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Issuing two hearing aids for simultaneous use

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In a recent circular (Circular No. C.260, dated July 1977) the Department of Health and Social Security gave the following guidance regarding the circumstances in which a patient may be issued with more than one hearing aid.

'Two hearing aids (body worn or post-aural) may be issued to patients only if they are prescribed as clinically necessary by an otologist or audiological physician and are intended for simultaneous use.'

It was specified that this guidance applied to all models of hearing aids supplied through the National Nealth Serivce and included those aids available only to children.

In view of this development it was thought advisable to summarize here the findings of a recent investigation into binaural hearing aids which was supported by the Wates Foundation and carried out at the Audiology Department of the Institute of Sound and Vibration Research, University of Southampton.

Introduction

EPICTETUS the Stoic, quoted by Colin Cherry (1953), said that 'God gave man two ears but only one mouth so that he might hear twice as much as he speaks.' The wisdom of the 'Almighty' was also recently referred to by Harris (1965) when he asserted that our creator would not 'have simply hung a second ear on our heads purely as a mechanical safety factor in a chancy world'. I, personally, would prefer to ignore theological arguments and to take the advice of the Stoic, not because he is my compatriot but because he advocates caution. I am intending therefore:

(a) to look into the documented advantages of binaural hearing;
(b) to summarize previous findings on binaural hearing aids, and
(c) to consider and discuss recent experimental findings in this field (Markides, 1977).

Advantages of Binaural Hearing

Much of the present interest in binaural hearing was stimulated by a short letter from Koenig published in the Journal of the Acoustical Society of America in 1950. In this letter the author asserted that binaural hearing offered the following advantages over monaural hearing:

(a) A remarkable ability to 'squelch' (to decrease, to reduce the effects of) reverberation and background noises.

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(b) The power to select one stimulus from a number of stimuli and as it were to 'tune in' to one sound source or one person, the 'Cocktail Party Effect' or the 'Box Social Effect', and
(c) to understand speech under extremely unfavourable signal-to-noise ratios.

More recently (Bergman, 1957; Groen and Hellema, 1960; MacKeith and Coles, 1971) supplemented the above advantages with the following:

(a) Enhanced localization.
(b) Summation of energy both at threshold and at supra-threshold levels.
(c) Summation of information content, especially when the hearing losses in the two ears are dissimilar in frequency distribution.
(d) Avoidance of headshadow, especially when listening with a background of noise.
(e) Better discrimination of speech in quiet and in noise.
(f) Ease of listening, and
(g) Better quality of sound.

Binaural Hearing Aids

The term 'binaural hearing aids' used in this paper relates to true stereophonic or dichotic listening whereby each ear is stimulated separately and homolaterally through an independent channel consisting of microphone, amplifier and receiver. This must not be confused with the diotic or 'Y' lead system which employs one microphone and one amplifier to feed two receivers.

Although interest in binaural hearing aids dates back to the beginning of this century (Soret, 1915) it is only in the last two decades that considerable research on this topic has been undertaken.

Most of the experimental studies so far published on binaural hearing aids deal solely with speech facilitation in noise, and their results are about evenly divided. Markle and Aber (1958), Belzile and Markle (1959), Wright and Carhart (1960) and Olsen and Carhart (1967), for example, reported in favour of binaural hearing aids, while Hedgecock and Sheets (1958), DiCarlo and Brown (1960), Jerger and Dirks (1961) and Jerger *et al.* (1961) did not find any significant difference between binaural and monaural hearing aid use with regard to speech facilitation.

The preponderence of subjective reports is undoubtedly in favour of binaural hearing aids (Poulos, 1950; Haskins and Hardy, 1960; Bender and Wiig, 1960; Jordan *et al.*, 1967), but such reports can hardly be considered as conclusive scientific evidence.

In spite of the contradictory evidence available, it may be stated that there exists a strong possibility that under certain conditions and for certain hearing-impaired people, two hearing aids are better than one. Previous research, however, has been unable:

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(a) to quantify binaural hearing aid advantages;
(b) to state the conditions under which such advantages may be obtained;
(c) to specify the types of aid with which such benefits may be obtained, and
(d) to identify which hearing-impaired people may benefit from two hearing aids as opposed to one.

These questions have already been answered by the author in a recent book (Markides, 1977) on binaural hearing aids. This paper summarizes the main findings included in the book and also reports on the findings of subsequent research on this topic.

