OPEN ACCESS GUIDE TO AUDIOLOGY AND HEARING AIDS FOR OTOLARYNGOLOGISTS

FITTING HEARING AIDS: CLINICAL & PRACTICAL ASPECTS

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This is the 2nd of two chapters on fitting hearing aids. The 1st chapter deals with the technical aspects of hearing aids, whereas this chapter deals with how best to accommodate an individual's unique hearing amplification needs.

Selecting proper amplification with appropriate characteristics is always a challenge. Advances in hearing aid technology have made this selection even more difficult. When fitting a hearing aid, one needs to remember that one is dealing with people, not "ears". People respond to aids differently, and individuals with the same types and degrees of hearing loss may benefit differently from the same hearing aid. This variable benefit may result from the individual pathology. A person may have poorer speech discrimination scores than others because of the way the cochlear hair cells or auditory nerve have been damaged; or it may be due to a patient's personality; or a combination of factors.

Considerations when fitting hearing aids

1. ***Candidacy for a hearing aid***
   a. ***Audiological factors***
      - *Audiometric data*
      - *Anatomy of the ear*
      - *Unilateral vs bilateral aids*
   b. ***Motivational factors***
      - *Occupation*
      - *Communication needs*
      - *Social lifestyle and personality*
      - *Handling*
      - *Sound quality*
      - *Cosmetic*
      - *Financial*
      - *Expectations*
   c. ***Other factors***
2. ***Hearing aid selection criteria***

1. Candidacy for a hearing aid

The 1st step is to assess the individual's candidacy for a hearing aid. Characteristics that determine candidacy in adults can be divided into ***audiologic, motivational, and "other" factors***. In children, greater reliance tends to be placed on audiologic factors.

a. Audiologic factors

Audiometric data

Audiometric data to be considered when deciding whether a patient is a candidate for a hearing aid include pure tone audiometric results, the speech audiometry results, the dynamic range and the uncomfortable loudness levels (UCLs).

- ***Pure tone audiometric results*** are important for describing the type of hearing loss, the degree of the hearing loss as well as the configuration of the hearing loss – all factors that must be considered when choosing an appropriate hearing aid.

- ***Speech audiometry results*** indicate cochlear function and assist to determine a patient's dynamic range.

- ***Dynamic range*** is the decibel range between thresholds for speech and the point at which a stimulus becomes uncomfortably loud. The dynamic range is often significantly reduced in individuals with sensorineural hearing loss. The upper limit of the dynamic range can be lowered because of loudness recruitment. Individuals with a large dynamic range are likely to be more successful hearing aid users than those with a severely reduced dynamic range.

- ***Uncomfortable loudness levels (UCL's)*** also play an important role in candidacy. A hearing aid wearer will reject an aid that provides too much gain and has an output level that exceeds the uncomfortable listening level.

Anatomy of the ear

Determine whether a person's ear canal anatomy allows for a specific choice of custom-made hearing aid or earmold style.

Not all ear canals are big enough to accommodate the components that need to fit into the shell of a custom-made hearing aid. Anatomical features such as the tragus or antitragus, may be prominent and interfere with the fit of a custom-made hearing aid, such as placement of the controls on the face-plate of a custom-made hearing aid.

The more severe the hearing loss, the bigger the components of a hearing aid need to be; sometimes an ear canal is simply too small to accommodate these components in the shell of a custom-made hearing aid.

If there are malformations of the ear *e.g.* an absent pinna, a stenotic ear canal, or atresia, then other options such as a BAHA (bone anchored hearing aid) should be considered: see chapter: *https://vula.uct.ac.za/access/content/group/27b5cb1b-1b65-4280-9437-a9898ddd4c40/Bone%20anchored%20hearing%20implants%20_aids_%20_BAHI_%20_BAHA_.pdf*

Unilateral vs. Bilateral hearing aids

Two ears are always better than one as it helps with sound localisation and increases understanding of speech in noise. Therefore, always recommend 2 hearing aids. However, there are situations when one would rather fit a unilateral hearing aid *e.g.* when a patient can only afford one aid).

b. Motivational factors

The audiologist must determine a candidate's perceived need for amplification, and the impact of hearing loss on his/her communicative abilities and quality of life. Candidates that believe they would gain from amplification are likely to perform well with hearing aids. However, those that do not see the need for amplification and do not think they are handicapped are not going to perform well.

