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Self-perceived Own-Voice Level and Sound Quality in Hearing Aid Users

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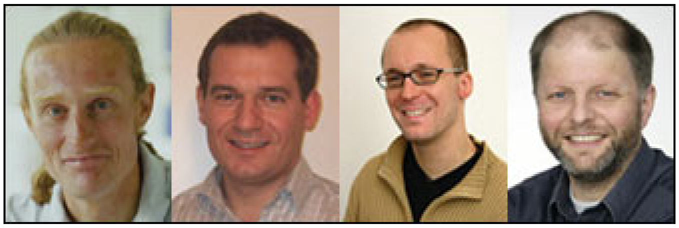

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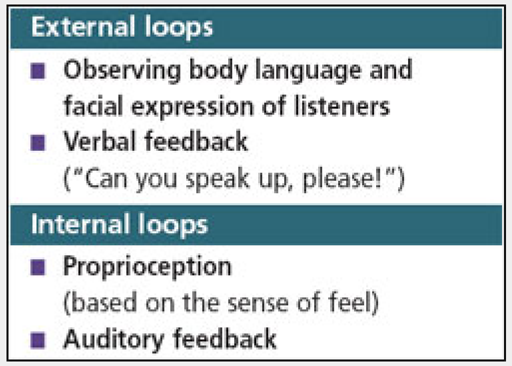
Getting the voice level correct for the occasion is difficult for many hearing aid users, and when it is finally accomplished, it may be at the cost of poor own-voice sound quality. This is illustrated in the present study, which also gives suggestions for the required improvement in the hearing aids.

An important part of achieving successful communication is to use the adequate voice level for the occasion.[1] While this is trivial for the vast majority of normal hearing people, it has been found to be difficult for many hearing aid users.[2,3]

The ability to perform own-voice level control relies on the feedback mechanisms listed in Table 1. Out of these, only the last—auditory feedback—is affected by hearing loss and hearing aids, and it is therefore straightforward to conclude that the hearing aid users' problems are caused by the changes to auditory feedback that the hearing loss and the hearing aids introduce.



External loops
- Observing body language and facial expression of listeners
- Verbal feedback ("Can you speak up, please!")

Internal loops
- Proprioception (based on the sense of feel)
- Auditory feedback

TABLE 1. Feedback mechanisms for own-voice level control. [1]

Hearing loss usually changes very slowly, which leaves plenty of time for adaptation. This is possible only up to a certain point, however; it is not uncommon to come across people with substantial untreated hearing loss who speak overly loud. In contrast, the changes to auditory feedback introduced by hearing aids are almost always abrupt. Accordingly, difficulties with own-voice level control typically arise immediately after the first fit with hearing aids, after fitting with new hearing aids, or after a substantial change in amplification.

Most hearing aid users eventually solve their problems with own-voice level control by internal recalibration, but the solution may be obtained at the cost of poor own-voice sound quality and the self-perception that their voice is too loud. This is illustrated by the experiment reported below, which also gives suggestions for the required improvement in the hearing aids.

Experiment and Methods

In the part of the experiment[4] that is considered here, the focus was on the speakers' own perception of their voice, as a function of hearing aid amplification, when they were speaking at the adequate level for the occasion.

Method. Each speaker addressed a listener/intervener with a predefined question across a range of distances in an otherwise quiet surrounding. The distance was varied between 1.5 m and 20 m, and in this way the adequate voice level for the occasion varied from a normal relaxed speaking voice up to a highly raised voice (including shouting for some speakers). The speakers spoke at the level found adequate by the intervener; that is, the speakers repeated the question until a satisfactory version was produced according to the intervener. After each repetition, the intervener would signal to the speaker by gesture to raise or lower his/her voice, as appropriate (Figure 1).