Method

A. Subjects

96 adults were included in this investigation: 30 had normal hearing, 22 had symmetrical hearing impairment*, 20 had asymmetrical hearing impairment† and 24 had unilateral hearing impairment. They participated in 850, 2-hour experimental sessions over a period of 14 months. Nearly half of the hearing-impaired subjects in each group suffered from conductive hearing impairment and the other half from sensorineural hearing impairment.

B. Tests

All the subjects were required to participate in two main tests:

(a) A free-field speech discrimination test with competing wide band noise, and
(b) A horizontal localization test.

These tests were carried out both in a reverberant and in a non-reverberant environment with the subjects using the following hearing aids:

(a) Two similar ear-level aids with external receivers.
(b) Two similar ear-level aids with conchal pick-up tubes.
(c) Two similar Medresco OL56 aids with OL575 receivers. (Effective frequency amplification 300–4,000 Hz).
(d) Two similar commercial body-worn hearing aids with extended low frequency response (Effective frequency amplification 50–4,000 Hz).
(e) Two similar commercial body-worn hearing aids with extended high frequency amplification (Effective frequency amplification 300–6,000 Hz).

* Differences in hearing levels between ears not exceeding 10 dB at any one of the audiometric frequencies 250-4000 Hz.

† Differences in hearing levels between ears in excess of 10 dB at least in one of the audiometric frequencies 250-4000 Hz.

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(f) High fidelity amplification (Effective frequency amplification 100–16,000 Hz).
(g) One CROS (Contralateral Routing of Signals) hearing aid used in subjects with unilateral unaidable hearing impairment.

(1) *Free-field speech discrimination test*

Figure 1 shows the physical arrangement of the free-field speech discrimination test. The speech materials used were groups of Fry's phonetically balanced word lists (Fry, 1961), each group containing 300 phonemes. The competing noise was continuous wide band noise shaped to correspond roughly to the speech frequency spectrum. Both the speech materials and the competing noise were recorded and presented through a twin-track Ferrograph series 7 tape recorder via Amplivox speech audiometer attachments terminating in two similar loudspeakers, one placed at 45° to one side for speech and the other one at 45° on the other side for noise and at 6 feet distant from the centre of the subject's head in the horizontal plane.

Each subject with either normal hearing or with a bilateral hearing impairment was tested under three modes of listening:

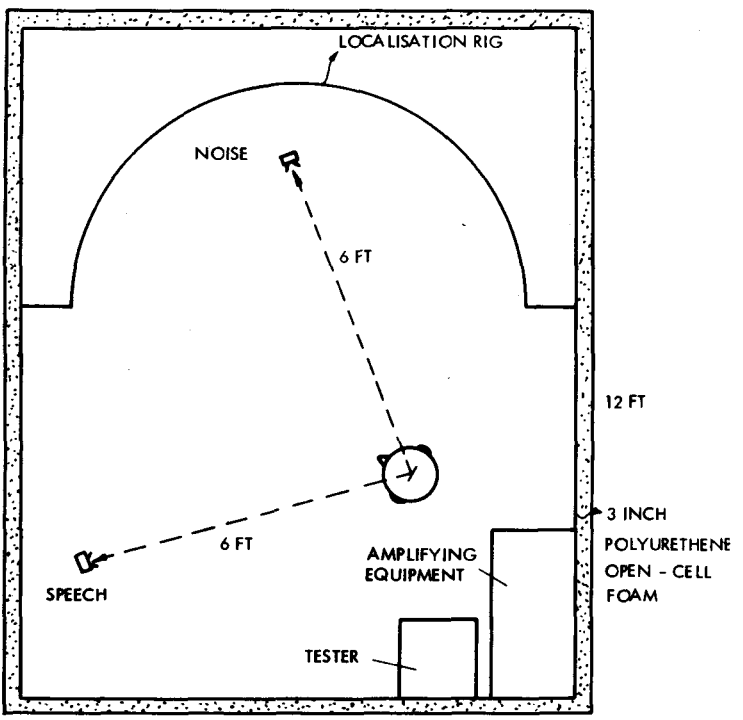


FIG. 1
Physical arrangement for the administration of the free-field speech discrimination test.

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(a) Monaural near ear listening; that is, listening only with the ear nearer to the source of speech.
(b) Monaural far ear listening; that is, listening only with the ear further away from the speech source.
(c) Binaural listening; that is, listening with both ears.

