\chapter{Effectiveness of Hearing Aids }

\label{sec:hearing-aids-effectiveness}

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\section{Characteristics}

\label{sec:hearing-aids-introduction}

Although hearing impairments happen in multiple forms, the most common is sensory neural hearing loss \cite{Hearing\_Aids\_Harvey\_Dilon\_Introduction}. Difficulties in understanding speech come from reduced audibility on some of the frequencies and complete loss on others, which causes the patient’s processed waveform to differ from the original signal. The most critical frequencies for understanding speech are between \lowspeechfrequency and \criticalspeechfrequency. Because most energy in speech is in frequency bands below \lowspeechfrequency, but most information is above this frequency, losing audibility in this range causes speech to be detectable but not understandable. This leads to statements about lack of clarity and mumbling of the speakers.

To correct this situation, HAs must amplify different frequencies according to the specific losses in the bands. The gain-frequency response defines the full profile prescribed for the patient. If amplification depends on frequency alone but not amplitude, the HA is said to be linear. In this chapter, we demonstrate the effectiveness of our program to analyze patient damage profiles and prescribe various HAs.

\section{History of Hearing Aids }

\label{sec:hearing-aid-history}

Although hearing amplification methods have been used since ancient times, such as putting one’s hand to one’s ear, until the 20th century all method were acoustical. Such methods have several limitations, largely because of the necessity of having large openings to collect a maximum possible acoustic energy and a long tube to gradually concentrate the collected sound. An excessively short tube will cause most of the pressure waves to reflect back. The lack of an active amplifier also means that amplification cannot exceed the collected energy because of energy conservation, so the gain-frequency profile is also limited. Thus, such devices cannot be adjusted to reliably amplify specific bands.

In 1902, the first commercial electronic HA became available in the form of carbon-based aids assembled from a microphone with a diaphragm that pressed dust or granules. It functioned as a variable resistor that controlled the current inside the receiver and amplified sound by 20 to 30~dB. With an additional carbon amplifier, a 70 dB gain was achieved, and the gain-frequency response profile could be set by arranging multiple systems in parallel with different dust concentrations. However, these were limited by their frequency resolution and the noise the dust itself created limited understandability.

The vacuum tube (VT) had a much better amplification profile than carbon dust but was too large and energy consuming to be practical as a mobile aid until the 1940s. With the advent of transistors in 1952, all VT HAs were replaced with transistor aids in 1954. The transistor has better amplification characteristics than the VT, does not need to heat up, and is smaller than a VT, which enabled manufacturers to reduce the device size and create the first Behind The Ear (BTE) HA. The invention of the integrated circuit (IC) allowed multiple transistors to be packed into a single device. Since the 1980s, the reduction in transistor size and the use of field-effect transistors mean that the signal can be processed and controlled numerically, so users can adjust their own settings by switching between multiple amplification profiles for different situations. Size reduction leads to aids completely inside the ear canal, which conceals them—an advantage for patients desirous to avoid the stigma of hearing loss.

The science of audiology started in the 1930s. Originally, amplifications adapted to mirror the audiogram HL; however, this caused over amplification at high amplitudes, causing discomfort and saturation and leading to unintelligible speech. In 1944, Linebarger established the half-gain principle, whereby the gain for each frequency is half of the audiogram HL.

\section{ Gain Calculations for Hearing Aid}

\label{section:hearing-aids-gain-calculation}

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\subsection{Hearing Aids Simulation}

By using FIR and IIR transfer functions, this program can simulate the effect of linear HAs for patients. If a HA is present we use $\sha$ instead of $\underline{S}$ (\cref{eq:signal-matrix}) to define $\sha$, so the HA frequency domain transfer function without loss of generality takes the form

\begin{equation\*}

H\_{Hearing Aids}(z) = \frac{\sum\_{j=0}^{n}b\_j z^{-j}}{\sum\_{k=0}^{m}a\_k z^{-k}},

\end{equation\*}

with $n$ and $m$ being the number of coefficients in the numerator and denominator, respectively. We work in the time domain, so $h\_{Hearing~Aid}(t) = \mathcal{F}^{-1}\{H\_{Hearing~Aids}(z)\}$, and

\begin{equation\*}

P\_{in}(t) = \underline{S}\_{NL,SL}^{HA}(t) = h\_{Hearing~Aid}(t) \conv \underline{S}\_{NL,SL}(t).

