

Annoyance and Hearing Aids

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Abstract: Listening to amplified speech through hearing aids all day can lead to fatigue and annoyance. Although they may not violate UnComfortable Loudness Levels (UCL), certain sounds may not be pleasant to listen to for an extended period of time. Our current fitting and fine-tuning guidelines do not typically address this dimension of listener experience. A variety of options exist to minimize difficulties for the hearing aid wearer reporting problems with annoyance. Future signal processing techniques will likely address this problem even more effectively.

An Untapped Dimension

In general, the field of Audiology has viewed the fitting of a hearing aid as a psychoacoustic challenge: how to amplify sounds optimally into the patient's remaining dynamic range. Over the past ten years, a significant amount of attention has been placed on understanding and assessing the patient's loudness perception, especially the UCL. In general, it is assumed that as long as amplified sound is kept below the patient's UCL, the sound will be acceptable to the patient. In addition, we know the static spectral shape of the hearing aid response will have a secondary effect on perception, typically in the domain of sound quality (too many high frequencies may sound "tinny", too many low frequencies may sound "boomy").

What needs to be remembered is that although the fitting of amplification may be viewed by the audiologist as a psychoacoustic challenge, the daily wearing of amplification by the patient is an even greater challenge and encompasses a vast perceptual experience. All listeners, whether normally hearing or hearing impaired, are susceptible to fatigue and annoyance when listening to sounds of the modern world all day long. As explained by Fidell & Pearsons (1998):

"Annoyance is not an immediate sensation such as loudness, governed solely by characteristics of acoustic signals, nor is it an overt behavior such as a complaint. Annoyance is instead an attitude with both acoustic and non-acoustic determinants."

When evaluated using methodology that is sensitive to the long-term nature of listening, it has been shown that a listener's reaction to incoming sound can be affected by acoustic factors

such as level and spectral composition, on-going cognitive demands, other sensory input, personality, and even cognitive "suggestion" (Baird, Harder, & Preis, 1997; Kjelberg et al., 1996).

Even parameters we believe we understand well, such as loudness discomfort, can be complicated by non-auditory factors. Fillion and Margolis (1992) studied the relationship between clinically measured UCLs and real-world occurrence of loudness discomfort. A group of seven subjects spent time in a loud night club and rated the percentage of time they felt their UCL was violated. Simultaneously, the actual sound levels in that setting were monitored. Based on the subject's clinically measured UCLs, they should have reported UCL violations between 65 and 95% of the time. However, five of the seven subjects reported violations less than 20% of the time and only one subject reported UCL violations as frequent as was predicted by the clinical assessment. Therefore, it is likely that there is more to UCL than the measurements made in a soundbooth. Specifically, being in a socially pleasant situation in which loud sounds are expected can affect the listener's criteria of what is too loud.

Getting the Most from the Auditory System

One of the primary goals of hearing aid amplification is to maximize the patient's remaining dynamic range. In practice, this goal is achieved by presenting speech and other interesting acoustic signals within comfortable hearing levels that are audible to the patient. The downside of this approach is the risk of making too much sound available for too long for the patient. Unfortunately, due to the nature of hearing loss and hearing aid amplification, hearing impaired listeners are forced to listen to amplification at levels higher than those experienced by normally hearing listeners. Although these sounds are below the patient's UCL and certainly not intense enough to cause acoustic trauma, these sounds, when present for an extended period of time, may still be bothersome. Therefore, amplified sound should not be viewed solely as instantaneous levels compared to the patient's dynamic range. Indeed, an additional perspective may well be warranted, whereby we view amplified sound as a "dose", based on sound pressure levels as a function of exposure time.

The gradual onset of hearing impairment further complicates the situation. The typical adult patient loses their hearing slowly, over the course of many years. Compared to the person with normal hearing, the unamplified hearing-impaired listener actually hears significantly less. However, when hearing aids are fit and new sounds are presented to the patient, we tend to be

concerned with ensuring audibility. However, from the patient's perspective, these new sounds doses may simply be too much to handle. It is a clinical reality that some patients reject amplification for vaguely stated "loudness" issues, although the amplified levels can be verified via real-ear testing to be below measured UCLs.

Solutions

The optimal solution would be intelligent signal processing techniques that can differentiate between wanted, important input and unnecessary, unwanted input. We have yet to create a truly advanced artificial system that can accomplish this goal. In the mean time, there are a variety of strategies that can be employed in current generation amplification to help address the annoyance issue.

