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A low-latency, low-complexity psychoacoustical masking model for hearing-impaired users

→ Introduction

Psychoacoustical masking models are useful for areas as diverse as audio coding, hearing aid processing or music quality enhancement.

Most models have focused exclusively on normal hearing. This study seeks to develop a masking model that extends previous efforts towards the option to incorporate hearing impairment.

Additionally, an objective evaluation model has been developed and used for validation.

→ The masking model

The proposed masking model builds on an already published psychoacoustical model [1], which is modified to be appropriate for hearing aid processing, and to account for effects of hearing impairment on masking. The model broadly consists of four parts; an overview can be seen in figure 1.

I. Inner ear processing

- Modelled as a filterbank of either Gammatone or –chirp filters, depending on computational limits and precision of response.
- Degraded frequency selectivity is incorporated by using a filter widening parameter *w,* which provides the bandwidth of the gammatone filters in ERBs

$$w = \frac{1}{1 + e^{-0.06(PTA - 65)}} + 1, PTA > 0$$

II. Spectral mask estimation

- It is assumed that the detection of distortions can be integrated over multiple auditory filters, giving the total detectability, *D(m,s)*, as

$$D(m,s) = C_s \sum_i \frac{\sum_f |\gamma_i(f)|^2 |s(f)|^2}{\sum_f |\gamma_i(f)|^2 |m(f)|^2 + C_a}$$

Where *s* is the signal power, *m* is the masker, y(f) the filter response and C_s and C_a as calibration constants.

III. Absolute threshold

- The spectral mask uses the minimum audible pressure (MAP) as the reference level, readily allowing for incorporation of individual hearing thresholds.

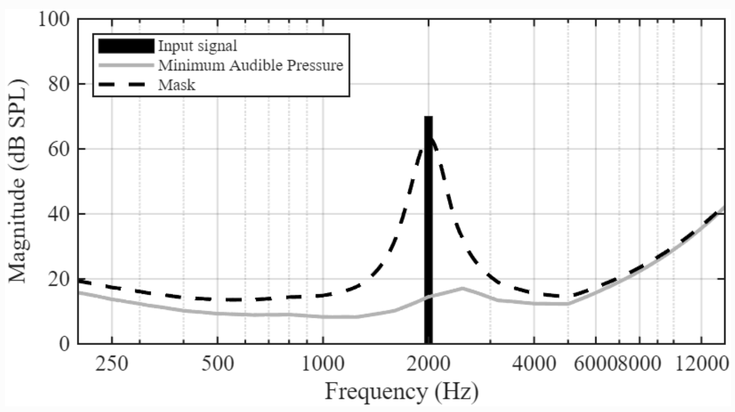

Fig. 2. Spectral mask in dB SPL for a pure tone using MAP as the reference level.

