounds the comfort with a hearing aid was significantly lower than without hearing aid ($p<0.001$). There was no significant difference between the unilateral and the bilateral conditions for the group who preferred a unilateral fitting. The group who preferred a bilateral fitting showed significantly better scores with one hearing aid than without a hearing aid for all categories ($p<0.001$) except for the comfort of loud sounds. Again this score decreases with a hearing aid ($p<0.001$). Contrary to the group who preferred one hearing aid, the bilaterally fitted group shows significantly better scores with two hearing aids than with one hearing aid ($p<0.001$), but again the comfort of loud sounds scores significantly worse ($p<0.001$).
In this study the subjects were asked to mention reasons why they preferred one or two hearing aids also. More than one reason was possible. 138 Times a reason was given for the advantage of a unilateral fitting and 649 times for a bilateral fitting. Most mentioned reasons for a unilateral fitting were: own voice was more pleasant with one hearing aid (31%) and the unaided ear was used for the telephone (25%). For the bilateral fittings most mentioned reasons were: intelligibility from both directions (20%), better localization (19%), better sound quality (20%), and a better stereophonic effect/balance (19%).

5. Can we predict the positive effect from diagnostic tests?

To determine whether the bilateral benefit could be predicted from a-priori tests a battery of diagnostic tests (by headphones: Binaural Masking Level Difference, Interaural Time Difference) were applied before the trial period.
Horizontal localization may be assumed to be improved especially in subjects that are able to exploit interaural cues in time and level. Therefore a test on the Interaural Time Difference (ITD) was selected. The differences in arrival time are most effective for low frequencies up to about 1500 Hz (Dillon, 2001). The ability to localize sounds is important, especially in conversations with several people. Binaural cues are also important to exploit phase differences between dichotically presented target signals and masking signals in order to separate both more effectively (binaural squelch). Therefore a test for the Binaural Masking Level Difference (BMLD) was selected to measure the effect of binaural squelch. This is an important aspect of the cocktail party effect (Cherry, 1953; Bronkhorst, 2000) that may yield improved speech intelligibility in conditions with separated (simultaneous) sound sources.

5.1 Interaural Time Difference

The ITD test measures the sensitivity of the binaural system to perceive Interaural Time Differences. The interpretation of the ITD-result is: the smaller the value the better the sensitivity to Interaural Time Differences. In the ITD test every time two brief noise bursts (narrow-band noise of 500 Hz, 125 ms in duration) were presented binaurally. The duration of the temporal gap between the noise bursts was 250 ms. The binaural noise bursts were presented with a short interaural time difference. Because the time difference between both noises in a binaural noise burst (Δt) was very small, it was perceived as one single percept (fusion of the sounds), but the location of the perceived sound image in the head was largely determined by the ear where the noise arrived first (this is called the precedence effect; Gardner, 1968; Moore; 1982; Goverts et al., 2000). In the second binaural noise burst, the order of both noises was reversed. For example, in the first noise burst the noise was presented first at the right ear and Δt later at the left ear. In the second noise burst the noise was presented first at the left ear and then at the right ear. Consequently, the perceptual image of these two noise bursts in this example was as a noise pair moving from the right-hand side of the head to the left-hand side. For Δt is zero the noise bursts would be heard in the middle of the head. Δt was varied adaptively, starting with a temporal shift of 0.3 ms. The subjects were asked to indicate to which side the noises were moving in their heads. A 3-up 1-down procedure was used to determine the ITD.

5.2 Binaural Masking Difference

For the BMLD test, an octave-band noise with a centre frequency of 500 Hz, was presented to both ears. A tone of 500 Hz was also presented binaurally, one measurement with the tone in phase and one measurement with the tone out of phase. The masked thresholds of the tones were determined according to a 3-up 1-down procedure. The Masking Level Difference is calculated by subtracting the in-phase threshold from the out-of-phase threshold. In subjects with normal hearing the threshold of the signal out of phase is considerably lower than for the signal in phase. This means: the more negative the BMLD-value, the better the binaural function (Moore, 1982).