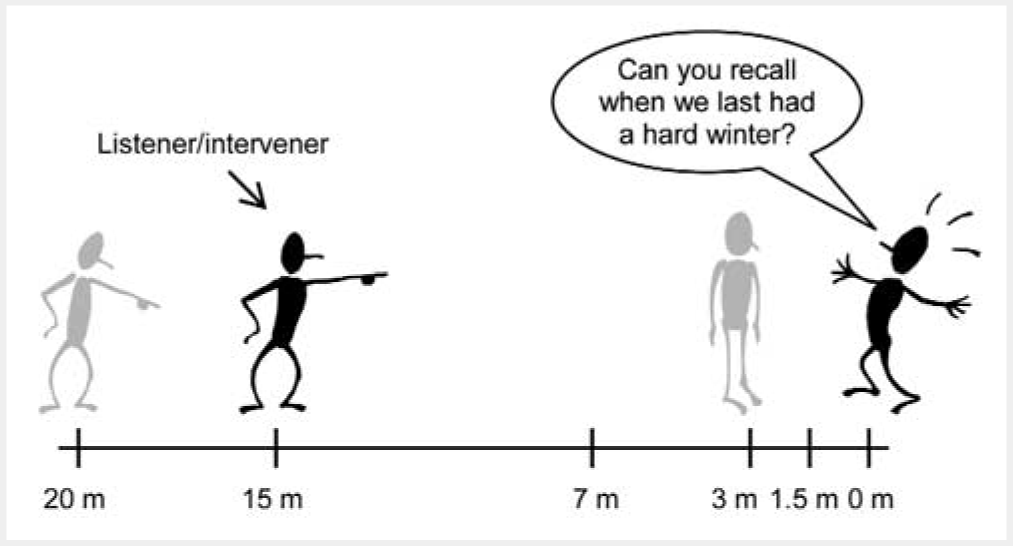


FIGURE 1. Simple sketch of the experimental setup.

Along with the variation in speaker/listener distance, the speakers were receiving amplification (through experimental bilateral hearing aids described below), which varied among four alternatives:

- *0 dB IG:* Transparent hearing aid, linear, unity insertion gain;
- *CompLoSlow:* Low-gain slow-acting compression prescription;
- *CompHiFast:* High-gain fast-acting compression prescription; or
- *Half-gain:* Half-gain prescription, linear setting.

Out of these, the first (0 dB IG) clearly provides too little gain (re: the hearing losses shown in Figure 4) while the last (half-gain) clearly provides too much gain for a relatively loud signal as own voice.[5,6]

The CompHiFast setting was chosen to mimic a standard fast-compression prescription with emphasis on good speech intelligibility. Finally, the CompLoSlow setting was obtained from CompHiFast by reducing gain and increasing compression time constants in order to mimic a prescription with emphasis on listening comfort. Figure 2 shows the insertion gain provided by the four prescriptions for a steady-state signal with the same long-term spectrum as own voice.[6]

Each speaker participated in two consecutive sessions. In one session (LEVEL session), the speakers were asked to rate the self-perceived level of their own voice on the upper scale shown in Figure 3, considering the last version of the question (ie, the one that was accepted by the intervener). In another session (SQ session), the speakers rated the self-perceived own-voice sound quality (see Figure 3, lower portion). In the LEVEL session, five distances were used; in the SQ session, only two. Distances and prescriptions were selected randomly by the control software, and the selection of prescription was blinded to both speaker and experimenter.