- ***Occupation:*** Communication demands differ for each occupation. The need for amplification for improved communication and speech intelligibility plays an important role in an individual's perceived need for hearing aids.
- ***Communication needs:*** Situations in which the individual needs to improve his/her hearing (work/ home/social activities).
- ***Social lifestyle and personality:*** Personality and social lifestyle influence perceived need for amplification.
- ***Handling:*** The smaller the hearing aid, the smaller the controls and the batteries. Small aids (custom-made or mini-BTE's) are not suitable for paediatric or geriatric patients.
- ***Sound quality:*** Technology has led to improved sound quality. The most sophisticated instruments are

usually digital hearing aids that are designed to achieve the best possible sound quality. These hearing aids, however, might not be affordable, or a patient that is used to analogue technology might find it difficult to adjust to the sound quality of digital hearing aids (see below).

- ***Cosmetic:*** Hearing aids come in a variety of sizes and colours. Most people are sensitive about their hearing aids being visible and insist on the most discreet option.
- ***Financial:*** Hearing aids come in different price ranges and vary from the most basic technology (most affordable/entry-level/budget hearing aids) to advanced techno logy (most expensive/top-end hearing aids).
- ***Expectations:*** Patients always expect the most discreet option possible, the most affordable option, and sound quality like normal hearing, especially if they had normal hearing before.

c. *Other factors to consider for hearing aid candidacy*

- ***Central auditory processing disorder:*** Such patients cannot process information they hear in the same way as others do, which leads to difficulties to recognise and interpret sounds, especially sounds composing speech. It is thought that these difficulties arise from dysfunction in the central nervous system
- ***Tinnitus***
- ***Vertigo***
- ***Conductive hearing loss*** *e.g.* with chronic otitis media or external otitis and/or cerumen
- ***Atresia or malformation*** of the ear canal and/or pinna
- ***Medically related contraindications*** *e.g.* sudden onset or rapidly progressive hearing loss
- ***Markedly asymmetrical idiopathic hearing loss***

2. Hearing aid selection criteria

The dispenser is responsible for making the best possible recommendation of a suitable hearing aid, and to program the hearing aid as closely as possible to the patient's needs, to modify the psycho-acoustic characteristics, and to ascertain the individual's residual difficulty.

The patient must work with the hearing aid using compensatory strategies like speech reading, to overcome residual difficulties. Referral for aural rehabilitation may be required.

The following should be considered when selecting a hearing aid:

- ***Required electroacoustic characteristics:*** This refers to gain, maximum output and frequency response required for the patient's hearing loss according to the audiogram *i.e.* degree, type, and configuration of hearing loss)
- ***Selecting the prescriptive formula:*** Non-linear amplification – Desired Sensation Level Input/Output (DSL I/O); National Acoustics Laboratory Non-Linear 1 (NAL-NL1); or Open fit
- ***Digital vs. digitally programmable vs. analogue technology:*** Select the type of technology that will best suit the patient's hearing loss, lifestyle, communication needs and finances. Select the features for the hearing aid based on the technology (digital or analogue) that is chosen
- ***Binaural vs. monaural fitting:*** It is always better to fit a patient binaurally, because of sound localisation, binaural

fusion and integration, as well as better speech understanding in especially in noisy listening conditions. Consider type, symmetry, configuration, as well as degree of hearing loss when deciding on binaural or monaural fitting. Also consider the patient's finances. Rather fit two hearing aids in a more affordable price range, than one more expensive hearing aid. Consider monaural fitting with unilateral hearing loss, or with anatomical/structural malformations of one ear. If only one hearing aid can be fitted and the hearing loss is symmetrical, consider fitting the ear with the better speech discrimination.

- ***Financial considerations:*** Consider the type of technology that the patient can afford. Most manufacturers offer a variety of hearing aid types (BTE's and custom-made) of the same technology within the same price range. In developing countries BTE´s are the most common and available hearing aids.
- ***Customer Support:*** Consider that in developing countries there are few providers for custom-made hearing aids.

Stages of hearing aid fitting

The 6 stages for fitting a patient with a hearing aid are:

1. ***Prescription of amplification***
2. ***Selection of amplification***
3. ***Verification of fitting***
4. ***Orientation and training***
5. ***Validation***
6. ***Follow-up***

1. Prescription of amplification

Information derived from a comprehensive diagnostic test battery is used to decide about hearing aid candidacy and to prescribe, select and fit amplification. Information used from the test battery includes:

- Behavioural pure tone thresholds (AC & BC)
- Uncomfortable levels (UCL's)
- Speech audiometry and, where possible, speech-in-noise testing

2. Selection of amplification

The clinician selects and adjusts hearing aids to match the prescription for amplification. The following must be considered when selecting a hearing aid: Practicality, flexibility of the hearing aid and future needs *e.g.* FM use. Selection is based on the

- Patient's individual needs and abilities
- Diagnostic information
- Degree of hearing loss
- Degree of communication disability
- Motivation to use the hearing aids (see section of factors to be considered in hearing aid fitting above)

3. Verification of fitting

Verification of fitting ensures that audibility of the speech signal is at a safe and comfortable listening level, and that the amplified speech spectrum closely approximates the prescription goals (thus measuring acoustic performance). It also informs the clinician whether the hearing aid will facilitate auditory development.

