Arguably the single most important component of any hearing aid fitting software is its implementation of a “best fit” — an algorithm that automatically adjusts the hearing aid gain to match prescriptive targets based on hearing loss. The prescription, or fitting rationale, will ultimately play a large role in the patient’s acceptance or rejection of amplification. First impressions count! The audiologist may well be able to make slight adjustments if the prescription isn’t just right, but for the patient who rejects amplification after the first fit, the opportunity for fine-tuning is lost.

But what defines “just right?” What should be the criterion for determining a good first fit?

- Minimizing initial rejection?
- Maximizing speech intelligibility?
- Maximizing usage of residual dynamic range?
- Maximizing patient comfort?
- Maximizing sound quality?
- Maximizing patient satisfaction?

Most fitting rationales attempt to optimize some combination of the above goals. Optimization is required because often the goals are in opposition to one another. For example, the patient might desire very little gain for maximum comfort, but require a lot of gain for maximum intelligibility. The more factors included in the optimization, the more complex the rationale becomes.

e-STAT®, Starkey Hearing Technologies’ proprietary fitting rationale, started out by leveraging the loudness and intelligibility optimization already done by the NAL (Nonlinear fitting formula), and further customized it to suit the company’s specific needs. This article attempts to explain e-STAT: why it started, how it has evolved, and why it will continue to change as we improve our hearing aids and gather more statistics on user trends and patient preferences.

History

Fitting rationales have been in use for many years (see Lybarger, 1978, for a review of early methods). The earliest fitting rationales were developed for linear amplification (since this was the only amplification in use at the time). The start of the modern era of prescriptive fitting could be the introduction of Prescription Of Gain and Output (POGO) (McCandless & Lyregaard, 1983). After POGO, the Australian National Acoustics Laboratories (NAL) method became quite popular for adults, and the Desired Sensation Level method became commonly used with children (Byrne & Dillon, 1986; Seewald, Ross, & Spiro, 1985).

As compressive amplification became increasingly popular in the 1990s, new fitting rationales were developed to specify targets for multiple input levels. FIG6 (Killion, 1994) ushered in the compressive prescription era, but it was quickly followed by DSL[i/o] (Cornelisse, Seewald, & Jamieson, 1995), the Independent Hearing Aid...
Fitting Forum (IHAFF) protocol (Valente & Van Vliet, 1997), and the Cambridge formulas (Moore, Alcántara, & Marriage, 2001) to name just a few. Currently the most popular nonlinear fitting formula is NAL-NL1 (Byrne et al., 2001).

At the time of this writing, there are second-generation versions of several formulas, such as NAL (NAL-NL2) and DSL (DSL v5.0).

Generic fitting rationales
Initially, fitting rationales were developed by researchers who were independent of manufacturers. These fitting rationales can be said to be “generic” in the sense that they are not designed for a specific hearing aid or compression architecture. Generic rationales have both advantages and disadvantages.

Advantages
One distinct advantage of generic fitting rationales is that they can and have been validated with large populations that would be practically impossible for manufacturers to study. Independent researchers (especially authors of competing rationales) are interested in validating manufacturer-independent rationales to further the body of knowledge about their prescriptions.

Many authors of generic fitting rationales have been very forthright in publishing the workings behind their algorithms (although some like DSL v5.0 and NAL-NL2 have chosen to keep the details of the calculation confidential). All have detailed the goals behind their rationale, but these goals are different for each. This has fueled the discussion about which rationale is “best.”

Disadvantages
Generic fitting rationales are not without their disadvantages. There is very little financial incentive for the development of generic fitting rationales. No one gets rich by publishing fitting rationales or software! In addition, generic fitting rationales need to remain stable so that they can be validated by others and incorporated into fitting software and third-party products such as real-ear measurement systems. For these reasons and others, generic rationales are not frequently updated. For example, NAL-NL2 came more than 10 years after NAL-NL1. The net effect is that generic fitting rationales are always behind in terms of incorporating the latest research.

