The Virtue of Simplicity in Hearing Aid Applications

By Christopher Schweitzer, PhD

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Einstein is reported to have said, "everything should be as simple as possible...but no simpler." The human auditory system is tremendously complex and a continuing source of justified admiration and wonderment. Nonlinear at multiple stages of signal management, brilliantly alert to manage speech-related sounds differentially from all other sounds, and highly sensitive to inter-ear differences in order to represent the panorama of acoustic events in space. The auditory system is so much more than the mere perception of tones under headphones. Not surprisingly, as computer chip capacities have expanded and power requirements have shrunk for such computation, hearing aid technology has moved increasingly toward new levels of complexity in recent years. The attempted remedies of hearing problems have looked to branches of computational acoustics that seek to identify the auditory scene and learn about an individual's "auditory ecology." Software engineering and the rigors of laboratory psychoacoustics have been joined in insightful and computationally-intensive efforts at bio-mimicry. The goal is to make hearing aids more and more like the human instrument. "What would nature (or natural hearing) do?" becomes the question that sets the agenda for the evolution of hearing devices.

While these technical accomplishments are laudable for their elegance and algorithmic cleverness, it seems worthwhile to keep the admonition of Einstein's comment on simplicity ever near. For as is no doubt true for advancements of all types, it's entirely possible that excesses will occur, and adjustments back to the mean will be necessary. For hearing aid clinicians, the expanding *complexification* of hearing aids has an assortment of nontrivial consequences. The vast array of potential parameter adjustments including multiple gain handles by frequency and level with inevitable effects on compression, AGC time constant choices, assorted directional property adjustments, expansion, noise reduction properties, feedback options, and more can challenge the typical hearing professional to no small extent. It is often left to the manufacturer's software engineer to apply their best understanding of psychoacoustics and hearing impairment to configure the device to factory proposals. But that engineer, unlike the fitting clinician, is vastly removed from the personal experience of the hearing aid user, and every experienced hearing aid professional knows that the *type of person* is often as crucial an element in success as the details of the hearing loss. That's why the personal and professional properties of the fitter are often as important as even the most brilliantly designed hearing aid system.

The personality attributes of engaged empathy and experience are vital, but also is a deep understanding of fundamental premises—*what are the acoustical properties of the desired speech signal? How should that signal be altered to maximize meaningful speech for this listener whose ears are damaged? What are the tradeoffs of fast (or slow) automatic gain control and the perception of both speech cues and environmental distractions?*

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It is argued that it is necessary to greet the growing technical complexities of hearing aids with some crucial balancing simplicity—a focused mastery of the first principles. Hearing instrument professionals are engaged in an adventure in pursuit of finding the Best Amplification Pattern (BAP) for the individual consumer that yields high satisfaction. Some premises related to the provision of BAP follow.

MCCLL Relates to Basic Gain Requirements

On the edge of almost too simple is the tenet that if one knows the Most Comfortable Level (MCL), actually a better term might be the MCCLL (Most Comfortably Clear Listening Level), then the required gain is fairly easily known. The typical audiometric MCCLL can be obtained by adjusting the hearing level of the audiometer during live voice presentation of connected discourse. Simple conversational dialogue informs the patient that it's important to know where he or she would set the level of the clinician's voice if a big knob were available to adjust. With a bit of bracketing, most patients have little trouble in helping the examiner converge around the center point of the listener's preferred listening level. It's noteworthy to realize that the audiometer is typically delivering the signal through an entirely *linear* system (no AGC) of amplification and the spectrum is flat across frequency (unless a hearing aid simulator introduces a low frequency filter). Yet, the otopathologic listener will usually be able to quite reliably report the level for each ear with reasonable precision (Schweitzer and Monroe, 1998) and remark how comfortably the voice sounds.

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The audiometric calibration for most headphones is 19 or 20 dB for the speech signal. An MCL of 70 dB HL is producing an SPL output in the listener's ear canal of approximately 90 dB. The consumer has essentially said, "I hear you at a comfortably clear level when speech is 90 dB spl in my ear canal." Assuming the typical average level for speech to be around 68 dB SPL, it makes a quick and simple case to reach 90 from an input of 68 that the necessary gain required is around 22 to 25 dB. Of course, the actual calibration for most earphones is only 19 dB, and while speech at one meter is often estimated to average around 68 dB SPL, it will, of course, vary with effort and distance. However, the simple premise of a gain estimate based on the MCCLL works fairly well in most cases. Allowances for some binaural summation and other variables can contribute to 3 dB or so of additional variation, but it is often surprising how some assumptions, such as what models can reach the patient's hearing loss, can be altered based on this simple examination using meaningful speech. We have seen many successful fittings with CIC type hearing aids when standard charts of fitting range based on the pure-tone audiogram suggested BTE or full shell ITE style were required. While this simple method can provide a quick way of determining the possibility of various classes of hearing aids, perhaps more importantly, it engages the fitter more directly in the amplification design with an emphasis on the speech signal. That has deep consequences on the skills of the professional.

