Short release note Verhulst et al. 2018 model, version 1.2

Model simulations using the updated IC stage

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Abbreviations	
ABR	Auditory Brainstem Response
CN	Cochlear Nucleus
IC	Inferior Colliculus
IIR	Infinite Impulse Response

1 Introduction

We found (and corrected) a bug in the implementation of the IC stage of the auditory model version 1.1 [1]. All previous stages (middle ear, transmission-line model, inner hair cell model, auditory nerve model, see Fig. 1 in [1]) remained unchanged. Further, only in the IC/CN stages a minor change was introduced. A new release of the model has been published (model version 1.2) where, in addition to the corrected IC stage, a different calibration procedure to match ABR amplitudes (waves I, III, V) was introduced. The implications of these changes on the simulation results presented in the model paper [1] are shown in the extended version of this document[1].

2 Model update

In **model2018 v1.2** there were two changes introduced to the CN/IC model (script ic_cn2018.py). One of the changes (correction of the bug) is very relevant and it affects the IC implementation while the other is a minor change that was introduced to the lowpass filter design of alpha functions (see Section 3, in the extended document). The bug in the IC implementation produced that IC outputs in model v1.1 were dominated by excitatory neural responses while the effect of inhibitory responses was nearly marginal. Due to the corrected IC implementation, the scaling factor M5 (referred to as $A_{\text{W-V}}$ in the model paper [1]) had to be updated. Additionally, we decided to implement a more accurate calibration procedure of the scaling factors, in line with the reference data of Picton [2]. In consequence, all scaling factors of model version 1.1 had to be readjusted. The new calibration procedure is described in the extended document and the adopted scaling factors are indicated in Table 1.

Table 1: Scaling constants to bring ABR Waves I, III, and V to a realistic peak amplitude before (v1.1) and after (v1.2) correcting the bug and adopting a new calibration procedure.

Constant label		Value (dimensionless)		ABR amplitudes from	
Paper	Model	Model v1.2 (New)	Model v1.1 (and earlier)	Model v1.2	Model v1.1
$A_{\text{W-I}}$	M1	$4.2767 \cdot 10^{-14}$	$6.2755 \cdot 10^{-14}$	0.15 [μV_p]*	0.30 [μV_{pp}]
$A_{\text{W-III}}$	M3	$5.1435 \cdot 10^{-14}$	$7.2161 \cdot 10^{-14}$	0.17 [μV_p]*	0.34 [μV_{pp}]
$A_{\text{W-V}}$	M5	$13.3093 \cdot 10^{-14}$	$3.5200 \cdot 10^{-20}$	0.61 [μV_{pp}]	0.61 [μV_{pp}]

* The Picton's normative data [2] is reported to be 0.30 and 0.34 [μV] peak-to-peak for waves I and III, respectively. We assumed that the corresponding baseline-to-peak voltages are approx. half of these values.

[1] The extended version of this document is in preparation and will soon be uploaded to the GitHub repository.

The minor change introduced to the lowpass filter implementation of alpha functions is summarised in Table 2 (whose comprehensive description is given in the extended version of this document) and it only brought the passband gain of the filter from nearly to exactly unity. This means that this change has only a marginal effect on the simulated outputs, and it was introduced for full mathematical agreement with the original continuous time formulation of alpha functions. The (digital) z-transform of the digital implementation of alpha functions is given by:

$$H(z^{-1}) = C \cdot \frac{b_0 + b_1 \cdot z^{-1} + b_2 \cdot z^{-2}}{a_0 + a_1 \cdot z^{-1} + a_2 \cdot z^{-2}} \tag{1}$$

where the coefficients a_0, a_1, a_2, b_0, b_1, b_2, and the constant C adopt the values indicated in Table 2.

Table 2: Coefficients of the transfer function (IIR filter) used within the CN and IC models. The time constants τ were kept ($\tau_{\text{exc}} = 0.5$ ms and $\tau_{\text{inh}} = 2$ ms for both CN and IC models, and f_s corresponds to the sampling frequency of the neural representations.

Model version	Numerator b_0	b_1	b_2	Denominator a_0	a_1	a_2	m	Factor C	Passband gain G [dB]
v1.2	1	2	1	1	$-2 \cdot m$	m^2	$\frac{2 \cdot f_s \cdot \tau - 1}{2 \cdot f_s \cdot \tau + 1}$	$\frac{1}{(2 \cdot f_s \cdot \tau + 1)^2}$	0.00
v1.1 (and earlier)	1	2	1	1	$-2 \cdot m$	m^2	$\frac{2 \cdot f_s \cdot \tau - 1}{2 \cdot f_s \cdot \tau + 1}$	$\frac{1}{(2 \cdot f_s \cdot \tau)^2}$	0.22 ($\tau = 2$ ms), 0.85 ($\tau = 0.5$ ms)*

*Gains assessed using the default sampling frequency $f_s = 20$ kHz that is used for simulated neural responses.

References

[1] S. Verhulst, A. Altoè, and V. Vasilkov. "Computational modeling of the human auditory periphery: Auditory-nerve responses, evoked potentials and hearing loss". *Hear. Res.* 360, (2018), 55–75.

[2] T. Picton. "Auditory brainstem responses: peaks along the way". In: *Human auditory evoked potentials.* Plural Publishing, 2011. Chap. 8, pp. 213–245.