An additional weakness that arises from the very nature of generic rationales is that they cannot account for proprietary signal processing. They must be designed around the least common denominator of generic signal processing. As rationales become more sophisticated and deal with second-order effects like dynamics and adaptive feature interactions, the details of the signal processing are likely to be the source of fitting rationale optimizations.

e-STAT
e-STAT is a proprietary fitting rationale, but it uses NAL-NL1 and NAL-RP as its foundation, with several modifications that are described in more detail in this section.

Initial Version — The first version of e-STAT was developed in response to customer reports of “too much mid-frequency compression.” Prior to e-STAT, the default fitting rationale was NAL-NL1* (NAL-NL1 with some reduction of high-frequency gain). A combination of NAL-NL1 and NAL-RP fitting rationales was used to reduce compression without significantly changing gain for moderate level speech.

Modifications were made to the targets based on the style of the hearing aid (see Figure 1).
Improved Modeling — The next step in the progression of the e-STAT fitting rationale was to improve modeling of the in situ hearing aid response. Although it might not be intuitively obvious, having an accurate model allows separation of model (hearing aid simulation) and target components. In turn, this allowed improvement of the target, independent of the hearing aid style.

Changes to compression — Simultaneously, Starkey Hearing Technologies developed a new, faster-acting compression scheme. The change in the dynamic behavior of the compressor was significant enough that loudness was affected and the e-STAT targets needed to change to compensate for it. The change was small and straightforward but is an example of how targets and hearing aid-specific processing cannot be treated independently.

Patient Preferences — e-STAT was further modified to incorporate the results of a research study in which subjects’ preferred gain settings were compared to their initial settings. The results were pooled across styles and analyzed for evidence of correlations that might account for variability in preferred gain. By and large, the preferred gain settings showed a fairly large spread, but were evenly distributed around the starting point. There was a weak correlation between preferred gain and the initial gain at some frequencies and some input levels.

For example, Figure 2 shows that at 4 kHz for a soft input, there is a weak trend towards a slight gain decrease when the initial target is low and a slight gain increase needed when the initial target is high. Correlations at each frequency and input level were calculated and have been incorporated into the e-STAT formula. Accounting algorithmically even for weak correlations can help to make the first fit successful for more patients. Furthermore, the same algorithm can be easily updated and expanded upon in the future when more trends are discovered.
What’s coming

Minimizing the vent-hearing aid interaction —
More patient data will be analyzed during an upcoming study in which new Starkey Hearing Technologies’ products are being evaluated. e-STAT targets for the study have been updated; this time to improve sound quality for vented fittings. In a typical vented hearing aid fitting, the sound follows two parallel paths: the amplified path and the path through the vent (i.e., direct path). These two sounds mix together in the ear canal, but they are out of sync. The amplified path is delayed because of the digital processing (i.e., throughput delay), while the direct path is not. This delay causes a rapidly changing phase response with frequency, which in turn adds constructively or destructively with the direct path. When the signals are of comparable magnitude, the result is a series of peaks and valleys across frequency, also known as a “comb filter” (see Figure 3). Although “comb filter” effects cannot be completely avoided, they can be minimized by modification of the target response.

Conclusion:
The Future of e-STAT
To remain competitive, any developer of hearing aid technology must incorporate the very latest in prescriptive research and tailor the prescription for its own brand of signal processing. Proprietary fitting formulas have a clear advantage in this respect. e-STAT, Starkey Hearing Technologies’ proprietary formula, will continue to evolve to keep pace with internal research findings and new, company-specific signal processing strategies. External research will also feed into e-STAT’s evidence base, as more ways in which the hearing aid fitting can be improved are reported. For example, we now know that gender plays a role in preferred listening levels, likely due to different physical characteristics of the ear (Keidser, 2008). We also know that audibility contributes less and less to intelligibility as the hearing loss progresses, especially in the high frequencies (Ching et al., 2001). Effects such as these can be integrated in the formula and released in e-STAT updates as frequently as needed.

Because we are operating at the limits of knowledge of hearing and hearing loss, we can’t rely on theory alone — we must also act on empirical data. This is the fundamental aspect of e-STAT: incorporating the latest data from every source into optimizing the prescription. The e-STAT fitting formula is Starkey Hearing Technologies’ commitment to ensuring patient success and spontaneous acceptance of hearing aids.

Acknowledgements

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