To summarize, the rule can be expressed simply:

Gain = MCL + 20 - 65

Example: Headphone MCL = 72 dB HL; add 20 to convert to SPL = 92
Subtract 65 (SPL for average speech input level—the 'target' signal)
Basic Gain for speech required: approximately 27 dB

The Three Seductions

The uniquely organized auditory system that operates in each individual hearing aid wearer will require a BAP that is obtained interactively between the clinician and the patient. It's somewhat regrettable that the term "fine tune" has the connotation of something trivial or small, because an argument could easily be made that those small adjustments are anything but trivial. In fact, they are critical skilled modifications, vital to the success of the fitting. Clearly, close interactive contact with the hearing aid wearer is integral to determining whether a two or three dB change in the slope of the frequency response results in the patient reporting "Ahh, much clearer" or "Yikes, too sharp!" The typical digital fitting software comes with an array of "canned" fixes for various complaints, but the application of such proposals without a sensitivity to the range of human perceptual responses and a strong foundation in the underlying principles of amplification is superficial at best.

Of course, good understanding of amplification principles is essential for the professional responsible for the in-office design of the amplification pattern. But there are commonly observed seductions, which often lead the fitter away from an approximation of BAP in the fine-tune stage. We'll name three, but certainly others come into play in some cases.

1. **The seduction to increase the compression.** Some hearing health professionals tend to obsess over the compression ratio. Often they may be inclined to move the fitting toward higher values with the assumption it is justified by the evidence of cochlear damage. In fact, less compression may be better in a high percentage of cases. Many successful fitters have observed that more linear amplitude dynamics may be a preferred signal processing choice. Of course, much discussion has transpired in the literature over the tradeoff of attempting to position the range of speech sounds within the restricted audibility area of the listener and the consequences of

altering the envelope cues. Certainly, the time constants have received expanded attention in recent years and the application of compression in current amplification schemes may be less problematic than some older versions. Nevertheless, the *rule of simplicity* argues to back off on the compression pedal and see if the result is satisfactory. Recall that the speech audiometer operates with a linear amplification scheme.

2. **The seduction to assume increasingly complex algorithms *solve* the acoustical environment problems.** A great deal of elegant and inspired signal processing work has been directed toward the manipulation of the amplification in response to changing acoustical environments. Some of these bear such compelling descriptors as artificial intelligence and dynamic scene analysis. To their credit these approaches often show impressive and robust electro-acoustic operating features. But they should be applied with the clinician's full awareness of some of the potential consequences and assumptions of application.

   Consider first that rarely are these features respectful of the natural binaural system where the two ears are integrally connected. Rather, they are applied independently to each of the two ears in the vast majority of products. Changes that may be implemented on one side of the head may lag or never align with those on the opposite side because of head shadow or local diffraction. This may potentially interfere with the listener's complex neuro-auditory processing which attempts to make its own decisions about acoustical conditions. In some instances, depending on the time constants, clients have been observed to have near vertiginous symptoms as certain noise and subsequent processing moved from one side of the head to the other. Some early versions of these scene analysis operations were clearly troublesome to critical listeners as they introduced audible artifacts and distractions. That is not to say that these approaches are without merit, but clearly there lurks the prospect of complexification with questionable net benefit. As newer iterations of these approaches are introduced, and more inter-ear communications are enabled, improvements might be expected. However, it is not uncommon to see patients who seem to move the tuning adjustment trajectory toward higher satisfaction by having the clinician minimize or disable some or all of the complex automatic features which clearly at minimum have added cost to the product. BAP clearly does not always derive from higher complexity and it borders on engineering arrogance to assume that it does.

3. **The seduction to mirror the slope of the threshold audiogram.** This one is fundamental, yet will beguile even the most experienced clinicians. How easy is it to forget that nothing about the pure-tone audiogram was ever originally intended to determine the best amplification pattern. Rather it evolved as primarily a means of establishing diagnostic description of a hearing pattern on each ear separately, and to assist in the determination of medical treatment options. From the barely audible, monaurally obtained, nonmeaningful narrowband signals presented via relatively low impedance headphones to the right alteration of the acoustic mass at the tympanic membrane, the path to amplification satisfaction is a tortured one, with unpredictable curves and bumps, and nonlinearities. There are many implications in that preceding sentence that all deserve elaboration that space does not permit. The notion that a "prescription" can be supplied for optimal listening based on the threshold map, as in the treatment of a thyroid imbalance based on blood chemistry, is inherently misleading.