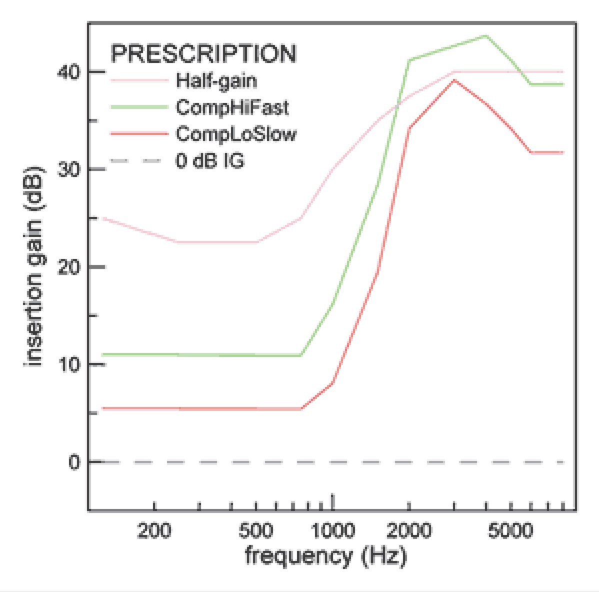
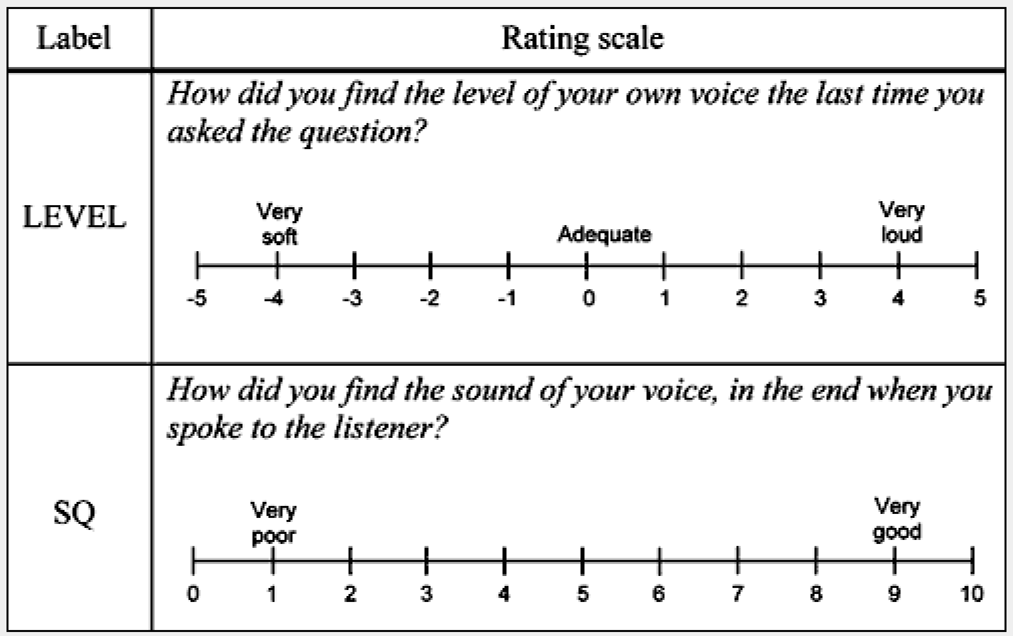


FIGURE 2. Insertion gain provided by the four prescriptions used in the experiment, calculated for a steady-state signal with the same long-term spectrum as own-voice, and for the maximum hearing loss according to the fitting range of the experimental hearing aid (see Figure 4).

The speakers' voices were recorded by means of the microphones of the experimental hearing aids. Each recording was later edited to contain only the last valid utterance that was accepted by the intervener, and finally synthesized into a single broadband long-term average sound pressure level (by the use of the appropriate calibration spectrum).



Label	Rating scale
LEVEL	*How did you find the level of your own voice the last time you asked the question?* Very soft (-4) — Adequate (0) — Very loud (4) -5 -4 -3 -2 -1 0 1 2 3 4 5
SQ	*How did you find the sound of your voice, in the end when you spoke to the listener?* Very poor (1) — Very good (9) 0 1 2 3 4 5 6 7 8 9 10

FIGURE 3. English translations of the questions and scales used in the LEVEL and SQ experiments.

Material. The experiment was carried out in a quiet corridor that allowed speaker-listener distances up to 22 m. Objective measurements showed that the sound pressure level (SPL) drops by less in the corridor than in a free field, but by much more than traditional "shoebox" room acoustics would predict.[7]

The experimental hearing aid was built around a DSP board installed in a standard PC. Sound was picked up by standard hearing aid microphones installed in otherwise empty BTE shells, and sound was delivered through standard hearing aid receivers driven by laboratory power amplifiers. The receivers were installed in soft silicone inserts that allowed a deep, closed fit in the bony part of the ear canal. In this way, the occlusion effect could be kept to a minimum and it was possible to provide gain throughout the range of speech frequencies (ie, down to 80 Hz).

Prior testing verified that it was possible to deliver distortion-free amplification according to the Half-gain prescription for all relevant levels of speech, and for hearing losses up to the fitting-range limit indicated in Figure 4. Before and after each session of the experiment, the acoustic seal was verified by measurement on every speaker. As already mentioned, the hearing aid microphones were also used for recording the speakers' voices. Recordings were made with the ProTools software running on another PC.

Seven test subjects (speakers) participated in the experiment: 4 males and 3 females, ages 27 to 74 years (mean age: 57.6 years). Subjects selected had normal voices, ear canals suitable for the receiver units described above, and hearing losses as close as possible to the fitting range of the experimental hearing aid, in order to create as much difference as possible among the four prescriptions (Figure 1). Mean audiograms and standard deviations are shown in Figure 4.