Regarding annoyance, there are two important things to remember. First, if annoyance is truly the problem, the complaint expressed by the patient may be rather vague. Vague complaints may be expressed as a concern about loudness which cannot be alleviated with changes in output level, or, the concern may take the form of a sound quality complaint that cannot be addressed through changes in frequency shaping or compression. Secondly, if the issue is annoyance, the audiologist will be unlikely to immediately confirm that fine tuning changes have solved the problem. Since annoyance is better viewed as a problem of sound dose, it is essentially impossible to confirm the in-office change has solved the problem until the patient has had the opportunity to use the device for an extended period of time.

Adaptation Management:

As indicated earlier, the first time user of amplification is a likely candidate to experience annoyance and fatigue. Adaptation management is one technique to assist the new user in getting used to the experience of hearing amplified sound. With traditional, linear amplification, the new user had the opportunity to self-manage the adaptation process via the volume control. If the newly amplified sound was "too much", the gain of the device could be turned down. However, with the widespread use of fully automatic devices, the user has no ability to make user-controlled changes. Even if gain and compression settings were carefully selected and verified based on the patient's loudness judgments, the levels selected may have been too great for long-term listening.

Oticon Adaptation Management:

At Oticon, we have included a software tool called the Adaptation Manager in our fully automatic devices to assist the user in getting used to the new device. The adaptation process is modeled in three steps. Most new patients can work from step 1 to step 3 during the first few weeks of hearing aid use.

The first step is normally used as the starting point of patients who have never used amplification before. The second step has a specified amount of one or more of the following: (1) reduction in gain, (2) increase in compression, (3) narrowing of the frequency response and (4) reduction in compressor attack times. The second step is a good place for previous users of amplification to start with new products if/when the fully prescribed response seems to be a little too "much" in one way or another. The third step is the fully prescribed setting for the particular fitting rationale of choice.

Adaptation Management does not provide a solution for the patient who feels that on-going levels of amplification are too much once the adjustment period is over. However, it has proven to be an effective strategy to reduce the likelihood of immediate rejection of amplification. Gain Reductions:

The most straightforward solution for annoyance with amplification is to simply turn down the gain. Reducing the gain will almost certainly effectively address the problem. However, this solution also compromises the audiologic benefit of the devices. For traditional linear instruments with a volume control, this strategy can be implemented by the user on a temporary, as-needed basis. However, for programmable, fully automatic devices, such a strategy can only be implemented by the audiologist and would be operational in the device full time.

WDRC Processing:

Compared to traditional linear amplification, the use of Wide Dynamic Range Compression (WDRC) is usually viewed in relation to the ability to improve the audibility of soft inputs. A second, but sometimes overlooked advantage of WDRC processing is that moderate to louder inputs are typically placed at lower signals levels in the user's ear. A common fitting approach is to match the output of a WDRC system to the output levels for linear systems for a 60-65 dB SPL input. Given that this input level is within the compression region for most WDRC systems,

any signal above 65 dB SPL would actually receive less gain than in a comparable linear system.

In our modern world, it is not uncommon to go throughout our days listening to inputs in the range from 60 to 80 dB SPL (Pearsons, Bennett, & Fidell, 1977; Gatehouse, 1998). The use of WDRC processing would thus simply expose the listener to less of a sound "dose" throughout the course of a normally moderate to noisy day.

Compression Type:

Although the relationships are not clear and predictable on a case by case basis, some patients will receive relief from annoyance by manipulation of the type of compression. In this context, "type of compression" refers to either fast acting, syllabic compression versus slow acting, automatic volume control. This contrast is usually achieved by changes in the release time of the compressors: release times less than 100 ms are considered fast acting and release times greater than 200 ms are referred to as slow acting. Interestingly, the ability of compression type to reduce annoyance can sometimes be achieved by switching from slow acting to fast acting or conversely from fast acting to slow acting. Both remedies are occasionally effective.

Syllabic compression (fast acting) is typified by gain change on a nearly phoneme-to-phoneme basis, meaning there is minimal variation in the spectral level over time. Moving towards a slower release time means there are greater variations between the more intense and less intense phonemes and therefore, less sound is "packed" into the dynamic range. From this point of view, a slower acting system provides a less dense signal to listen to.

Alternatively, slow acting systems are typified by more dramatic moment to moment variation in the amplified signal. Patients, particularly those with reduced dynamic ranges, may find constant swings in signal levels to be bothersome. They may prefer a more stable signal level.

