## Annex: Extended abstract

A new implementation of hearing impairment simulator WHIS based on the gammachirp filterbank
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A new implementation of Wakayama-university (Wadai) Hearing Impairment Simulator, WHIS, is reported. For this purpose, the gammachirp auditory filterbank (GCFB) was renovated to represent absolute thresholds for persons with normal hearing (NH) and with hearing loss (HL) (Fig.2, $\mathrm{GCFB_{v231}}$). Frame-base processing was also introduced to improve processing speed to be almost real time while the conventional GCFB (Fig.1, $\mathrm{GCFB_{v211}}$) took more than a few ten times of real time. Moreover, the outer haircell gain ($G_{out}$) in Eq. 15 and the inner haircell gain loss ($L_{out}$) was included into $\mathrm{GCFB_{v231}}$. The OHC health $\{\alpha | 0 \leqq \alpha \leqq 1\}$ was introduced into the parameter $c_2$ as in Eq. 9 to represent the hearing loss caused by the outer haircell dysfunction. The hearing loss by OHC and IHC was formulated as shown in Eq. 8. Figure. 3 shows schematic cochlear input/output (IO) functions where the output level is relatively defined from the absolute threshold. In contrast with the NH case (blue solid line), the OHC health $\alpha$ of 0.5 reduces the degree of compression (red dashed curve). The IHC loss $L_{IHC}$ is further introduced to make the IO function across the point of HL 45 dB (purple dashed and dotted curve).

Figure 5 shows a new implementation of the analysis part of WHIS ($\mathrm{WHIS_{V300}}$) based on $\mathrm{GCFB_{v231}}$ in Fig. 2. The main filters are the same and there is difference in the used of the IO function. Two synthesis methods were developed: direct time-varying filter (DTVF) used in the previous WHIS ($\mathrm{WHIS_{v225}}$) [1] and filtebank analysis/synthesis (FBAS). DTVF is advantageous in the quality of simulated sound while FBAS is advantageous when simulating degradation of temporal resolution in the auditory pathway.

Comparisons were performed between the output of GCFB with hearing loss (HL) condition ($\mathrm{GCFB^{(HL)}}$) and the output of GCFB with normal hearing (NH) condition followed by WHIS ($\mathrm{WHIS + GCFB^{(NH)}}$). Figure 4 shows the IO functions of NH (blue solid line) and HL of the average 80 years-old Japanese male [9] when the OHC health $\alpha$ is 0 (dark red dashed and dotted line), 0.5 (purple dashed and dotted line), and 1 (green dashed line). Panels (a1)sin(a4) show the results of $\mathrm{GCFB^{(HL)}}$. Other panels show the results of $\mathrm{WHIS + GCFB^{(NH)}}$ when using $\mathrm{WHIS_{V300}^{DTVF}}$, $\mathrm{WHIS_{V300}^{FBAS}}$, $\mathrm{WHIS_{v225}}$, and Cambridge version of hearing loss simulator (CamHLS) [3, 4]. The IO functions of $\mathrm{GCFB^{(HL)}}$ are similar to those of $\mathrm{WHIS + GCFB^{(NH)}}$ except when $\alpha = 1$, i.e., healthy OHC. Figure 6 shows spectral distance $d_S$ (Eq. 22) calculated between $\mathrm{GCFB^{(HL)}}$ and $\mathrm{WHIS + GCFB^{(NH)}}$ when SPL level ($L_{eq}$) is 50 dB (upper panels) and 80 dB (lower panels) and when $\alpha = 1$, 0.5, and 0. $d_S$ values of $\mathrm{WHIS_{V300}^{DTVF}}$, $\mathrm{WHIS_{V300}^{FBAS}}$, and $\mathrm{WHIS_{v225}}$ are almost the same and smaller than those of CamHLS. This might be because CamHLS performs spectral smearing which increases the distortion.

$\mathrm{WHIS_{V300}}$ would be useful because it is possible to use the same GUI as in $\mathrm{WHIS_{v225}}$ for interactive experience of hearing loss as well as to use batch processing for producing experimental stimuli. The software of $\mathrm{WHIS_{V300}}$ [10] and $\mathrm{GCFB_{v231}}$ [11] will be provided in GitHub.