Finally, the same listener/intervener (the fourth author) was used throughout the experiment. The intervener's hearing thresholds were well within the normal range at all frequencies and on both ears. In a follow-up study,[8] it was verified that relying on a single intervener is relatively unproblematic.

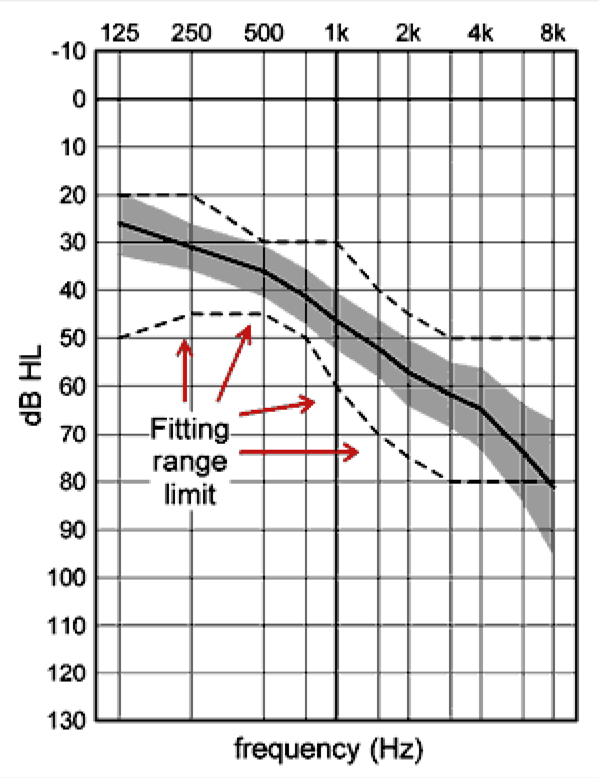


FIGURE 4. Hearing loss specification range (dashed lines) and the actual distribution of hearing losses included in the study, in terms of mean value (solid line) and mean ±1 SD (grey area) of all ears.

Results

The main experimental variables were *speaker, distance,* and *prescription*. The results were analyzed by means of a mixed-model ANOVA, with distance and prescription as fixed factors and speaker as a random factor.[9] Throughout, a 0.01 limit for statistical significance has been assumed.

Own-voice LEVEL session. For the LEVEL session (assessment of sound level), two sets of data are available as described above: the broadband long-term average levels produced by the speakers, and the speakers' ratings of the self-perceived own-voice level.

Considering the levels produced by the speakers, the statistical analysis suggests that only *speaker* and *distance* are significant (both *P* <10-15). In contrast, there is no systematic difference among the *prescriptions*, which is reasonable since the intervener was in control of voice level. Also, neither of the higher-order interactions was significant. In the mixed-model ANOVA, the significance of the *speaker* variable indicates that there is a substantial random variation in the mean levels produced among the speakers, and the corresponding between-speaker standard deviation can be estimated to 2.3 dB. The systematic effect of the *distance* variable is illustrated in Figure 5, together with predictions based on objective measurements in the corridor.

The key observation from Figure 5 is the gradual increase in vocal level of about 14 dB in total when distance increases from 1.5 to 20 m. It is interesting to compare this level growth function with the predictions based on objective measurements; that is, what the speakers would have done if they had compensated perfectly for the raw attenuation with distance. The two curves agree quite well at intermediate distances, whereas there are deviations at both ends of the range.

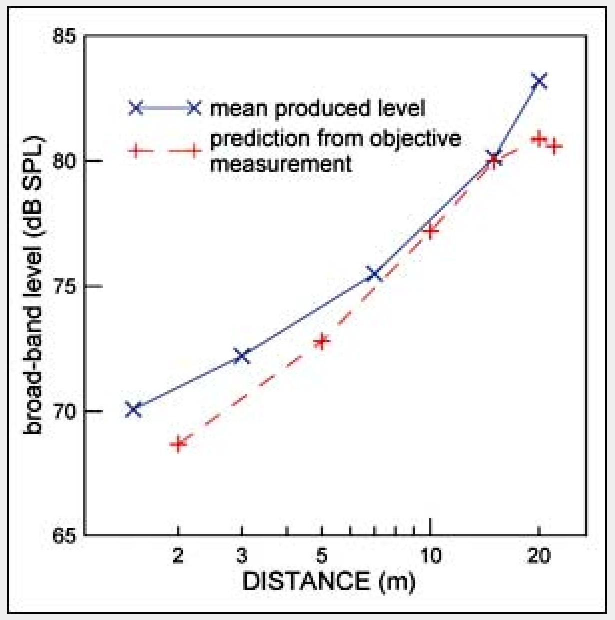


FIGURE 5. The blue curve shows the mean broadband levels averaged across speakers and prescriptions. The red curve suggests what the speakers should have done to perfectly compensate for the attenuation with distance in the corridor (the red curve is arbitrarily aligned with the blue curve at the 15 m distance).