   In the constraints of this brief article, let it at least be argued that this seduction often leads to excesses in the high-frequency gain and insufficiencies in the low-frequency amplification. A simple loudness matching of sounds across frequency for mid to high level listening levels will generally point toward a flatter slope of amplification than the threshold audiogram proposes for a high proportion of sensorineural sloping losses.

The Four Agreements

In contrast, to the three seductions, it's often pertinent and practical to keep in mind a generalized list of agreements that relate to the transaction between the professional dispenser and the consumer. Some may think of these as goals, but it seems to promote greater interactive potency to think of them as agreements.

1. **We will not worsen your hearing stress.** It's remarkable how often a fitting results in *reduced* hearing at some frequencies compared to unaided conditions. Occlusion and complaints of the consumer's own voice are, of course, common and have received much attention. But, reductions in low-frequency sensitivity, directionality, and tolerance of loud sounds are all too frequent consequences of hearing aid fittings as well. Some of these can naturally be attributed to the constraints of high impedance and low power devices that characterize hearing aids generally. It is not facetious or overly simplistic to keep this agreement near and dear. Essential to staying true to this agreement is a fierce determination to listen with cultivated sensitivity to the comments of the patient. Worsening the hearing stress can result from the provision of too much amplification of undesired sounds as from potential losses of sensitivity in regions that hearing aids do not perform well, such as the extreme low frequencies. In either case, it's the premise of the agreement that matters and must be given appropriate attention.

2. **We will make soft, *meaningful* sounds less difficult to hear.** The brain treats sounds that it assumes to be speech differently than other sounds of similar pitch, duration, and loudness. Clearly, few people seek potential hearing help from amplification for the purposive of hearing nonmeaningful sounds better. It is unlikely that other nonmeaningful soft sounds will be entirely excluded from the hearing aided listener's auditory experience with optimized amplification. It is most likely that the majority of measurable soft sounds in a person's daily life are non-speech and, generally, not particularly

symbolic (such as a turn signal). But once again, the purpose of the agreement is to formulate the *intention* of the fitting. Note also, the agreement does not say the outcome will be to hear all soft, meaningful sounds. Rather it will be *less difficult*. Hence, the expectations of the hearing aid consumer are more properly formed.

The benefit of expressing several such agreements is to...clarify the objectives of the fitting in the simplest terms as possible.

3. **We will make average conversational speech comfortably clear.** This is, of course, a foremost goal of most fittings. But like the others, it seems to assist in the fitting process to have it specifically articulated as one of the agreements. It is the power of intention that comes into play here. But it also forces the clinician to think at a fundamental level about the acoustics of speech. What are the properties of average conversational speech? How much gain and amplification pattern adjustment is required to move that target into the comfort zone of the listener presently in my care? How can the relation of foreground and background sounds be improved? These questions are the basis for more considerable elaboration as they relate to the fundamental premises of amplification, but whether these agreements are explicitly shared with the consumer or not, they provide a framework for operational adjustments throughout the fitting process.
4. **We will make loud, nonmeaningful sounds tolerable.** Making the elemental distinction between sounds that are meaningful versus other loud acoustic events is an intrinsic component of this agreement. The control of the maximum output SPL of programmable hearing aids makes it generally possible to level out the noisy world's excesses to an essentially negative gain. How much of this agreement should be managed by automatic output control versus control of the user is something that must be worked out on a case by case basis. Clearly, there may be cases where aggressive output reduction may have undesirable consequences, such as when applied to music, or possibly on the telephone. However, the point here is to formulate an agreement which structures the intention of the fitting process.

These four agreements are simply sample suggestions. The benefit of expressing several such agreements is to force the clinician, and the consumer, to clarify the objectives of the fitting in the simplest terms as possible. Kahlil Gibran made the comment that the obvious is never seen until someone expresses it simply. In a world of increasing complexification the comment seems remarkably relevant.

Finally, a recent laboratory experience illustrates rather keenly the importance of distilling complex issues down to simple realities. It is well known that open-ear products are the most recent rapid growth product category in the industry. Likewise it is commonly understood that directional microphone systems can improve hearing in noise by providing a spatial advantage of the sound region in front of the user. But what if the two amplification systems are combined? How are the relative acoustics to the tympanic membrane when sounds strike the head from various regions in space? And does an open-ear fitting, with or without a directional microphone array, have the level of processing advantage observable in a closed fitting?