Because prescription goals are defined electroacoustically, verification is done using electroacoustic measures using veryfication equipment *e.g.* Verifit. Electroacoustic measures provide precise hearing instrument-responses by frequency. It is measured either real-ear or in the 2cc coupler. This is more efficient, reliable and valid than clinical evaluation. The measurements are defined as sound pressure level (SPL).

Unfortunately, verification equipment is often not available in low- and middle-income countries. In such situations obtaining aided sound field and speech perception performances as well as conducting filed evaluations are recommended.

4. *Orientation and training*

To promote consistent use, patients need information about care, appearance and benefits of hearing aids. The following principles should be applied when orientating and training about use of hearing aids:

- Demonstrate how to put the hearing aid in and out of the ear
- Demonstrate how to operate the aid
- Patient skill and comfort affect settings
- Practice and repetition are important to become comfortable operating the aid
- Daily checks are crucial (visualisation/ batteries/on-off/volume control/listening/feedback, etc.
- Written information must be provided
- Important to repeat and review information at each session

5. *Validation*

Validation demonstrates benefits or limitations of an individual's aided listening ability to perceive speech and is determined over a period of time, using information derived through the aural rehabilitation process and by directly measuring the individual's aided auditory performance. Information is gathered from parents/ caregivers, significant others/close communication partners, the patient, as well as the clinician. Validation practices should be used in conjunction with prescriptive fitting and traditional measures.

Benefits of validation of the fitting process are to:

- Facilitate validation of information obtained through other measures
- Evaluate information that is difficult to elicit in a standard assessment paradigm
- Provide information on changes in sensory perception and speech production
- Ongoing assessment of the relationship between the individual, the auditory environment and the individual's amplification system

Validation is usually done by clinical evaluation, assisted by speech perception responses, and field evaluation

Clinical evaluation

Clinical evaluation is done by means of behavioural observations and provides information about the functional benefits of the fitting and provides a baseline for monitoring. It is not used to change hearing aid settings. Clinical evaluation has certain limitations:

- Prolonged cooperation from the patient is required
- Time consuming
- Poor frequency resolution
- Poor test-retest reliability
- Can be misleading with non-linear processing (compression).

Clinical evaluation uses ***Functional Gain Testing*** that involves obtaining ***aided sound field responses*** as well as ***aided speech perception responses***.

- ***Aided sound field responses***
    - In soundproof booth
    - Patient wears hearing aids
    - Position patient to face speaker who is seated approximately 1m from patient
    - Can test binaurally or ear-specific (monaural hearing)
    - For monaural testing, turn one hearing aid off to block use of that ear

- Use pulsed warble tones or narrow-band noise (NBN) to avoid triggering feedback management system
- A long inter-stimulus presentation time is important to allow the compression circuit to recover once the stimulus has been presented

- ***Aided speech perception responses***

    - To obtain aided, free field responses to speech stimuli
    - Determine maximum percentage correct discrimination of speech sounds with hearing aids in and on
    - Ear-specific information can again be obtained, as with aided sound field-testing
    - Speech perception scores can be obtained by using word or sentence stimuli with/without lip-reading
    - The percentage obtained is an indication of what the maximum speech perception benefit for the patient is
    - The level used for aided speech perception testing varies according to the degree of deafness. but averages around 55dB HL or 70dB SPL

- ***Field evaluation***

    There is a growing trend to employ self-assessment scales or question-naires to determine the individual's satisfaction and benefit in everyday listening situations. It rates the overall success of the fitting and service delivery processes. Examples of available questionnaires or scales are:

    - Glasgow Hearing Aid Benefit Profile (GHABP)
    - Glasgow Benefit Inventory (GBI)
    - Hearing Handicap Inventory Adult/ Elderly (HHIA or HHIE)
    - The Speech, Spatial and Qualities of Hearing Scale (SSQ)
    - International Outcome Inventory-Hearing Aids (IOI-HA)
    - Measure of Audiologic Rehabilitation Self-Efficacy for Hearing Aids (MARS-HA)
    - Nijmegen Cochlear Implant Questionnaire (NCIQ)
    - Nijmegen Group Questionnaire for BAHA

6. Follow-up

Fitting amplification is not a once-off event but is an ongoing process. The patient should be seen regularly to monitor progress and success of the fitting, initially two weeks after the fitting; and thereafter on demand and at least once a year. By following the patient one can monitor the individual's progress and adaptation to hearing amplification. Modifications to the initial fit can be made and ongoing counselling can be provided about coping with the hearing aid in everyday life. Booklets covering the topic are available from most hearing aid suppliers.