Subjects with unilateral aidable hearing impairment (30–80 dB hearing level, averaged across 500, 1,000 and 2,000 Hz in the affected ear) were tested both with and without an ear-level hearing aid in their bad ear. Subjects with unilateral unaidable hearing impairment (80 dB+ hearing level averaged across 500, 1,000 and 2,000 Hz in the affected ear) were tested both with and without a CROS aid.

The speech material for each listening mode was presented at four signal-to-noise ratios, 300 phonemes at each signal-to-noise ratio; that is 1,200 phonemes for each listening mode. Binaural hearing advantages were explored in terms of the 'binaural squelch effect', that is the difference (in dB) in terms of signal-to-noise ratio at the 50 per cent discrimination level between binaural and monaural near-ear listening and in terms of the 'head-shadow effect', that is the difference (in dB) in terms of signal-to-noise ratio at the 50 per cent discrimination level between near-ear listening and far-ear listening.

(2) *Horizontal localization test*

Figure 2 shows the physical arrangement for the localization test. Localization ability was tested by using a semi-circular rig with nine high-fidelity loudspeakers placed at intervals of 15° and hidden from the subjects by non-transparent curtaining material. On the side facing the subjects a wooden semi-circular scale marked at intervals of one degree was placed to be used by the subjects to indicate the apparent position of the signal.

The stimulus material used was recorded speech, controlled with a multi-position switch activating independently each one of the nine loudspeakers.

The localization ability of each subject for each listening mode and for the various hearing aids used was calculated by finding the difference in degrees between the actual source of the speech stimulus and the presumed source as stated by the subjects.

Results

A. Free field speech discrimination test

(1) *Subjects with normal hearing and subjects with bilateral hearing impairment*

Figure 3 summarizes the speech discrimination abilities of the subjects with normal hearing and of the subjects with bilateral hearing impairment. In summary the results were the following:

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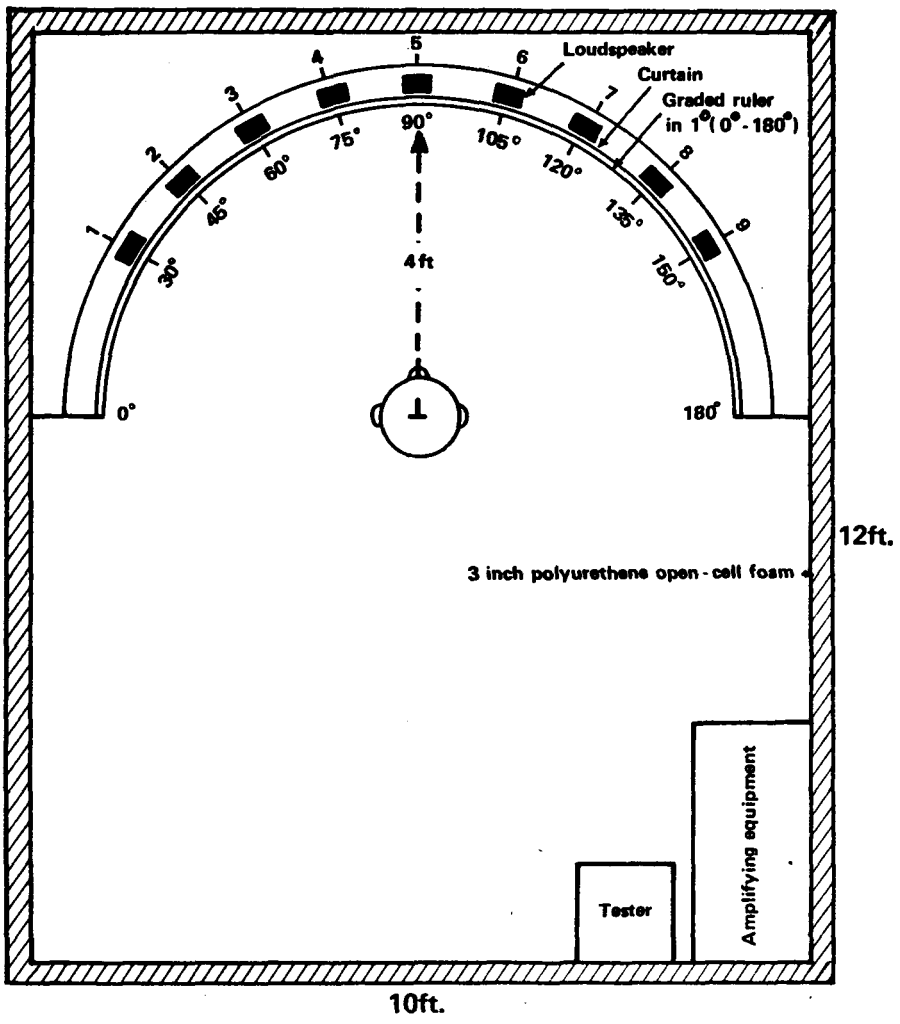


FIG. 2

Physical arrangement for localization test.