\end{equation\*}

\subsection{Database generation}

Our program allowed \citealt{odedst2017} to generate a large database of over 10\,000 different impairment profiles. To test HA prescriptions for the patient we scan the database and take the OHC or IHC profile that satisfies

\begin{equation} \label{eq:min-jnd-hl}

\min\_{\substack{OHC/IHC~\\profile}} \sqrt{\sum\_{f \in (Measured~Frequencies)}(JND\_{Patient}(f)-JND\_{SPL}^{profile}(f))^{2}}.

\end{equation}

We denote by $JND\_{Patient}(f)$ the measured JND SPL at the frequency $f$ and by $JND\_{SPL}^{profile}(f)$ we denote the function that takes the frequency $f$ for profile and returns the JND SPL in dB, which is the value loaded from the database.

The program can emulate the HA formula as part of the cochlea \ref{sec:parallel\_input\_generation}, thus allowing us to calculate the JND with the HA effect ($\alpha$ is calculated before passing the signal through the HA). We use formulas based on \cite{Sandlin\_Hearing\_Aids\_Linear\_Prescriptions}, which give values only for specific frequencies. To find the full gain profile, we use linear interpolation for the remaining frequencies. We define $NH$ as normal hearing, such that $JND\_{SPL}^{NH}(f)$ returns the JND for a healthy model at frequency $f$. The JND HL can therefore be replaced as follows:

\begin{equation} \label{eq:jnd-hl}

JND\_{HL}^{profile}(f) = JND\_{SPL}^{profile}(f) - JND\_{SPL}^{NH}(f).

\end{equation}

A prescription method is a function that takes $JND$ and returns gain. It is denoted $gain\_{prescription}$. Our gain method is

\begin{equation}

\begin{aligned}

DiscreteGain(profile,prescription,f) = & gain\_{prescription}(JND\_{HL}^{profile}(f)).

\end{aligned}

\end{equation}

However, the only allows use of known frequencies from \cite{odedst2017}. We denote by the series $f\_1 \dots f\_n$ the speech bandwidth that satisfies $f\_{i+1} - f\_i \gg 20$~Hz.

We define $\fnyq=\frac{F\_s}{2}$ such that

\begin{equation}

\fnorm{i} = \frac{f\_i}{\fnyq},

\end{equation}

and $f\_{-1}^{norm}=0$, $f\_{n+1}^{norm}=1$. We can now define the average gain for each bandwidth, $G\_i^{BW}$, with each defined in a range of $\frac{\fnorm{i-1}+\fnorm{i}}{2}+\epsilon\_f+ \cdots+ \frac{\fnorm{i}+\fnorm{i+1}}{2}$, with $\epsilon\_f=\frac{20\text{ Hz}}{\fnyq}$.

We define a dense grid of frequencies with intervals $\Delta f$ such that $\inv{\Delta f} \gg n$ and the number of points in the grid are $npt=\inv{\Delta f}$. The gain for interpolated point at index $k$ that satisfies $\fnorm{i-1} < k\Delta f < \fnorm{i}$ is

\begin{equation}

\begin{aligned}

BW\_k^{position} = &\frac{(k\Delta f -\fnorm{i-1})}{\fnorm{i}-\fnorm{i-1}}, \\

MidGain\_k = & BW\_k^{position} JND\_{HL}^{profile}(\fnorm{i})\\

& + (1- BW\_k^{position}) JND\_{HL}^{profile}(\fnorm{i-1}).

\end{aligned}

\end{equation}

The filter will then time shift by a half length to ensure the real-time domain filter, and the pre-windowed $H$ will be the inverse fast Fourier transform (FFT) of the gain concatenated with its mirrored conjugate, inversed, and then truncated to $n$:

\begin{equation}

\begin{aligned}

Gain\_k & = & MidGain\times e^{-0.5 i \pi k \Delta f}, \\

cGain\_k & = & conj(Gain\_k), \\

H\_{pre~window} & = & [Gain\_1 \cdots Gain\_{npt}~cGain\_{npt-1} \cdots cGain\_2] ,\\

h\_{pre~window}(t) & = & iFFT\{H\_{pre~window}\}.