At follow-up appointments one should

- Monitor hearing status through audiometric evaluation to record both unaided and aided thresholds
- Assess communication abilities, needs and demands
- Adjust amplification based on updated audiometric information
- Periodic electroacoustic evaluations
- Listening checks
- Check fitting of earmold or custom-made hearing aid shells
- Periodic probe-microphone measurements following replacement of earmolds
- Periodic functional measures to document progress of auditory skills
- Periodic field evaluation to document patient satisfaction and benefit from amplification
- Hearing aid insurance or service dates

Analogue Hearing Aids

Fitting strategies

Before the advent of digital sound technology, analogue hearing aids were the only form of hearing aids. Today they are hardly manufactured anymore. However, fitting analogue hearing aids is still applicable in many poorer countries and it is therefore good to have knowledge of the more basic analogue technology. This is described in the 1st chapter of hearing aids, page 2 and 3. https://vula.uct.ac.za/access/content/group/27b5cb1b-1b65-4280-9437-a9898ddd4c40/Fitting hearing aids - Technical aspects.pdf

Analogue hearing aids make continuous sound waves louder and amplify all sounds (speech and noise). They use either linear or non-linear amplification. A linear circuit amplifies all incoming signals equally strongly whereas non-linear uses a fixed "knee-point" to make soft sounds louder but reduces amplification of loud incoming sounds. Analogue hearing aids use transistors in a circuit to amplify and modify incoming sound. Some advantages are that they cost less than digital hearing aids, sometimes are more powerful than digital hearing aids and that they often appeal to previous and long-term users. Analogue hearing aids also usually sound better for music, particularly recorded music.

- Determine the ***type of hearing loss*** (conductive/perceptive/combined)
- The ***pure tone audiogram*** tells which ***type of hearing loss*** there is and something about the ***frequency characteristics*** to which one should adjust the hearing aid *i.e.* how strongly sound should be presented at different frequencies to be at least audible
- ***Speech audiometry*** provides some insight about the ***amount of amplification required*** and the consequences of excessively amplified speech
- ***Conductive hearing loss is generally easily correctable;*** such individuals want complete compensation for their hearing loss
- However, many times they also have a ***perceptive loss*** in which a ***recruitment*** phenomenon (weaker sounds are loud and unpleasant) may limit the amount of amplification possible
- Patients with ***combined or perceptive hearing loss need less amplification*** than those with pure conductive loss
- A rule of thumb is that patients with ***perceptive hearing loss have the gain control of the hearing aid set so that the shift in the speech audiogram is reduced by half***. More amplification is nearly always uncomfortable and results in complaints of "too loud"
- Hearing aid fitting methods are used to determine how much amplification to provide for specific hearing losses

"Half-Gain Rule" with perceptive hearing loss

When fitting a perceptive hearing loss with a full gain hearing aid, first let the patient set the preferred volume; this would usually be with the volume set half-way. By trial and error, patients can get a comfortable amount of gain for both soft and loud speech and still be able to tolerate the output.

The half-gain rule according to Samuel Lybarger [1, 2] is based on a patient's audiometric thresholds. It was designed for linear hearing aids and allows one to select a maximum output level ***(maximum gain)*** and a preferred gain ***(operating gain).***

Operating gain is determined by bringing the average conversational speech level (65dB SPL) within the most comfortable loudness range of the listener. The formula according to Lybarger for operating gain in a monaural arrangement is the following:

$$\frac{AC\ loss}{2} + \frac{AC\ loss - BC\ loss}{4} + 5\text{dB}$$

The air conduction loss (AC) and bone conduction loss (BC) are pure tone averages obtained at 500Hz, 1000Hz and 2000Hz.

Reserve gain is an additional 15dB. The constant +5dB is changed to -10dB for binaural fitting.

Maximum gain is operating gain plus a certain amount of reserve gain.

The half-gain rule is valid for speech reception thresholds except with mild hearing losses where the gain obtained is a little less than one-half of the unaided hearing threshold level. The half-gain rule is easily calculated and provides a good first-order approximation of needed operating gain.

On/Off switch

The On/Off switch on older and analogue hearing aids is a small switch, mounted on the hearing aid case – this is usually marked M-T-O (Microphone-Telecoil-Off) *(Figure 1)*. Newer and smaller hearing aids have the On/Off switch integrated into the battery compartment; the hearing aid is switched on and off by opening or closing the battery door *(Figure 2)*.

Microphone-Telecoil switch (M-T switch or M-T-O switch) *(Figure 1)*

The microphone function is usually used to enable the hearing aid to receive a signal from the microphone. When the M-T switch is in the T-position, the hearing aid receives a signal from a magnetic loop system, used in some theatres, cinemas and churches. The microphone is usually disabled in the T-position. However, some hearing aids have an M-T option where the microphone is enabled (either 25 or 50%) in the T position. In this way the user can follow a conversation on the telephone via the telecoil while hearing speech in the environment.