(a) The binaural advantage of 'squelch effect' was consistently 2–3 dB.
(b) The binaural advantage of 'head-shadow effect' was consistently 6–7 dB.
(c) No significant differences were observed in terms of squelch and head-shadow effects when the performance of the normally hearing subjects using ear-level hearing aids and the performances of the subjects with bilateral hearing impairment using ear-level hearing aids were compared with one another. This was true for both the conductive and the sensorineural groups, be they of the symmetrical or the asymmetrical type.

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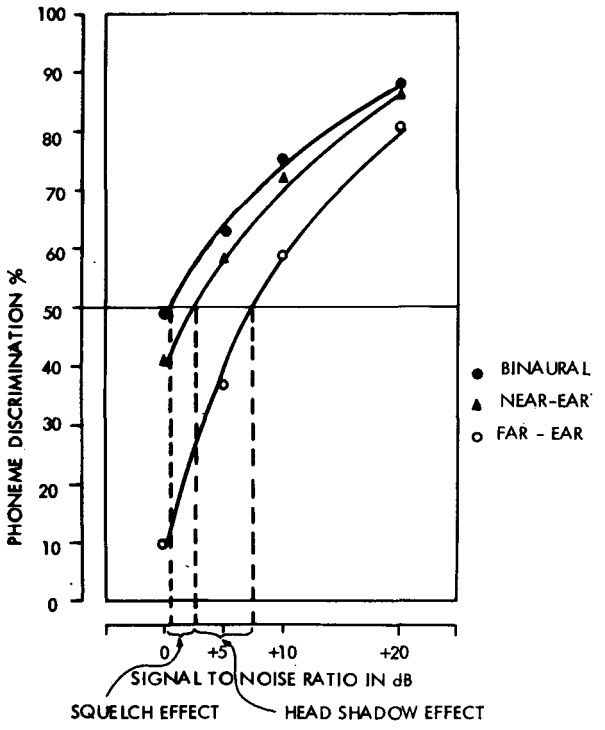


FIG. 3

Summary of speech discrimination scores.

(d) No significant differences were observed between the two pairs of ear-level hearing aids used.

(e) No significant differences were observed between the three pairs of body-worn hearing aids used.

(f) There were, however, significant differences in favour of high-fidelity amplification as compared to ear-level hearing aid use.

(g) The use of a body-worn hearing aid with 'Y' lead was found to be similar to a single monaural hearing aid but significantly inferior to a true binaural hearing aid system.

(h) The 'squelch' and 'head-shadow' advantages were calculated at the 50 per cent discrimination level. These advantages, however, tended to increase with more unfavourable signal-to-noise ratios. In other words, in a quiet environment binaural advantages in speech discrimination were minimal; in noisy environments binaural advantages were substantial.

(i) All the subjects with binaural hearing impairment derived significant speech discrimination advantages when using two hearing aids as opposed to one, except:

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(i) Subjects with a relatively flat hearing impairment in one ear and with a steeply falling pure tone audiometric configuration in the other ear, and

(ii) Subjects suffering from diplacusis binauralis. (The smallest magnitude of diplacusis found to interfere with binaural hearing aid candidature was a combination of 15 per cent at 500 Hz, 10 per cent at 1,000 Hz and 10 per cent at 2,000 Hz).

(j) The above results relate both to a non-reverberant and to a reverberant environment.