\end{aligned}

\end{equation}

Calculating the HA response filter $h$ is done by applying the window, and tests show Kaiser to fit:

\begin{equation}

h(k) = h\_{pre~window}(k) \frac{I\_0\Big(\beta\cdot\sqrt{1-\big(\frac{k-\frac{n}{2}}{\frac{n}{2}}\big)^{2}}\Big)}{I\_0(\beta)}.

\end{equation}

\section{Hearing Aid; OHC damage}

\label{sec:hearing-aids-ohc-damage}

The patient profiles used here are based on the work of \cite{odedst2017}, who used this program with audiograms of volunteers to produce OHC and IHC profiles. We use \cref{fig:mt8-spectrogram-lpf-butterworth} to simulate crowd noise.

\begin{figure}

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\mbox{\subfigure[Normal Hearing JND]{\includegraphics[width=0.9\textwidth,keepaspectratio=true]{figs/JND\_OHC\_100\_IHC\_100\_n\_3\_p\_41\_f\_7}

\label{fig:normal-hearing-jnd}}

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\mbox{\subfigure[Normal Hearing ANR]{\includegraphics[width=0.9\textwidth,keepaspectratio=true]{figs/LHIGH\_SHEN\_70dB\_OHC\_100\_IHC\_100\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:normal-hearing-shen-response}}

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\caption{Normal hearing model: ANR response for the Hebrew word ``shen’’ spoken by female at comfortable sound level. We see differences in detected signals. The simulation results are consistent with results of experiments. The detection of the consonant ``she’’ is shown on the neural response graph.}

\label{fig:normal-hearing-patient}

\end{figure}

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\mbox{\subfigure[OHC at 25\% and IHC at 87\% JND]{\includegraphics[width=0.78\textwidth]{figs/JND\_OHC\_25\_IHC\_87\_n\_3\_p\_41\_f\_7}

\label{fig:low-ohc-jnd}}

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\mbox{\subfigure[OHC at 25\% and IHC at 87\% ANR]{\includegraphics[width=0.78\textwidth]{figs/LHIGH\_SHEN\_70dB\_OHC\_25\_IHC\_87\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:low-ohc-shen-response}}

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\caption{Patient with OHCs at 25\% and IHCs at 87\% ANR response for the Hebrew word ``shen’’ spoken by a female at a comfortable sound level. We see differences in detected signals when comparing ANR and JND to healthy mode (see \cref{fig:normal-hearing-patient}). For hearing impaired patient, most consonants disappear, so the remaining sound is a weak ``he,’’ which makes the word ``shen’’ difficult if not impossible to understand. Also note that, with IHC loss, is not constant the IHCs pass 2.5--3 kHz frequencies are damaged substantially more. This is also shown by the JND SPL graphs, which use crowd noise passed through a Butterworth low-pass filter with a passband of 800~Hz (see spectrogram in \figref{fig:mt8-spectrogram-lpf-butterworth}), and a stop band of 1.2 kHz with attenuations $-3$ and $-30$ dB, respectively.}

\label{fig:low-ohc-hearing-patient}

\end{figure}

The first example in \cref{fig:normal-hearing-patient,fig:low-ohc-hearing-patient} compares hearing impairment with the normal model. OHC damage mainly reduces hearing sensitivity for signals above 1 kHz, which is the characteristic frequency of the OHCs.

\begin{figure}

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\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/SIGNAL\_MT8\_BUTTERWORTH\_FP\_800\_AP\_3\_FS\_1200\_AS\_30}

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\caption{Normalized energy density of noise for JND test in \figref{fig:normal-hearing-jnd, fig:low-ohc-jnd}.}