Figure 1: On-off switch and volume control wheel mounted on hearing aid case of analogue hearing aid

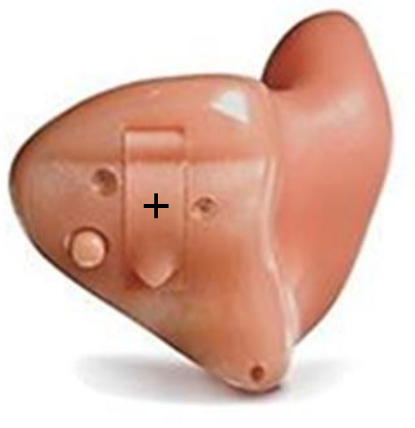


Figure 2: Door to battery compartment (+)

Adjusting amplification with analogue hearing aids

Volume control: Analogue hearing aids have a volume control wheel *(Figure 1)*. It is an adjustable electrical resistor and controls the presented electrical alternating voltage. The voltage regulator is called a potentiometer and is a logarithmic type.

Consequently, turning of the control corresponds with the change in volume. The control wheel is graduated in figures that may vary in number from model to model.

Tone control *(Figures 3, 4):* Most analogue hearing aids contain more potentiometers called ***trimmers***. They are shaped like small screws and are adjusted with an insert screwdriver. They are used for tone control and adapt the frequency characteristics of the hearing aid to the patient´s audiogram. But, there is not a simple relationship between the audiogram profile and the "sound quality" the patient prefers. Tone control generally weakens the low tones to some degree and is therefore called a "bass-cut". This makes the hearing aid sound as though it emits more high tones. With the trimmer set to N (Normal), nothing is filtered out; when set to H (High) the circuit functions maximally and emphasises high tones. Sometimes there is also a tone control which in a similar way can weaken the high tones. It can be set to High-cut or L (low emphasis) and is occasionally used to counteract whistling of the hearing aid.

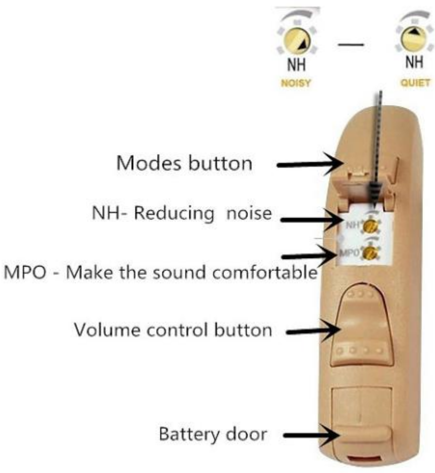
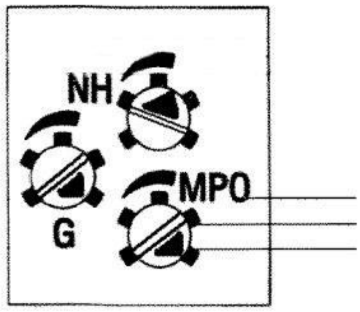


Figure 3: Trimmers are adjusted with an insert screwdriver for tone control

Low-tone filtration below 1000 Hz and automatic signal processing (ASP) that splits the input signal into two frequency bands are used to reduce the negative effect of low frequency background noise. These switches can improve the understanding of speech in company and in ambient noise. However, many users find that these functions alter the sound quality too much.



IF TOO LOUD:	NH	G	MPO
Loud sound (horn, dish breaking, door slamming)			CCW
High frequency loud sound (dish breaking)	CW		CCW
Low frequency loud sound (door slamming)	CCW		CCW
High frequency soft sound (bird chirping)	CW		
Low frequency soft sound (fan blowing)	CCW		
All sound		CCW	CCW
IF TOO WEAK:	**NH**	**G**	**MPO**
Loud sound (horn, dish breaking, door slamming)			CW
High frequency loud sound (dish breaking)	CCW		CW
Low frequency loud sound (door slamming)	CW		CW
High frequency soft sound (bird chirping)	CCW		
Low frequency soft sound (fan blowing)	CW		
All sound		CW	CW

Figure 4: Example of instructions how to adjust the trimmers

Limitation controls: These limit the output of the hearing aid. There are two types – ***Peak Clipping (PC)*** or ***Automatic Gain Control (AGC)***.