Toward the shortest distances, the curve of the produced levels becomes shallower than the prediction. This is probably because of a flooring effect due to the fact that there is a limit to how low it is possible to speak without going into a whisper,[10] which would be unreasonable given the experimental circumstances.

At 20 meters distance, the predicted curve breaks off because, at this distance, reverberant sound was finally beginning to dominate over the direct sound. Nevertheless, the intervener forced the speakers to raise their voices. A plausible explanation is that the intervener increased the speakers' voice level in an attempt to improve the speech intelligibility that was reduced due to the increased amount of reverberation.

Next, the speakers' ratings of the self-perceived own-voice level are considered. In this case, the statistics again suggest a significant random variation in the *speaker* variable (which expresses itself as two significant interactions). However, the really interesting results are the significant effects of *distance* ($P < 0.0000003$) and *prescription* ($P < 0.000002$), which are illustrated together in Figure 6.

The most striking observation from Figure 6 is the very clear effect of *prescription*: as more gain is applied, LEVEL rating goes up—in perfect agreement with expectations. There is also a tendency toward higher LEVEL ratings as distance increases.

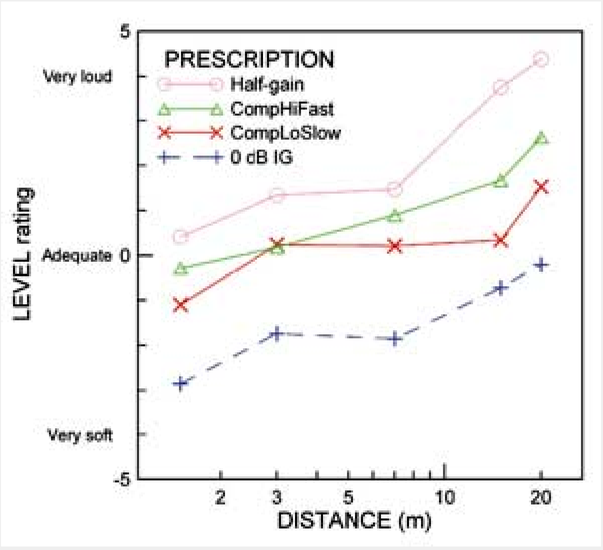


FIGURE 6. Subjective LEVEL ratings, averaged across speakers. Results are shown for each prescription separately.

Figure 6 also suggests that this increase with distance is more pronounced for the two linear prescriptions than the compression prescriptions. Indeed, this is in agreement with what compression is doing (turning down gain as input sound level goes up), but the effect is not statistically significant ($P = 0.07$). The results also indicate that *neither prescription* is able to provide an own-voice level that is rated as adequate by the speakers themselves at all distances, when the speakers are speaking at the level that satisfies the intervener.

Own-voice sound quality (SQ) session. For the SQ session, only the speakers' ratings of self-perceived own-voice sound quality were collected. Furthermore, this was done only at two distances: 1.5 m and 15 m. The statistical analysis suggests that the most interesting result is the interaction between *prescription* and *distance* ($P = 0.005$), which is illustrated in Figure 7.

From Figure 7, it is seen that, when the speaker and the intervener are close together (1.5 m) and the speaker hence speaks at a soft level, the strong compression prescription (CompHiFast) obtains the highest sound-quality rating, whereas the unity gain prescription (0 dB IG) receives a poorest SQ rating, which obviously is associated with too little gain. At 15 m, where the speakers have to speak considerably loud, the soft compression prescription receives the highest SQ rating, whereas Half-gain prescription is scored very poorly; this time, obviously associated with too much gain.

Thus, poor own-voice sound quality can be associated with both too little and too much gain. As was also noted in relation to Figure 6, it is noteworthy that *no single prescription* is optimal for both distances.

