A weighting-function-based approach to subjectively modify the frequency response of a hearing aid

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Introduction
One of the most important parameter settings on a hearing aid is the Frequency Gain Curve (FGC) which describes how the input sound is amplified as a function of frequency. Typically, the shape of the FGC is determined by a formula applied to the audiogram (e.g., [1]). In addition, several other methods have been proposed in which the FGC is refined by a subject's subjective preference judgements. Here we propose a new method to adjust the FGC based on such preference judgements that was designed to circumvent drawbacks of previous approaches. Specifically, previous approaches tend to split the entire spectrum into only 2 or 3 channels [2], thereby limiting the number of potential FGCs. Second, most of these methods are designed to converge on the final FGC, and previous work has shown that the result of convergence-based methods is highly dependent upon the initial FGC [3]. Here we present a non-convergence-based method with a wide range of potential final FGCs.

Step 1: Measure Audiogram + Generate Base FGC
An audiogram (blue curve, below) is measured using an automated tracking procedure at octave frequencies from 250 to 4000 Hz with three repetitions per frequency. The average spectrum of the speech stimuli used here (IEEE sentences, Adult Female Talker presented at 78 SPL) is the green curve in the left plot below. For the displayed audiogram, much of the spectrum is below the threshold of audibility.

A Base FGC (m iddle plot, below) is applied to ensure that the average speech spectrum is at least 20 dB SL at all frequencies - a requirement for the current procedure. The right plot, below shows the average speech spectrum after the Base FGC is applied. The Base FGC is applied to all subsequent sounds in this procedure.

Step 2: Measure Ratings of Clarity
On each of 40 trials, a probe FGC is applied to a randomly-selected sentence. The listener is asked to determine the “clarity” of the speech, and responds by moving an on-screen slider (displayed below). Each probe FGC is created using 22 frequency channels spaced equally on an ERB scale from 200 to 4000 Hz. The probe FGCs are created by concatenating Gaussian functions with random bandwidths (from 12-40 channels), amplitudes (from -20 to 20 dB), and center frequencies. Initially 1000 probe FGCs are computed. The first one is selected randomly. Subsequent probes are selected to be maximally different from the ones that preceded it. Each probe FGC is added to the base FGC before being applied to the stimulus (see schematic, next column). A single linear-phase FIR filter is generated and applied to the sentence. To minimize the influence of loudness on clarity ratings, the post-FIR filtered RMS value of the speech is adjusted to be equal to that of the speech filtered by the base FGC alone.

Step 3: Compute the Weighting Function
After the listener completes 40 ratings, there are also 40 gain values for each of the 22 frequency channels (one gain value from each probe curve). On a channel-by-channel basis we correlate the listener ratings with the gain values. Examples of these correlations are plotted in the insets of the figure on the right. We reason that the direction and extent that a particular channel influences clarity will be reflected in the slope of the regression line. Therefore we compute regression slope as a function of frequency -- the Weighting Function (main curve, right). The weighting function is normalized by the slope with the largest absolute value.

Step 4: Measure the Scaling Function
To determine the appropriate scaling of the weighting function, the listener rates the clarity of speech filtered by the Base FGC + the weighting function multiplied by either 0, 4, 8, 12, 16 or 20 (left plot, below) using the same procedure as before. Each multiplier is tested 6 times, and the order is determined randomly. A second order polynomial is fit to the average rating as a function of the multiplier. The polynomial (the arrow) is interpreted as the user’s preferred multiplier.

Step 5: Compute The Final FGC
The final FGC is the weighting function times the preferred multiplier added to the base FGC.

Footnotes
4. Ackroyd & Segments
Deepika Srinath, Grace Lee, and Chizelle Rush helped with data collection. Bryan Pardo provided helpful conversation.

Preliminary Evaluation
Method:
Three listeners with sensorineural hearing loss participated (4 ears in total, separate rows to the left). Listeners completed between 2 and 4 runs per ear (each run is different color) over headphones in a quiet room.

Results:
Weighting functions were evaluated by correlating each of the weighting functions for a single ear with each other (distribution: bottom row, left; median r = 0.93). Scaling functions were evaluated by correlating listener responses with the fitted scaling function (distribution: bottom row, middle; median r = 0.626). FGCs were evaluated by computing the root mean squared error between all FGCs for a given ear (distribution: bottom row, right; median = 1.9 dB).

Conclusions/Future Work
This preliminary evaluation indicates that the weighting function calculation is highly replicable. The shape of the weighting functions differ dramatically across listeners, suggesting that subjective preference is not entirely predictable by the audiogram. In contrast, the scaling procedure is less replicable, with preferred multipliers varying widely from one run to the other. Considering modifications to this aspect of the current procedure. We are beginning to examine how the base FGC and the choice of probe FGCs influences the final FGC. Further, in future work we intend to evaluate whether the FGC generated by the current procedure provides a benefit to understanding speech both in quiet and in noise, and whether this FGC improves user reports of hearing aid satisfaction. Finally, we also intend to evaluate whether there are systematic changes to FGC preference based on the choice of signal (e.g., music vs. speech) and/or the context (e.g., quiet vs. noise).