- ***Peak Clipping*** ensures that maximum output never exceeds a certain limit and is intended to protect patients with recruitment from unpleasant loudness. A drawback is that the amplifier begins to distort strongly the moment it cuts in.
- ***Automatic Gain Control*** adjusts the amplification smoothly depending on the sound input. A drawback is that it takes a moment to become effective (attack time) and to cut itself off (release time). The wearer usually notices very little/nothing of the attack time, but the release time may have an audible effect. For individuals with

recruitment a short release time is desirable. However, a short release time has the disadvantage that background noise, suppressed during speech, immediately becomes loud when speech is paused. This leads to a variable “pumping” sound picture and it then becomes necessary to alter the AGC trimmer to a slightly longer release time. A long release time, on the other hand does not work well for speech in a quite environment. In perceptive hearing loss a slightly active AGC is often appreciated because it makes the amplified sound milder and less aggressive. Different AGC´s work in different ways. Some start early at low intensities and others function above a certain volume, almost like a PC function. The AGC can react to the input signal of the hearing aid (AGC-I) independent of the volume control or react to the output signal (AGC-O) and compress it depending on how high the volume control of the hearing aid is set.

- ***PC vs AGC:*** The advantage of PC is that there is no interference with the signal until a certain level is exceeded; the disadvantage is that above this level much distortion occurs. The advantage of AGC is less distortion under all circumstances; the disadvantage is that AGC may alter the dynamics of the signal over a large part of the volume range (sometimes unpleasantly so)

Remember that the relationship between the audiogram curve and the most desirable frequency amplification is not simple and varies from patient to patient.

Making Digital Hearing Aids Analogue

Unfortunately, the major hearing aid manufacturers no longer produce analogue hearing aids. Often an analogue user cannot get used to or has severe difficulty with the sound quality of digital hearing aids. So what solutions are available for such patients? An approach could be to use various digital instruments from the major manufacturers and try to make their sound as “analogue” as possible. This involves turning off various features that generally make digital hearing aids better for patients with less severe hearing loss, reducing automation, making the sound quality as "linear" as possible etc.

Digital hearing Aid Fitting Strategies

Hearing aid ***prescriptive or fitting methods*** focus on how much amplification to provide for specific hearing losses. For every specific hearing loss, many fitting methods that can be used, and each one will lead to a prescription of somewhat different amounts of amplification at different frequencies.

Except for some recent approaches, research fundamental to prescriptive hearing aid selection has been conducted only with linear hearing instruments. New procedures, specifically offered for non-linear hearing aid circuits, include the DSL I/O, NAL-NL1, IHAFF, and the FIG6 prescriptive formulae (explained below). The appropriate choice of algorithm may determine the success of the prescriptive hearing aid fitting. There is a significant interaction effect between prescriptive fitting techniques and persons with different hearing loss characteristics. The challenge is to select the correct prescriptive fitting technique or to modify it, so it becomes the right approach for a given patient.

Purpose of prescriptive formulae

Prescriptive formulae apply scientifically-based procedures to maximise user benefit in a short space of time and permit an organised systematic approach to fitting hearing aids.

It might seem attractive to simply 'mirror' hearing aid gain with the audiogram. Doing so would require only one prescriptive method for all people with hearing loss.

However, people with sensorineural hearing loss have a reduced dynamic range. A reduced dynamic range generally implies that soft sounds are not audible, while intense sounds are heard as loudly as they are by those with normal hearing. Think of it as the "floor" of hearing sensitivity that is elevated, but with that the "ceiling" of loudness tolerance remains relatively unchanged. For someone with this type of hearing loss a hearing aid needs to significantly amplify soft sounds below their threshold, whereas intense sounds cannot be amplified by the same amount without considerably exceeding the patient's tolerance for loud sounds. ***Amplification therefore must be provided in a nonlinear fashion to accommodate everyone's unique hearing needs.***

All prescriptive approaches have some common objectives to provide:

- Gain appropriate to the hearing loss and achieve functional threshold shifts that approach "normal hearing"
- An average speech spectrum at a comfortable level to the ear
- Maximum dynamic range
- Signals that restore equal loudness function
- Aided speech signals at the MCL's (most comfortable level) in the speech frequencies
- Gain based on the size and shape of the dynamic range
- Gain based on the discomfort level (based on uncomfortable loudness levels - UCL's)

Which prescriptive formula to use?

A variety of prescriptive or fitting formulae are available. Some are directed at linear instruments, while others are appropriate for non-linear instruments.

Fitting formulae for non-linear hearing aids include:

- Desired Sensation Level Input/Output (DSL I/O)
- National Acoustics Laboratory Non-linear 1 (NAL-NL1)
- National Acoustic Laboratory (NAL)
- National Acoustic Laboratory-Revised (NAL-R)
- Prescription of Gain and Output (POGO) (POGO II)
- Independent Hearing Aid Fitting Forum (IHAFF)
- FIG6 Procedure

The increase in programmable and digital hearing aid circuits has created an interest in new prescriptive methodologies to accommodate non-linearity and to assist clinicians to fit such products easily and accurately. Specifically, approaches that are the result of this research include DSL I/O, IHAFF and FIG6 fitting formulae.