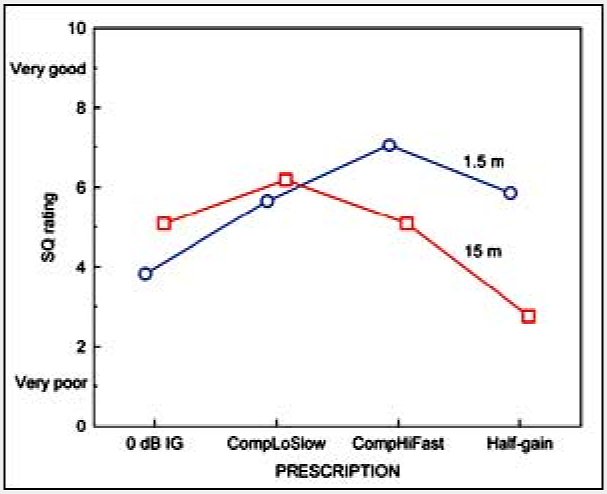


FIGURE 7. Ratings of self-perceived own-voice sound quality (SQ), averaged across speakers. Results are shown as a function of prescription (more gain toward the right) and for each distance separately, as indicated.

Conclusion

First, it can be concluded from the results of this experiment that, in terms of self-perceived own-voice level and sound quality, hearing aid users react basically as one would expect to changes in auditory feedback introduced by variations in hearing aid amplification. When the speakers were supervised into speaking at the adequate level for a given distance (according to the supervisor), their rating of self-perceived level of own-voice went from soft, through adequate, to loud, as amplification was increased. Self-perceived sound quality was rated as poor, with both too little and too much amplification. Less amplification was preferred for a loud voice used at the long distance compared to a normal voice used at the short distance.

Thus, none of the four gain prescriptions tested was able to provide adequate self-perceived own-voice level or optimal own-voice sound quality across the range of distances (and the corresponding required vocal levels). The results indicate that, compared to a standard listening rationale, less gain is preferred for a loud voice. Accordingly, a reduction of gain for loud own-voice is part of the MyVoice feature in the Oticon Epoq hearing aid.

Acknowledgement

The data presented in this article was used in a podium presentation at IHCON 2006, Lake Tahoe, Calif. Handouts for references 2-4 can be obtained from the lead author by request.

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References

1. Lane HL, Tranel B. The Lombard sign and the role of hearing in speech. *J Sp Hear Res*. 1971;14(4):677-709.
2. Nielsen C, Laugesen S. Why own voice is different. Seminar presented at: American Academy of Audiology Convention; Salt Lake City; April 2004.
3. Jensen NS, Maas P, Nielsen C, Laugesen S, Flynn M. A first attempt at a comprehensive Own Voice Qualities (OVQ) questionnaire. Poster presented at: IHCON 2006; Lake Tahoe, Calif; 2006.
4. Laugesen S, Nielsen C, Maas P, Jensen NS. Effects of amplification variations on vocal level and own-voice sound quality of hearing-aid users. Podium presentation at: IHCON 2006; Lake Tahoe, Calif; 2006.
5. Cornelisse LE, Gagné JP, Seewald RC. Ear level recordings of the long-term average spectrum of speech. *Ear Hear*. 1991;12(1):47-54.
6. Elberling C, Nielsen C. The dynamics of speech and the auditory dynamic range in sensorineural hearing impairment. In: Beilin J, Jensen GR, eds. *Recent Developments in Hearing Instrument Technology, Proceedings of the 15th Danavox Symposium 1993*: 99-133.
7. Wang LM, Rathsam J, Christensen CL, Rindel JH. Sound-pressure level distribution in a long, narrow hallway: measurements versus results from a computer model with scattering from surface roughness and diffraction. *J Acoust Soc Am*. 2005;118:1998.
8. Laugesen S, Jensen NS, Maas P, Nielsen C. Variations in "adequate" own-voice level used by speakers and preferred by listeners when communicating across a distance. *ISAAR 2007 Proceedings*. In press.
9. Bech S, Zacharov N. *Perceptual Audio Evaluation: Theory, Method and Application.* London: John Wiley & Sons; 2006:141-224.
10. Traunmüller H, Eriksson A. Acoustic effects of variation in vocal effort by men, women and children. *J Acoust Soc Am*. 2000;107(6):3438-3451.

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