Sound Quality Considerations of Hearing Instruments

by Ravi Sockalingam, PhD; Joel Beilin, MScEE; and Douglas L. Beck, AuD

Evidence for the importance of sound quality in hearing aids

Hearing aid manufacturers desire to maintain and increase sound quality through advanced technology and innovation. Recently, spatiality and intelligent binaural processing have become commercially available and have further increased the ability of hearing instruments to achieve high-quality outcomes.

Sound is often characterized by its quality. The perceived quality may determine if we will listen to it and, if so, for how long. It's quite the same when individuals with hearing impairment wear hearing devices for the first time. The quality of amplified sound is likely to be perceived as "different" from the unamplified sound they're accustomed to hearing through compromised auditory systems.

Initial quality perceptions are often used by new hearing instrument wearers to form opinions and make decisions regarding perceived benefit of amplification and may impact the continued use of their hearing instruments.[1] Therefore, the sound quality perceived by the hearing instrument wearer must be maximal.



Ravi Sockalingam, PhD, is senior audiologist, and **Joel Beilin, MScEE**, is director of audiology at Oticon A/S in Smørum, Denmark; **Douglas L. Beck, AuD**, is director of professional relations at Oticon Inc, Somerset, NJ.

Defining sound quality is difficult. Arguably, in the final analysis, "quality" is a subjective measure which may or may not include objective parameters. For example, psychologists may refer to sound quality as a perception, engineers and physicists might define it in terms of replicable physical attributes, musicians might refer to sound quality with respect to timbre and overtones. Audiologists may address sound quality in terms of loudness, background noise, internal instrument noise, bandwidth, total harmonic distortion, etc. However, wearers of hearing instruments define sound quality based on their own terms, their past listening experience, their sound perceptions and preferences.

Amplified and Unamplified Sound Quality

Unamplified sound is typically altered by unintentional factors and variables based on the contents and shape of the local environment (ie, room size, reverberation, background noise, damping materials, loudness, duration, signal-to-noise ratio, etc). As unamplified sound enters the hearing instrument, it is intentionally altered through signal processing and the resultant sound quality is a key consideration for manufacturers. Indeed, a key concern for hearing instrument engineers is that optimal sound quality must be achieved.

Acoustic Transparency

One qualitative measure of sound quality is the concept of "acoustic transparency." Sandlin[2] stated acoustic transparency is achieved when hearing-impaired listeners perceive the sound from the hearing aid as the same (or nearly the same) as the sound heard without the hearing instruments.

For our purposes, we consider acoustic transparency to mean the output of the hearing aid must be "true" to the original sound source while facilitating audibility for speech and other sounds, which the wearer would not hear without hearing aids. In other words, an acoustically transparent hearing aid should deliver the original sound source, while simultaneously compensating for the hearing loss the wearer presents without audible artifacts.

Evaluating Sound Quality

Questionnaires, interviews, and rating scales have been used in controlled laboratory environments and in the real world to investigate sound quality. To date, consensus as to how to evaluate sound quality does not exist.

Dillon et al[3] used six stimuli to compare the sound quality of five advanced hearing instruments. The six stimuli included subject's own voice, a female voice, a male voice, and a male voice in impulse noise. Subjects compared the sound quality of two instruments at a time and rated one instrument as better by indicating "much better, moderately better, or slightly better."

Munro and Lutman[4] and Keidser et al[5] used paired comparisons to evaluate sound quality. Hearing instrument wearers rated two different hearing instruments or two different features of a particular instrument across a range of situations for clarity, comfort (in quiet and in noise), music listening experience, and naturalness. Paired-comparison methods have the inherent potential to minimize subjective influence in sound quality judgments.

Gabrielsson, Schenkman, and Hagerman[6] developed the Judgement of Sound Quality (JSQ) which employs eight dimensions. Seven dimensions relate to various qualities of sound and one relates to the overall impression. The seven sound quality dimensions are softness, brightness, clarity, fullness, nearness, loudness, and spaciousness. Though this scale was developed to assess the performance of loud speakers,[7] it has been used for earphones, earmolds and hearing instruments.[8,9]

Narendran and Humes[10] studied the potential of the JSQ to use sound quality as an outcome measure for a group of elderly hearing aid wearers. The authors concluded the JSQ was potentially a useful measure of hearing aid outcome with particular regard to groups, but was less applicable to individuals with respect to analysis of hearing aid quality.