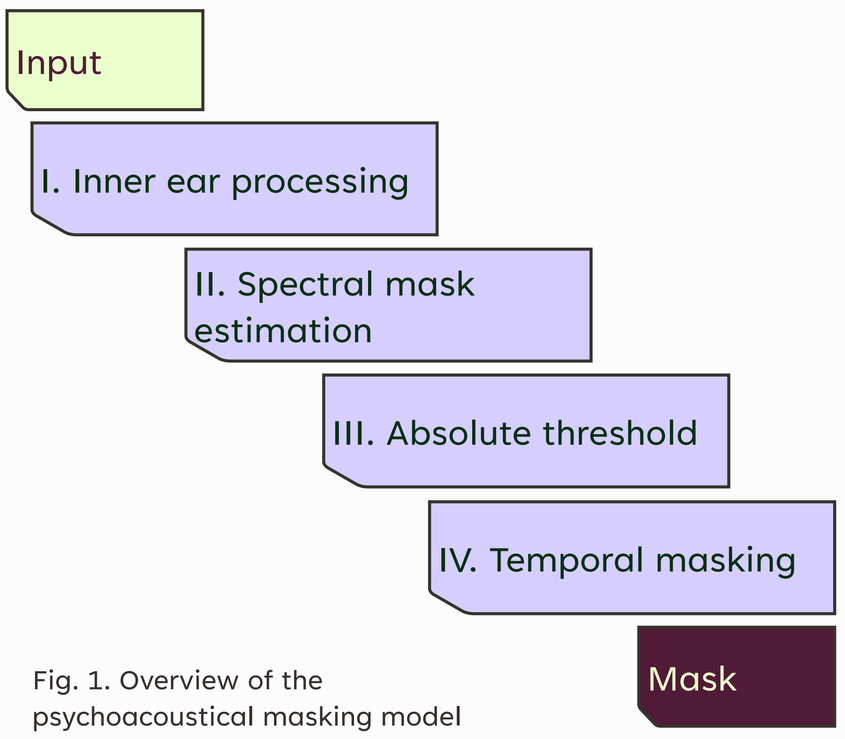

Fig. 1. Overview of the psychoacoustical masking model

IV. Temporal masking

- Forward temporal masking is modelled as an asymmetric 1st order low-pass filter (figure 3) with instantaneous attack.
- This inherently incorporates hearing loss as the response decays to the individual hearing threshold.
- The total mask is then the max of the spectral mask and the forward masking response.

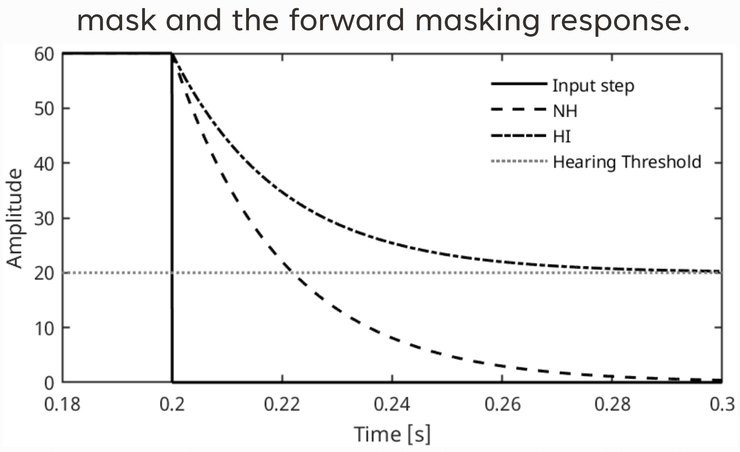

Fig. 3. Impulse response of the forward masking filter.

→ Evaluation procedure

Hypothesis:

An observer with a more severe hearing loss than the one used to calculate the masked threshold in the psychoacoustical masking model, will be less likely to perceive noise injected under the masked threshold of a signal, compared to an observer with a less severe hearing loss than the one used in the masking model.

Noise is shaped to the masked threshold and injected to the sound stimuli, as shown in figure 4.

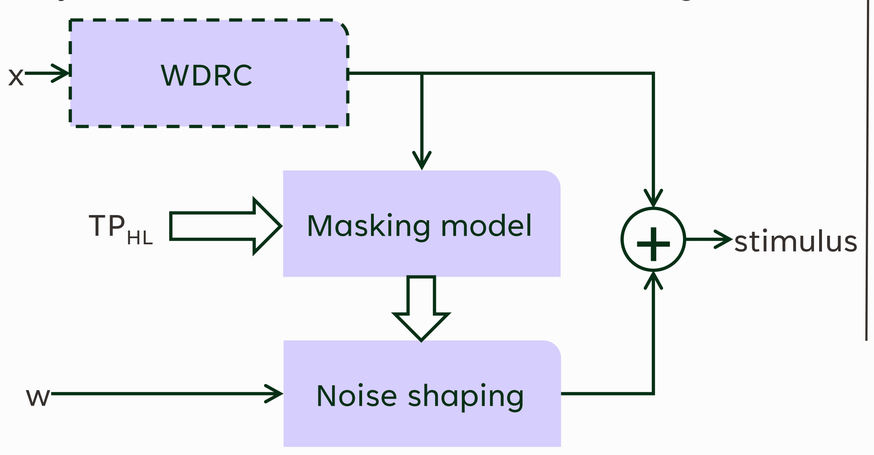

Fig. 4. Noise injection procedure for generating sound stimuli.