Prescriptive procedures for non-linear hearing aids

Newer fitting methods address compression in hearing aids and are referred to as "suprathreshold-based" or "compression-based" fitting methods. Although they utilise the patient's hearing thresholds, they also address what takes place above one's hearing threshold, such as restoring normal loudness growth to the impaired ear.

Desired Sensation Level Input/Output (DSL I/O)

Oral speech and language development depends first and foremost on the audibility of speech, or the ability to hear all speech sounds. This is especially important for children who have hearing loss prior to, or during the period of speech and language acquisition.

The DSL method was designed to make soft, medium and loud speech sounds audible and comfortable for such children. DSL I/O was subsequently (1996) further developed to address compression-hearing instruments. The DSL fitting algorithm is still being constantly updated. The latest version is DSL *m* [I/O] v5 (Desired Sensation Level Multistage Input Output version 5), which was introduced in 2005. Although DSL was developed for the paediatric population, its use has since been generalised to adults.

The main goal of the DSL I/O fitting formula is audibility of speech. To maximally utilise residual hearing, the entire unaided speech spectrum must be amplified to above the hearing thresholds, but still below the loudness discomfort levels (within dynamic range). Furthermore, the amplified speech spectrum must be as comfortable and undistorted as possible. It is important that children hear high frequency consonants of their own voices to properly acquire speech. Thus, DSL I/O advocates more high frequency output than most other fitting methods.

With DSL I/O, the output from the hearing aid is of ultimate interest, not the gain (think of output as the final delivered "groceries" to the eardrum). Unlike other fitting methods, DSL I/O is concerned with "in-situ" measures, not "insertion" measures. DSL I/O therefore looks at output that is delivered to the eardrum, and derives this output from the input SPL plus the in-situ gain.

Therefore, the purpose of the DSL I/O approach is to develop a device-independent formula for the specification of the electroacoustic characteristics of a personal hearing aid or, theoretically, the ideal amplified output for a range of input levels. It can be described as a series of mathematical equations that describes the relationship between the input level of a signal delivered to a hearing aid and the output level produced by the hearing aid.

> *"DSL is more than just an algorithm for electro-acoustic selection; it is a method consisting of sequential stages in a well-integrated hearing instrument fitting process. The emphasis of our work has been on audiometric assessment, hearing instrument selection and verification of aided performance."*
>
> *Richard Seewald, 1995*

Calculation of DSL I/O: DSL I/O is a complex formula and considers many variables at many frequencies simultaneously to facilitate accurate calculation of specific parameters of fitting. ***The use of a computer program that only requires the clinician to enter threshold data and automatically calculates the variables and presents ideal I/O curves for a particular hearing impairment is needed and of great help.***

More information on DSL I/O can be obtained from: https://www.dslio.com/

National Acoustic Laboratories Non-linear One (NAL-NL1)

NAL-NL1 was designed for non-linear signal processing and provides different prescriptive targets as a function of input level, because hearing aid compression offers different gain for different input levels. The goal of this prescriptive hearing aid fitting strategy is to maximize speech recognition for a given speech input level (dB SL) within the constraints that the hearing aid wearer should perceive the overall level of speech no louder than an individual with normal hearing. At a given input level however, the relative loudness across the frequency regions is prescribed with the goal of maximising intelligibility – in other words NAL-NL1 aims to make all frequency elements of speech equally loud, along with maximal speech intelligibility. This strategy therefore has a loudness equalisation rationale. A unique aspect is that this strategy takes the impact of high sensation levels and the degree of hearing loss with regard to speech recognition into account (NAL-NL1 assumes that effective audibility decreases with increased degree of hearing loss). This results in less prescribed gain in regions of severe hearing loss than would be expected if audibility alone were considered.

Thus 2 features characterise the NAL-NL1 method for compression hearing aids:

1. Equalising, rather than normalising the loudness of speech, meaning that it tries to make all speech frequency bands contribute equally towards the overall loudness (audibility) of speech
2. Providing less gain for frequencies where hearing loss is worse and more gain where hearing is best.

NAL-NL1 also allows the user to enter the patient's date of birth to include age-appropriate correction factors or to enter these data directly. It can therefore be used on the paediatric population (although DSL I/O remains the fitting formula of choice for this age group***). The clinician enters the audiometric and hearing aid data into the fitting software on the computer and does not need to calculate gain manually***.