Looi et al[11] evaluated timbre of different music samples in a group of cochlear implant users using a dichotomous scale along 6 dimensions. Individuals were asked if their listening experience for a particular music piece was unpleasant or pleasant, unnatural or natural, empty or full, tinny or rich, dull or sharp, and rough or smooth.

Scientists at Delta Senselab (Denmark) are developing an evaluation protocol to delineate subtle differences in sound quality between hearing instruments. Investigations are underway to formulate the optimal combination of sound samples, sound quality dimensions, and trained listeners to differentiate hearing instruments based on subjective sound quality judgements in complex listening situations.

Sound Quality and Speech Intelligibility

Previous research has shown that, when listeners were asked to select a sound system based on sound quality, they often selected systems that did not provide maximum speech intelligibility. Generally, listeners prefer frequency responses with greater low frequency amplification, even though greater high frequency amplification provides better speech intelligibility.[12]

Although speech intelligibility and sound quality are two distinct entities, Killion[13-15] contends they tend to go hand in hand. He notes that hearing instruments that provide better speech intelligibility in noise are the ones with good sound quality. Boike and Souza[16] also reported a high correlation between speech intelligibility scores and sound quality ratings for single-channel wide dynamic range compressed speech.

Therefore, the relationship between sound quality and speech intelligibility is far from clear and warrants systematic research.

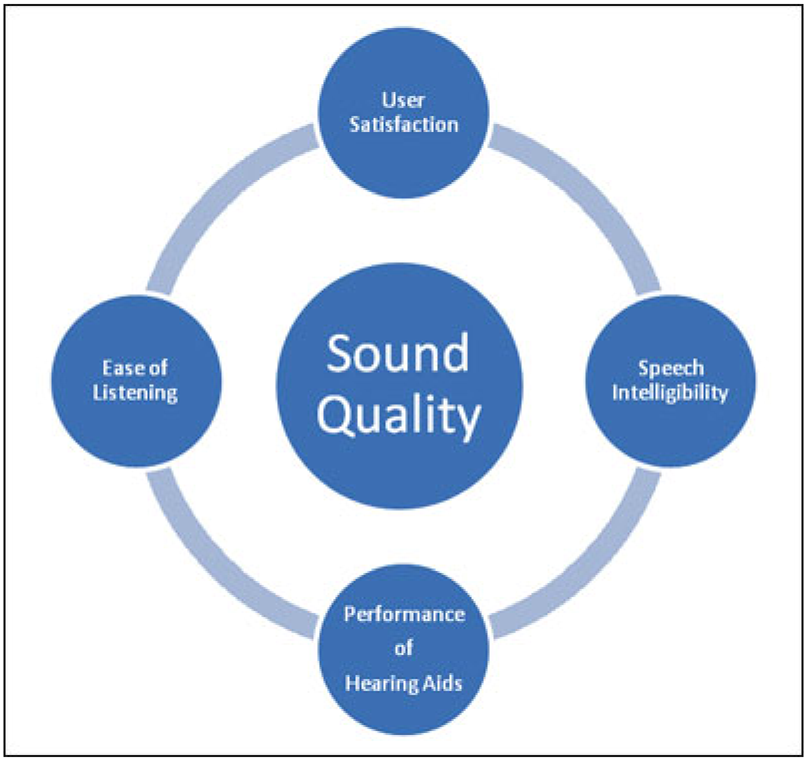

FIGURE 1. A flow diagram showing the relationship between sound quality, ease of listening, speech intelligibility, performance of hearing aids, and user satisfaction.