There simply is no data available to clear up this argument. However, it is a reasonable clinical strategy to change from one type of compression to another if the patient reports vague complaints consistent with previously suggested annoyance concerns.

Selective Channel Reductions:

A variation on the previously mentioned strategy of generally reducing gain to minimize annoyance is to reduce gain in particular frequency bands when sound levels rise and the need for full audibility across all frequency regions is not great. Several manufacturers have offered circuitry that, on a channel-by-channel basis, will evaluate amplitude fluctuations of the incoming signal. If the pattern of amplitude fluctuations is similar to that of speech, no gain reductions are applied. However, if the pattern of fluctuation mimics steady-state noise, gain is reduced in that channel. These systems are often touted as "noise reduction" systems, but they do not perform true noise reduction (noise reduction is typically defined as an improvement in the signal-to-noise ratio of the overall signal). Rather, they probably do help under certain noisy conditions by reducing the overall sound level. If the information in a given channel that was reduced was truly not needed, the effect can be expected to generally help/reduce annoyance issues.

Even without sophisticated, dedicated circuitry, most multi-channel channel WDRC systems will likely have a similar effect in real world noisy situations. This effect is particularly noted when the noise is dominated by other people talking. In such a situation, the input signal is likely to be dominated by low frequency energy. The compression system in the lower frequency channels will have the effect of reducing gain as the signal level rises. Given that the amount of information transmitted in the lower frequency is minimal, reduced levels of audibility (and gain) in the low frequencies is a reasonable compromise. If annoyance seems to be an issue with the patient, decreasing gain and/or increasing compression in the lower frequencies may have a beneficial effect.

Manual Mode Switching:

Although the popularity of multiple memory instruments has declined sharply in recent years, one of the advantages of such instruments was that different device characteristics could be set-up for specific listening situations. Within the context of annoyance, it is reasonable to set up one dedicated memory for times in which the patient would rather not hear as much. The limitation to such an approach is that the patient has to manually make such changes. In general, multiple memory devices have been supplanted on the market by fully automatic, single memory devices designed to provide optimal performance in all listening situations. Nearly all fully automatic implementations make use of multi-channel WDRC and, as indicated previously, such a processing approach can help with annoyance concerns.

Interestingly, a new market trend is the inclusion of manually activated directionality. In many of these applications, when the directional microphone is activated, additional low-frequency roll-off is introduced in the core frequency response of the device. These devices offer two potential benefits regarding annoyance. First and foremost, the directional response reduces the effective level of the background noise, yielding an improved signal-to-noise ratio. The improved signal-to-noise ratio will mean less concentration needed to understand the message. Secondly, the low frequency roll-off provides an additional decrease in the overall sound level in situations where the overall sound pressure level was probably higher than desired by the hearing aid wearer.

A Glimpse into the Future: Advanced Signal Analysis

As can be seen, none of the currently available options offer a complete solution to annoyance issues. Most simply rely on signal level reductions. Unfortunately, as indicated earlier, annoyance is more complicated than just high sound levels. Aspects of the temporal and spectral components of the signal will contribute to annoyance as will the concept of dose. Additionally, meaningfulness and desirability of the signal, as well as personality and/or cognitive factors and compression factors may contribute to annoyance.

In the future, hearing aids will incorporate an ever increasing array of intelligent signal processing routines. To a greater and greater degree, the incoming signal will be evaluated and identified. Subsequent signal processing will eventually be based on decisions made concerning not only the physical content of the sound source, but eventually linguistic importance of the incoming signal will be evaluated by the amplification system. At some point in time, such systems will essentially decide what is important for the listener to hear and what is not. Such "gatekeeper" signal analysis will attempt to process only input which is likely relevant and interesting to the listener.

Theoretically, gatekeeper systems could have application beyond hearing impaired listeners. Applications could easily be found in special needs children, learning disabled adults and certainly these technologies could impact the day-to-day lives of normally hearing people with auditory processing disorders (APD).

Another major advantage of a gatekeeper system would be to decrease the cognitive workload

of the listener. Instead of listening to virtually all of the input sounds and cognitively sorting through all of it, these powerful systems will perform a certain amount of pre-processing before the sound reaches the ear, and the brain. Such functionality is sure to reduce the workload of the listener, while decreasing the amount of irrelevant sound made audible, while decreasing dosage, and eventually leading to less annoyance, and a more pleasurable amplified listening experience.

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