\label{fig:mt8-spectrogram-lpf-butterworth}

\end{figure}

\paragraph{Measuring effects of different hearing aid prescriptions.}

\label{par:diffrent-prescription-ohc-damage}

As discussed in \cref{sec:hearing-aid-history}, most linear HAs follow the half-gain rule with some minor adjustments for two factors: The first factor is that, although most of the energy in speech is in the lower frequencies (<500 Hz), most of the information is at 2 to 4 kHz. The second factor is that, because most high-frequency sound pressure is absorbed by relatively small objects, most noise is in the lower frequencies. The combination of these factors with upward masking of the hearing impaired means that it is preferable to amplify the 2--4 kHz speech band than the lower frequencies. We test three types of linear HAs:

\begin{enumerate}

\item[\namedlabel{itm:nal-revised-method}{NAL Revised Method}] The NAL procedure (Dylon \& Bryn, 1986) works to amplify each frequency to the preferred hearing level, thereby maximizing speech intelligibility. The formula sums the audiogram HL values for 0.5, 1, and 2 kHz and divides the result by 20. It then adds 0.31 of the audiogram HL of the amplified frequency and applies a fix factor that amplifies frequencies between 1 and 1.5 kHz. The lower amplification is for frequencies significantly below 1 kHz, which contributes to preventing upward masking from low frequencies.

\item[\namedlabel{itm:pogo-method}{Prescription Of Gain and Output (POGO)}] This method is based on the Linebarger half-gain principle with mild attenuations for lower bands, which contain most of the noise. This ensures an easy-to-calculate method and improves speech intelligibility. POGO also includes a formula to determine the maximum power output by averaging the user-discomfort thresholds at 0.5, 1, and 2~kHz. The maximum power output was not implemented in our program because we focused on the lower hearing thresholds.

\item[\namedlabel{itm:berger-method}{Berger method}] This linear approach is based on the assumption that comfortable speech intensity is between 55 and 70 dB with critical tones at 2 to 4~kHz. As opposed to other methods, the amplification is stronger than the half-gain principle and approaches $\tfrac{2}{3}$. Because frequencies below 500 Hz do not contribute to intelligibility, these frequencies are not amplified in the Berger method.

\end{enumerate}

\begin{figure}

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\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/AudiogramHL\_OHC\_25\_IHC\_87\_With\_Without\_Aid\_POGO\_NAL\_BergerITE\_BergerBTE}

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\caption{Different audiogram HL for patient with OHC damage, without HA, and with different HA prescriptions described in \ref{par:diffrent-prescription-ohc-damage} and calculated by the program.}

\label{fig:compare-hearing-aids-for-ohc-damage}

\end{figure}

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\mbox{\subfigure[NAL Revised]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_NAL\_OHC\_25\_IHC\_87\_PATIENT\_4}

\label{fig:prescribe-hearing-aid-shen-ohc-damage-nal}}

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\subfigure[POGO]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_POGO\_OHC\_25\_IHC\_87\_PATIENT\_4}

\label{fig:prescribe-hearing-aid-shen-ohc-damage-pogo}}

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\caption{Comparison of the four HA prescriptions with \cref{fig:prescribe-compare-hearing-aids-ohc-damage-berger-methods}. POGO is the only method that accentuates the higher frequencies. }

\label{fig:prescribe-compare-hearing-aids-ohc-damage-nal-pogo}

\end{figure}

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\mbox{\subfigure[Berfer Behind The Ear]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_BergerBTE\_OHC\_25\_IHC\_87\_PATIENT\_4}

\label{fig:prescribe-hearing-aid-shen-ohc-damage-berger-bte}}

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\mbox{\subfigure[Berger Inside The Ear]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_BergerITE\_OHC\_25\_IHC\_87\_PATIENT\_4}

\label{fig:prescribe-hearing-aid-shen-ohc-damage-berger-ite}}

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\caption{Comparison of four HA prescriptions with \cref{fig:prescribe-compare-hearing-aids-ohc-damage-nal-pogo}. Berger method provides much more amplification. }

\label{fig:prescribe-compare-hearing-aids-ohc-damage-berger-methods}

\end{figure}

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\mbox{\subfigure[\ac{nal} Revised]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/LHIGH\_SHEN\_70dB\_Pres\_NAL\_OHC\_25\_IHC\_87\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-damage-nal}}