(2) *Subjects with unilateral hearing impairment*

TABLE I

		dB improvement	
Unilateral Aidable			
1. Single ear-level with external receiver—speech from the side of *good ear*	C	−0·75	NS
	S	−2·50	NS
—speech from the side of *bad* ear	C	3·00	NS
	S	3·00	NS
Unilateral Unaidable			
2. CROS			
—speech from the side of *good* ear	S	−13·25	P>·01
—speech from the side of *bad* ear	S	5·13	P>·01

Table I shows the relative effects of a single ear-level hearing aid and of the CROS aid on the speech discrimination ability of unilaterally deaf people. It may be noted:

(a) For people with unilateral aidable impairment a single ear-level hearing aid in their affected ear, when speech comes from the side of the good ear, has a deterimental effect. When speech comes from the side of the affected ear the hearing aid has a marginal beneficial effect.

(b) The CROS hearing aid was found to have a disastrous effect on the speech discrimination of people with unilateral unaidable hearing impairment when speech was coming from the side of the good ear. The CROS was beneficial when speech was coming from the side of the bad ear.

(3) *Localization test*

Figure 4 summarizes the localisation ability of the subjects with normal hearing and of the subjects with bilateral hearing impairment. The results were as follows:

(a) When listening with the right ear the tendency was to shift the actual source of the stimulus towards the right ear. The same

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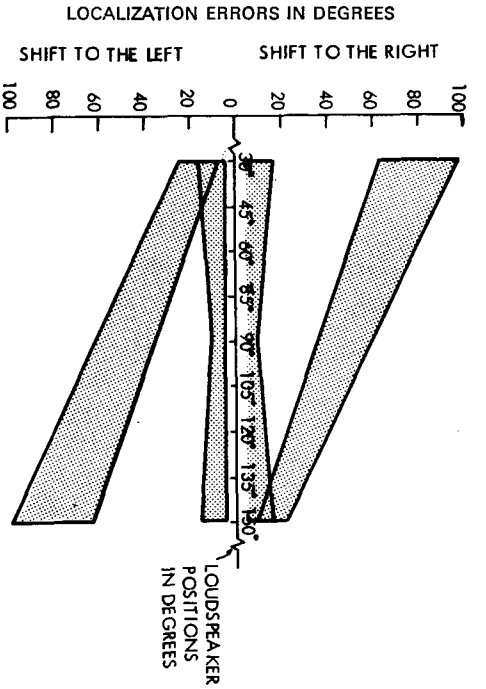


FIG. 4

Summary of results of localization measures.

happened when listening with the left ear but this time the actual source of the stimulus was shifted towards the left ear.

(b) Binaural listening, under normal listening conditions or through hearing aids, showed a significant improvement in localization ability over either monaural listening mode. This was true for both ear-level and body-worn hearing aids.

(c) Binaural localization under normal listening conditions was significantly superior to binaural localization with hearing aids.

(d) No significant differences were observed in binaural localization between the two pairs of ear-level hearing aids used. The same was true between the three pairs of body-worn hearing aids.

(e) The use of a body-worn hearing aid with a 'Y' lead was found to be detrimental to localization.

(f) Subjects with unilateral hearing impairment showed significantly better monaural localisation ability than normal subjects listening with only one ear. Their monaural localization ability, however, was greatly disturbed when they were fitted with an ear-level hearing aid or with the CROS aid.

(g) The minimum stimulation required for an ear to contribute significantly to binaural localization was about 10 dB above the speech detectability threshold for that ear.

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Discussion

As stated, the purpose of this paper was to provide answers to several fundamental questions.

The first of these questions was: Are there benefits to be gained from binaural hearing aids as opposed to monaural hearing aids?

The answer is 'yes'. Two hearing aids, ear-level or body-worn, facilitate speech discrimination in noise and also dramatically enhance localization ability. The first benefit provides an ease of listening and fosters an attitude of psychological well-being stemming from attention selectivity.

The second question was: Can these benefits be measured?

It has been shown that binaural ear-level hearing aids as opposed to a monaural ear-level hearing aid use provide significant advantages in the order of 2–3 dB 'squelch effect' and 6–7 dB 'head-shadow effect'. These advantages are additive. Thus binaural ear-level hearing aids, on average, can provide up to 10 dB advantage. This translated in terms of speech discrimination shows a maximum binaural hearing aid enhancement of speech discrimination in noise by as much as 40 per cent.

For binaural body-worn hearing aids the 'head-shadow effects' are, of course, not applicable. The 'squelch effect', however, was again in the region of 2–3 dB or 10 per cent better discrimination ability over the monaural body-worn hearing aid case, this being true also in situations where both speech and noise were coming from directly in front of the subjects.