More information on NAL-NL1 can be obtained from: https://nal.gov.au/

Independent Hearing Aid Fitting Forum (IHAFF)

The IHAFF protocol assumes that if an appropriate hearing aid operates to restore the sensation of standard loudness perception over a wide bandwidth, the wearer of the hearing aid will have a good opportunity to achieve maximum speech recognition ability. The primary goals of the IHAFF protocol are to provide for amplification so that soft speech is perceived as soft; regular conversational level speech is perceived as comfortable, and loud speech and sounds are loud but not uncomfortable. To facilitate these goals, the IHAFF group has recommended the use of software-assisted loudness judgment measures, a selection of specific electroacoustic characteristics of hearing aids, and a self-assessment questionnaire that is useful before and after the fitting.

The rationale behind the circuit selection process is based on the loudness growth information, obtained by using the Contour Test that involves the use of warble tones presented to the patient at a minimum of two frequencies, typically at 500Hz and 3000Hz. The patient judges the loudness on a scale of seven categories of loudness. At the heart of the IHAFF procedure is the software "Visualization of Input/Output Locator Algorithm" (VIOLA), which assists with management of the variables involved in hearing aid circuit selection. It calculates the relationship between overall speech input levels for soft, average, and loud speech at the hearing aid microphone and the user's loudness judgments for warble tones.

More information on IHAFF can be obtained from: http://europepmc.org/articles/PMC4172239

FIG6 Procedure

This is a computerised loudness-based fitting formula designed to accommodate different types of hearing loss. The name is derived from the loudness-growth concept. In its current form it uses a spreadsheet approach to estimate the level-dependent gain and frequency responses of non-linear hearing aids. Since these aids can change their gain and frequency responses depending upon the input level, the FIG6 can be utilised to calculate gain and frequency response for low-level, moderate-level, and high-level sounds.

New developments in amplification – over-the-counter (OTC) hearing aids, self-fitting hearing aids and personal sound amplifiers

Recent developments in amplification have included many options to make treatment of hearing loss more easily accessible and affordable. These have included over-the-counter hearing aids, self-fitting hearing aids and personal sound amplification devices.

Over the counter (OTC) hearing aids

A recent randomised double-blind placebo-controlled clinical trial[3] reported that adults who were provided with hearing aids in a consumer-decided over-the-counter (OTC) model (consumers choose their own pre-programmed hearing aids) only had slightly poorer outcomes (55% overall satisfaction) as compared to for those fitted and counselled according to an "Audiology best practices model" (81%). They concluded that efficacious OTC models might increase accessibility and affordability of hearing aids for millions of older people. Purchase price had no effects on outcomes. However, it is important to note that all participants in this study had small amounts of hearing loss and underwent audiological assessment prior to the OTC trial to ensure that they were suitable candidates.

Unfortunately, OTC hearing aids are sold in many countries without any involvement of hearing care professionals and to patients irrespective of the type or amount of hearing loss. As stated in a comment to the Larry Humes' article [4], our overall goal should be better access and better health and hearing outcomes for everyone, not improved access at the expense of poorer outcomes.

Self-fitting hearing aids (SFHAs)

SFHAs are intended to be housed in a BTE hearing aid and fitted entirely by the wearer [5]. The concept is that no audiologist or hearing health provider needs to be engaged and no consumer support needed. It is not a new concept, as the concept of SFHAs was already patented in 1984.

The greatest obstacle is to obtain accurate hearing thresholds without an audiological assessment, and that the hearing aid should calculate and program itself. To utilise the hearing aid to determine hearing thresholds has so far had limited success.

None of the present SFHAs is considered self-contained as they require access to other hardware such as a proprietary interface, computer, smartphone, or tablet for manipulation. Assistance with the self-fitting process and on-going use of SFHAs is still recommended.

However, the concept appears feasible and in underserved areas of the world, representing the majority of those with disabling hearing loss, these types of devices may offer real solutions in the light of shortages of hearing health personnel[5]. Affordability and sustainable delivery systems remain the major challenges for SFHAs in developing countries.

In a recent review article of SFHAs by Keidser and Convery in 2016 [6] the authors state that SFHAs and self-manageable hearing applications (apps) might be an option, although they are so far accessible mainly through an unregulated, direct-to-consumers market and unsupported by evidence-based data. Future predictions include a growth in self-fitting products, with most future SFHAs consisting of earpieces that connect wirelessly with a smartphone and providers assisting through a telehealth infrastructure, and the integration of SFHAs into the traditional hearing health-care model.

Personal sound amplification product (PSAP)

Unlike hearing aids that require accurate measurement of an individual´s actual hearing loss, PSAPs are simply defined by the US FDA as amplifiers for "non-hearing impaired" consumers. They have been commercially available for many years. PSAPs are designed to accentuate sounds in specific listening environments and not to compensate for any hearing impairment. They do not depend on measuring the user´s hearing loss, but some advertisements claim that they could be advantageous for those who have hearing problems. Such advertising can only confuse consumers, and hearing-impaired individuals should avoid buying them and rather have a conventional hearing assessment done.

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