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\subfigure[POGO]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/LHIGH\_SHEN\_70dB\_Pres\_POGO\_OHC\_25\_IHC\_87\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-damage-pogo}}

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\caption{Comparison of results of ANR for Hebrew word ``shen’’ spoken by a female at a comfortable hearing level and with different HAs. The response without HA appears in \cref{fig:low-ohc-shen-response}. Both POGO and NAL methods result in severe under-amplification, and the ``she’’ consonant has effectively disappeared. The Berger method is shown in \cref{fig:compare-hearing-aids-ohc-damage-berger-methods}. }

\label{fig:compare-hearing-aids-ohc-damage-nal-pogo}

\end{figure}

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\mbox{\subfigure[Berfer Behind The Ear]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/LHIGH\_SHEN\_70dB\_Pres\_BergerBTE\_OHC\_25\_IHC\_87\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-damage-berger-bte}}

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\mbox{\subfigure[Berger Inside The Ear]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/LHIGH\_SHEN\_70dB\_Pres\_BergerITE\_OHC\_25\_IHC\_87\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-damage-berger-ite}}

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\caption{Comparison of ANR for Hebrew word ``shen’’ spoken by a female at a comfortable hearing level and with different HAs. The response without aid is shown in \figref{fig:low-ohc-shen-response}. Although the Berger method gives better results than the NAL and POGO methods shown in \cref{fig:compare-hearing-aids-ohc-damage-nal-pogo}, the results differ significantly from those of a healthy cochlea. This means that OHC damage cannot be fixed by HAs. }

\label{fig:compare-hearing-aids-ohc-damage-berger-methods}

\end{figure}

\section{Hearing Aid: Combined \ac{ohc} and \ac{ihc} Damage}

\label{sec:hearing-aids-ohc-n-ihc-damage}

In contrast to the patient evaluated in \ref{sec:hearing-aids-ohc-damage} who had mostly \ac{ohc} damage but almost no \ac{ihc} damage, we evaluate here the effectiveness of different prescriptions on patients with moderate damage of both IHCs and OHCs.

\begin{figure}

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\mbox{\subfigure[OHC at 40\% and IHC at 68\% JND]{\includegraphics[width=0.83\textwidth,keepaspectratio=true]{figs/JND\_OHC\_40\_IHC\_68\_n\_3\_p\_41\_f\_7}

\label{fig:moderate-ohc-n-ihc-jnd}}

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\mbox{\subfigure[OHC at 40\% and IHC at 68\% ANR]{\includegraphics[width=0.83\textwidth,keepaspectratio=true]{figs/LHIGH\_SHEN\_70dB\_OHC\_40\_IHC\_68\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:moderate-ohc-n-ihc-shen-response}}

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\caption{Model with OHC+ 40\% and IHC 68\% \ac{anr} when compared to with NH patient shown in \cref{fig:normal-hearing-patient}. Response for the Hebrew word ``shen’’ spoken by a female at a comfortable sound level compared with the response of patient with sever OHC damage to the same signal in \cref{fig:low-ohc-shen-response}. The degradation of the JND is more significant for the lower frequencies, as seen both for the \ac{spl} audiogram in \cref{fig:moderate-ohc-n-ihc-jnd} and for the ANR in \cref{fig:moderate-ohc-n-ihc-shen-response}, where for this patient the very low response for the ``she’’ consonant remains, and the low-frequency component of the vowel ``e’’ is much weaker than for the other patient. }

\label{fig:normal-and-moderate-ohc-n-ihc-hearing-patient}

\end{figure}

\begin{figure}

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\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/AudiogramHL\_OHC\_40\_IHC\_68\_With\_Without\_Aid\_POGO\_NAL\_BergerITE\_BergerBTE}

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\caption{ Comparison of patient audiogram HL with different prescriptions. The major differences with respect to \figref{fig:compare-hearing-aids-for-ohc-n-ihc-damage} are that the critical frequencies of 2--4~kHz are amplified much more than the lower frequencies. This both prevents low-pass noise amplification and avoids upward masking from the signal components in the lower-frequency bands.}