The performance of 12 samples of open type hearing aids on an artificial head and ear were examined. Probe microphone measures of the output of speech noise were taken from directly in front of the head and from the rear shoulder region of the aided side (0° versus 135° azimuth). In the open ear, with no hearing aid, the natural acoustics actually favor the non-frontal region by 6 to 8 dB across much of the hearing aid operating range. It shouldn't be surprising that many of the measurements with open couplings showed that, in the aided condition, a negative number (0° minus 135°) was observed. Even with amplification, more sound pressure was reaching the eardrum in many cases from the rear and side than from the front. (All were fit to a standard appropriate audiogram for open fittings and noise reduction was disabled for the speech noise signal.) Figure 1 shows the average data taken from multiple frequency points. The values are the average differences in dB for sounds presented directly from the front minus from the rear and back at a controlled distance. Within the data are some samples which did not include a directional option, but in only a few exceptions can a directional benefit be expected. The range of these scores is considerable (over 18 dB). Again, all these hearing aids were given a target fitting based on the same audiogram. Clearly, some models do provide a forward benefit for this type of test, which is of some comfort. It is the clinician's credibility that suffers most when product expectations are misaligned with technical realities.

Open H. Aid Sample:	**ab**	**cc**	**dd**	**ff**	**hh**	**mm**	**qq**	**ss**	**tt**	**ww**	**yy**
Avg O-D (8 freq):	**–8.1**	**–4.9**	**8.5**	**3.5**	**2.8**	**–7.6**	**–1.4**	**–0.1**	**–10**	**4.3**	**0.4**

Figure 1

What's most troubling about these findings is that rarely do clinicians seem to appreciate the natural consequence of refraction and diffraction of sound around the human head, and that highest sound pressures are not from directly in front as directional hearing aids tend to imply, albeit not by intentional deceit. Moreover, while the loudest perceived sounds are at a forward angle between 30° and 45°, sounds from the region over the back shoulder are also commonly louder than those arriving from in front of the listener at the same source level. This has clear implications for counseling and progressing in the fitting process toward a BAP. This small, unpublished study illustrates the kind of fundamental premise, ripe with simplicity, that can well serve every clinician in counseling and implementing hearing aid rehabilitation. To take advantage of the ever-expanding range of complex technical operations available in digital signal processing hearing aids, a thorough grounding in the basic relevant sciences is essential for the hearing professional, regardless of formal training. *THP*

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1. Which of these is not a complex aspect of modern digital hearing aids?
a. feedback cancellation
b. adjustable expansion
c. MPO adjustment
d. variable noise reduction

2. The author argues that often as important as the type of hearing loss is the:
a. type of person
b. density of the mastoid bone
c. type of previous hearing aid
d. drug or medication types

3. BAP is used as an abbreviation for:
a. Better Acoustic Program
b. Benign Acoustic Pathology
c. Best Amplification Pattern
d. B-class Amplifier Performance

4. A calculation of the Most Comfortably Clear Listening Level (MCCLL) could be related to average speech inputs which might be estimated to be around:
a. 75–78 dB SPL
b. 65–68 dB SPL
c. 55–58 dB SPL
d. 72–75 dB HL

5. The amplification delivered by an audiometer's speech channel is generally best considered:
a. highly nonlinear
b. TILL type amplification
c. multi-channel AGC
d. linear

6. Once the MCCLL on the audiometer is determined in HL, a conversion to Sound Pressure Level would require an adjustment of:
a. adding 30 dB
b. subtracting 20 dB
c. adding 20 dB
d. subtracting 14 dB

7. The author argues that in many problem cases it may be a "Seduction" worth avoiding to:
a. increase the compression ratio
b. flatten the frequency response
c. decrease the compression ratio
d. reduce the dynamic range

8. Which of these is not a suggested "Agreement?"
a. to make loud, non-meaningful sound tolerable
b. to make soft meaningful sound easier to hear
c. to make average speech comfortably clear
d. to make ambient sounds inaudible

9. The temptation to have the slope of a hearing aid response follow the threshold audiogram is minimally likely to result in:
a. too much gain in the middle frequencies
b. insufficient low frequency gain and excessive gain in the high frequencies
c. barely audible sounds above 1500 Hz
d. disturbing transient distortion

10. Which of these is not likely to be associated with high amounts of *complexification* in signal processing?
a. auditory scene analysis
b. automatic noise reduction
c. user-adjustable volume control
d. adaptive feedback management

THE VIRTUE OF SIMPLICITY IN HEARING AID APPLICATIONS—JULY/AUGUST 2006—DEADLINE: AUGUST 2007

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4.	a	b	c	d	9.	a	b	c	d
5.	a	b	c	d	10.	a	b	c	d