It has also been shown that binaural hearing aids, of the ear-level or the body-worn type, provide dramatic and immediate better localization ability than monaural hearing aids.

The effect of the combination of these two benefits is considerable. These results were obtained with adults who were linguistically proficient. The long-term effect of these benefits on the education of hearing-impaired children can be very substantial indeed.

The third question was: Under what conditions can benefits be obtained from two hearing aids as opposed to one?

Binaural hearing aid advantages can be achieved both in a reverberant and in a non-reverberant environment, especially when there is an appreciable noise background. In very quiet environments binaural hearing aids do not improve speech discrimination appreciably but they will certainly enhance localization ability.

The fourth question was: With which type of aid can benefits be achieved from two hearing aids as opposed to one?

Binaural hearing advantages can be achieved with both the ear-level and the body-worn types of aid. Obviously in cases where the ear-level type is indicated (for patients with moderate hearing impairment) such aids should be preferred (as opposed to body-worn aids), mainly because they

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provide both 'squelch' and 'head shadow' advantages and also better localization ability. Binaural body-worn hearing aids are suitable for patients with more severe hearing impairment and they provide improvement over monaural body-worn hearing aid use both in speech discrimination and localization ability. This is true whether the body-worn hearing aids are separated on the chest by six inches or even by only two inches.

These comments relate to patients with bilateral hearing impairment. Attempts to restore binaural hearing advantages to unilaterally deaf people were less successful.

People with unilateral aidable hearing impairment did not show significant improvement in either speech discrimination or localization ability when fitted with an ear-level hearing aid in their affected ear. Experience in the use of a single aid, however, may modify this conclusion. The CROS hearing aid if unselectively used was found to have detrimental effects on both speech discrimination and localization ability.

The final and most important question was: Which hearing impaired people can benefit from two hearing aids as opposed to one?

The most crucial question here relates to the minimum stimulation required for an ear to contribute to binaurality. It has been found that, provided an ear receives speech or can accept speech through a hearing aid which is 20 dB (10 dB for localization) above its Speech Detectability Threshold (SDT), then such an ear contributes significantly to binaurality.

Exceptions to this are:

(a) Patients with a flat hearing impairment in one ear and a steeply falling audiometric configuration in the other.
(b) Patients suffering from diplacusis binauralis. The minimum degree of diplacusis found to interfere with binaural hearing aid candidature was a combination of 15 per cent at 500 Hz, 10 per cent at 1,000 Hz and 10 per cent at 2,000 Hz.
(c) Subjects with severe fine manipulation problems (mainly elderly people).
(d) Subjects with predominantly retrocochlear (peripheral neural) lesions, as it is universally accepted that such people have poor speech discrimination ability and many of them benefit very little from amplification.
(e) Subjects with unilateral unaidable hearing impairment.

Binaural Hearing Aid selection — Practical guidelines

(1) Otological examination.
(2) Audiological investigation (minimum requirements).
  (i) Pure tone threshold of hearing (air conduction and bone conduction with masking when necessary).
  (ii) Uncomfortable Loudness Level (ULL) for pure tones in each ear (250–4,000 Hz).

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(iii) Earphone speech audiometry (to verify that the patient actually receives benefit from amplification in terms of speech discrimination).

(iv) Speech Detectability Threshold (SDT) of the patient in each ear.

(v) Diplacusis binauralis measurement at 500, 1,000 and 2,000 Hz. (This measurement may not be strictly necessary as the number of hearing-impaired people suffering from gross binaural pitch discrimination disparities is relatively small).

(3) Binaural hearing aid candidature.

(i) Subjects with symmetrical or asymmetrical conductive or sensorineural hearing impairment with average hearing levels falling between 40/50 to 90 dB (averaged across 500, 1,000 and 2,000 Hz). The severity of hearing loss can, of course, be higher than 90 dB, provided the patient can accept amplification which is around 20 dB (10 dB for localization) above his/her Speech Detectability Threshold (SDT) at each ear.

(ii) Where possible, priority should be given to ear-level hearing aids rather than body-worn ones, as they provide head-shadow advantages as well as squelch ones and better localization ability. For subjects with average hearing levels of around 80/90 dB+, body-worn hearing aids instead of ear-level hearing aids are indicated for obvious reasons.

(4) It is estimated that at least 45 per cent of all hearing-impaired people requiring amplification can benefit from the use of two hearing aids.

(5) Exceptions:

As specified in the previous section of this paper.

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