→ Objective evaluation model

- The objective evaluation model is based on a phenomenological model of the auditory periphery [2-3] giving a neurogram.
- Two equally weighted pairwise measures are computed for the neurograms; Kolmogorov-Smirnov statistical test and Euclidian distance.
- The objective model allows for testing a range of observer hearing profiles, in this cases using the standard audiograms for flat and moderately sloping hearing losses.
- The hearing profile for the masking model is kept constant with varying observer hearing profiles.

→ Results

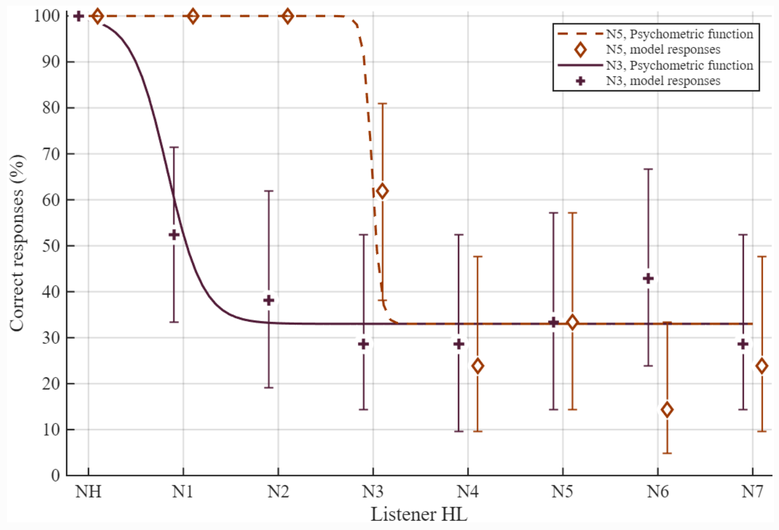

Fig. 5. Gammatone detection rates for 8 observer hearing profiles with the masked threshold calculated from either an N3 or N5 hearing loss.

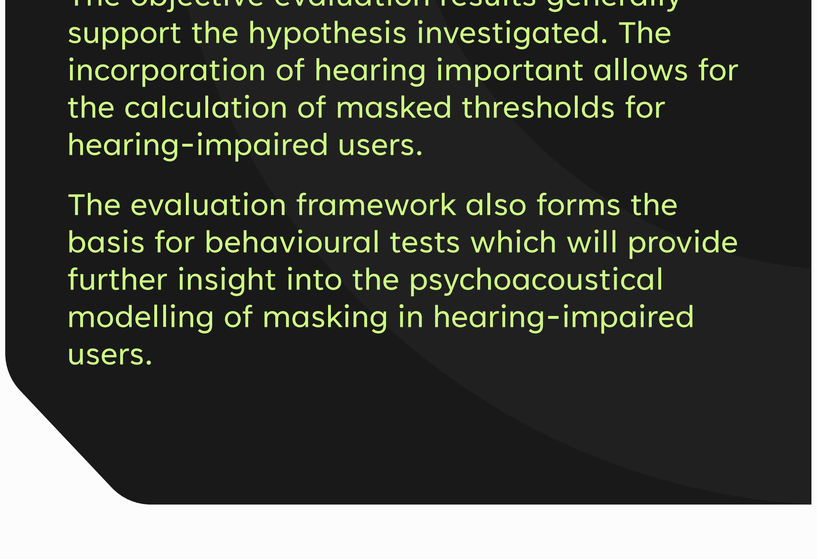

Fig. 6. Detection rates for the Gammatone filterbank model. The audio stimuli have been pre-processed with a wide dynamic range compressor with NAL-NL2 compression gains.

→ Conclusions

The objective evaluation results generally support the hypothesis investigated. The incorporation of hearing important allows for the calculation of masked thresholds for hearing-impaired users.

The evaluation framework also forms the basis for behavioural tests which will provide further insight into the psychoacoustical modelling of masking in hearing-impaired users.

[1] S. van de Par et al. (2002). A new psychoacoustical masking model for audio coding applications.
[2] Bruce, I.C., Erfani, Y., and Zilany, M.S.A. (2018). "A Phenomenological model of the synapse between the inner hair cell and auditory nerve: Implications of limited neurotransmitter release sites,"
[3] Bruce, I., Buller, A., and Zilany, M. "Modeling of auditory nerve fiber input/output functions near threshold,"

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