Sound Quality and Adaptation

Munro and Lutman[4] studied elderly hearing instrument users who used linear programmable hearing devices for at least 4 hours daily. Sound quality was reported along dimensions of clarity, comfort, and overall preference while listening to running speech in quiet, steady noise, and speech babble. Sound quality evaluations did not change significantly over a 24-week period. This dramatic finding holds an important take-home message. Specifically, sound quality reports early in the fitting process appear to reflect personal sound quality precepts which are unlikely to change in the short term.

Bilateral Advantage and Sound Quality

There is little doubt that better sound quality is experienced by exploiting binaural cues in bilateral hearing aid fittings. The advantage of listening with two instruments has been reported along several dimensions of sound quality, such as clarity, fullness, spaciousness, and overall quality.[17]

The just noticeable difference (JND) for intensity and spectral features is also smaller when listening with two ears, thus indicating wearers can make finer judgements with two instruments than with one.[18,19] Providing the brain access to spatial cues by having the compression settings of the two instruments co-ordinated wirelessly allows for enhanced natural perception of spaciousness and externalization of sound.

Sound Quality and Hearing Instrument User Satisfaction

Most hearing aid satisfaction ratings have examined extrinsic and intrinsic factors. Intrinsic factors include: age, gender, demographics, hearing loss, self-perceived disability and handicap, hearing aid experience, expectations of hearing instruments, attitude and personality, and hours of aid usage. Extrinsic factors are associated with sound quality, types of hearing instrument, listening situations, benefit, fitting-related problems, and counseling.[20]

Several studies[20] have documented positive relationships between sound quality and hearing aid user satisfaction (Figure 1). Of the top-10 factors most highly associated with overall hearing instrument satisfaction, Kockkin[21] noted three factors related to issues of sound quality (#2 "clarity of sound"; #5 "natural sounding"; and #7 "richness or fidelity of sound").

Bentler and colleagues[22] found some 20% of variance in hearing aid satisfaction can be attributed to sound quality. Naturalness, music quality, clarity of voice, and loudness have been reported to improve satisfaction.[23,24]

Improving Sound Quality

In 1979, Killion noted the importance of broader bandwidths and less distortion.[25] Many hearing instruments (in 2009) have bandwidths that extend to 10 kHz and beyond.

It has been noted hearing instruments with the latest technology often give the best customer satisfaction ratings.[20] Kochkin[26,27] found that individuals using instruments less than a year old were more satisfied than users of older instruments. Hansen[28] reported better sound quality and speech perception in complex listening environments when using high performance wireless hearing instruments.

Other studies have demonstrated a positive relationship between sound quality associated with bilateral fittings and user satisfaction. Kochkin[29] found an overall improvement in satisfaction for bilateral users of hearing devices. Sinclair and Goldstein[30] and Kochkin[31] also suggested higher satisfaction among bilateral users of hearing instruments.

Signal Processing Technology and Sound Quality

Ricketts and Hornsby[32] found the sound quality of speech in noise to be better with digital noise reduction than without it. Ricketts and colleagues[33] noted subjects with mild to moderate hearing loss rated speech amplified in the higher frequencies (up to 12 kHz) as higher quality than speech amplified only up to 6 kHz. Beck and Olsen[34] reviewed a number of publications that noted extended bandwidths offer improved sound quality for speech and music.

Neuman et al[35] and Souza et al[36] reported that compression impacts sound quality, too. They noted subjects preferred lower compression ratios, longer release times, and fewer compression channels.

With the advent of extended bandwidth and binaural processing, synchronization and coordination between hearing instruments, the concept of spatial fidelity[37] has assumed extraordinary importance. In other words, sounds originating from different directions and distances have become paramount considerations with respect to quality. For the first time in subjective sound quality evaluations, quality dimensions of spatial hearing such as "nearness," "fullness," and "spaciousness" (see Gabrielsson[6]) have been incorporated in the product verification process for advanced wireless broadband hearing instruments.

Conclusion

Hearing aid manufacturers desire to maintain and increase sound quality through advanced technology and innovation. Recently, spatiality and intelligent binaural processing have become commercially available and have further increased the ability of hearing instruments to achieve high-quality outcomes. Manufacturers strive to optimize sound quality while achieving the best speech intelligibility in quiet and noisy listening environments.

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