For both adaptive procedures (ITD and BMLD) the thresholds were determined by averaging of eight turning points. The subjects could exercise first until they understood the instruction. Before the ITD and the BMLD test, a matching test at a calculated stimulus level was used, to establish the same loudness of the stimuli in both ears. The stimulus level at the better ear was fixed at 60 dB SPL for average hearing losses up to 40 dB HL (averaged at 500, 1000, 2000, and 4000 Hz). For higher losses the stimulus level was set at the average hearing loss + 20 dB. The stimulus level at the other ear (the poorer ear) was determined by the result of the matching test (the average of three measurements provided that the differences between the test results were smaller than 10 dB. If not, the matching test had to be repeated).

5.3 Results

For the results of the hearing-impaired subjects again both groups were distinguished: the group who preferred one hearing aid (n=14), and the group who preferred two hearing aids (n=200). The median scores and the 25 and 75 percentile scores for the ITD-test and the BMLD-test are presented in Table 3. A lower score means a better result. As a reference also subjects with normal hearing were tested. They showed a better result than the hearing-impaired subjects for the BMLD-test, but there is a considerable overlap between the normal-hearing and the hearing-impaired groups.

	ITD (µsec)		BMLD (dB)	
	Median	*P25 / P75*	*Median*	*P25 / P75*
Unilateral fitting (n=14)	123.6	71.3 / 392.3	-15.5	-18.3 / -11.0
Bilateral fitting (n=200)	158.6	81.4 / 793.5	-14.4	-18.4 / -8.6
Normal hearing (n=10)	40.7	33.2 / 48.5	-19.5	-21.5 /-12.0

Table 3. Results of the unilaterally fitted group, the bilaterally fitted, and the normal-hearing group for the Interaural Time Difference-test. and the Binaural Masking Level Difference-test.

For the ITD-test the differences between the groups are larger, but the trends are similar. There is a clear difference between the hearing-impaired groups and the normal-hearing group. Again, the differences between both hearing-impaired groups are small and there is an overlap between both groups. A few subjects found the test very difficult. The choice for one hearing aid proved to be not related to poor results of the binaural tests.

6. Conclusions

The benefit of a second hearing aid is obvious. This effect is shown objectively with localization tests and speech intelligibility with spatially separated sound sources, but also subjectively with the AVETA questionnaire. Localization proved to be rather independent of the other data, but is related to total auditory functioning

However the benefit of a second hearing aid is hardly to predict with ITD and BMLD tests. The most important factor for predicting different outcome measures (including the bilateral benefit for speech) was the PTA in the better ear. Binaural diagnostic tests by headphones did not contribute significantly to a better prediction of the bilateral benefit.

Our conclusion is that every hearing impaired subject should start with a bilateral fitting to experience the benefits and the drawbacks. It is very useful to evaluate the trial period with good localization tests and with speech intelligibility tests with spatially separated sound sources.

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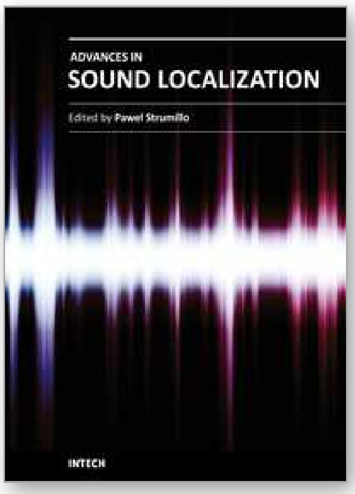

Advances in Sound Localization

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Sound source localization is an important research field that has attracted researchers' efforts from many technical and biomedical sciences. Sound source localization (SSL) is defined as the determination of the direction from a receiver, but also includes the distance from it. Because of the wave nature of sound propagation, phenomena such as refraction, diffraction, diffusion, reflection, reverberation and interference occur. The wide spectrum of sound frequencies that range from infrasounds through acoustic sounds to ultrasounds, also introduces difficulties, as different spectrum components have different penetration properties through the medium. Consequently, SSL is a complex computation problem and development of robust sound localization techniques calls for different approaches, including multisensor schemes, null-steering beamforming and time-difference arrival techniques. The book offers a rich source of valuable material on advances on SSL techniques and their applications that should appeal to researches representing diverse engineering and scientific disciplines.

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