\label{fig:compare-hearing-aids-for-ohc-n-ihc-damage}

\end{figure}

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\mbox{\subfigure[NAL Revised]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_NAL\_OHC\_40\_IHC\_68\_PATIENT\_15}

\label{fig:prescribe-hearing-aid-shen-ohc-n-ihc-damage-nal}}

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\subfigure[POGO]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_POGO\_OHC\_40\_IHC\_68\_PATIENT\_15}

\label{fig:prescribe-hearing-aid-shen-ohc-n-ihc-damage-pogo}}

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\caption{Comparison of the four HAs prescriptions. The Berger method is shown in \cref{fig:prescribe-compare-hearing-aids-ohc-n-ihc-damage-berger}. NAL and POGO significantly under-amplify the higher frequencies relatively to the Berger method.}

\label{fig:prescribe-compare-hearing-aids-ohc-n-ihc-damage-nal-pogo}

\end{figure}

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\mbox{\subfigure[Berfer Behind The Ear]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_BergerBTE\_OHC\_40\_IHC\_68\_PATIENT\_15}

\label{fig:prescribe-hearing-aid-shen-ohc-n-ihc-damage-berger-bte}}

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\mbox{\subfigure[Berger Inside The Ear]{\includegraphics[width=0.95\textwidth,keepaspectratio=true]{figs/PRESCRIBE\_BergerITE\_OHC\_40\_IHC\_68\_PATIENT\_15}

\label{fig:prescribe-hearing-aid-shen-ohc-n-ihc-damage-berger-ite}}

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\caption{Comparison of the four HA prescriptions. NAL and POGO are shown in \cref{fig:prescribe-compare-hearing-aids-ohc-n-ihc-damage-nal-pogo}. The Berger method provides much more amplification and POGO is the only method that accentuates the higher frequencies. }

\label{fig:prescribe-compare-hearing-aids-ohc-n-ihc-damage-berger}

\end{figure}

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\mbox{\subfigure[NAL Revised]{\includegraphics[width=0.95\textwidth]{figs/LHIGH\_SHEN\_70dB\_Pres\_NAL\_OHC\_40\_IHC\_68\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-n-ihc-damage-nal}}

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\subfigure[\ac{pogo}]{\includegraphics[width=0.95\textwidth]{figs/LHIGH\_SHEN\_70dB\_Pres\_POGO\_OHC\_40\_IHC\_68\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-n-ihc-damage-pogo}}

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\caption{Comparison of results for ANR for Hebrew word ``shen’’ spoken by a female at a comfortable hearing level and with different HAs. The response without HA is shown in \figref{fig:moderate-ohc-n-ihc-shen-response}. For the NAL and POGO methods, amplification is insufficient. }

\label{fig:compare-hearing-aids-ohc-n-ihc-damage-pogo-nal}

\end{figure}

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\subfigure[Berger Inside The Ear]{\includegraphics[width=0.95\textwidth]{figs/LHIGH\_SHEN\_70dB\_Pres\_BergerITE\_OHC\_40\_IHC\_68\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-n-ihc-damage-berger-ite}}

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\mbox{\subfigure[Berfer Behind The Ear]{\includegraphics[width=0.95\textwidth]{figs/LHIGH\_SHEN\_70dB\_Pres\_BergerBTE\_OHC\_40\_IHC\_68\_NOISELESS\_MIN\_60\_MAX\_400}

\label{fig:hearing-aid-shen-ohc-n-ihc-damage-berger-bte}}

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\caption{Comparison of results of ANR for Hebrew word ``shen’’ spoken by s female at a comfortable hearing level, with different HAs, and for Berger method with HA behind the ear and inside the ear. The response without HA is shown in \figref{fig:moderate-ohc-n-ihc-shen-response}.This methods provides much better amplification than does POGO or NAL, which are shown in \cref{fig:compare-hearing-aids-ohc-n-ihc-damage-pogo-nal}.}

\label{fig:compare-hearing-aids-ohc-n-ihc-damage-berger-methods}

\end{figure}