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Cross-correlation model of interaural time difference coding in listeners with bilateral cochlear implants

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Introduction

- Sound localization is crucial for successful communication in natural acoustic environments.
- Listeners with binaural hearing loss or deafness are increasingly prescribed with bilateral cochlear implants (BiCI) which provides the listeners an access to binaural input. However, the BiCI listeners show severely impaired sound localization ability, despite an access to the binaural signals.
- It has been suggested that the impaired localization is mainly due to the inability of the BiCI listeners to utilize interaural time difference (ITD) cues.
- Various stimulation related parameters (e.g. pulse rate or shape of the envelope) have been shown to affect ITD coding, however neural factors that affect the encoding of ITD in BiCI listeners are unknown.
- The current study presents a physiologically inspired model of ITD coding in BiCI listeners, which simulated the responses of electrically stimulated auditory nerve fibers (ANF) from ipsilateral and contralateral ears and performs a coincidence detection using a neural cross correlation analysis.
- The model predictions are compared with behavioral data from several studies.

Cross-correlation model of ITD coding

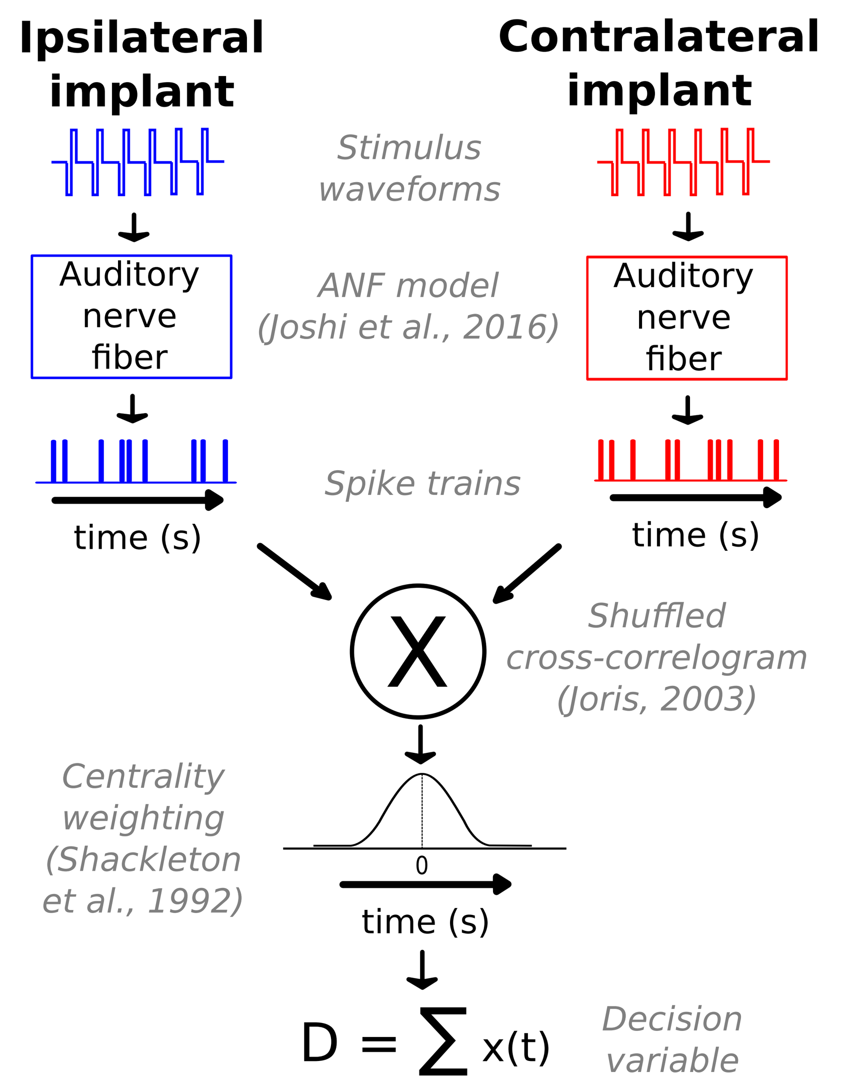

Figure 1 The structure of the cross-correlation model of ITD coding, consisting model of electrically stimulated auditory nerve fiber responses, cross-correlation stage and decision device.

Model of electrically-stimulated auditory nerve responses

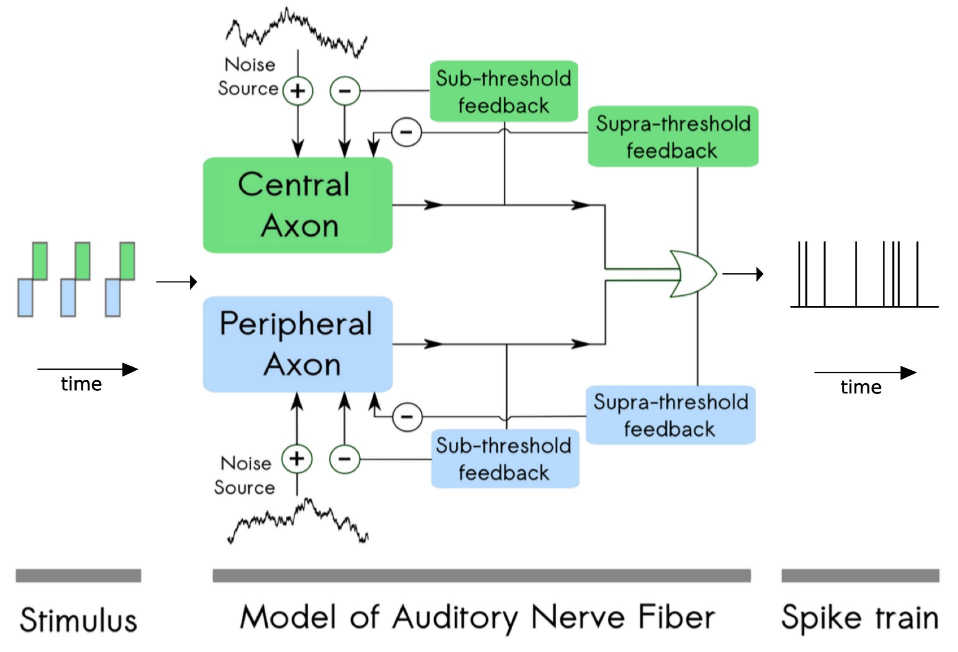

Figure 2 The structure of the model of electrically stimulated auditory nerve fiber responses (Joshi et al, in press). The model consists of two sites of spike generation as well as sub-thresholds and supra-threshold adaptive current feedback loops. The model has been shown to correctly account for the effect of stimulation with various pulse shapes and pulse rates on response statistics of the ANFs.

Stimuli

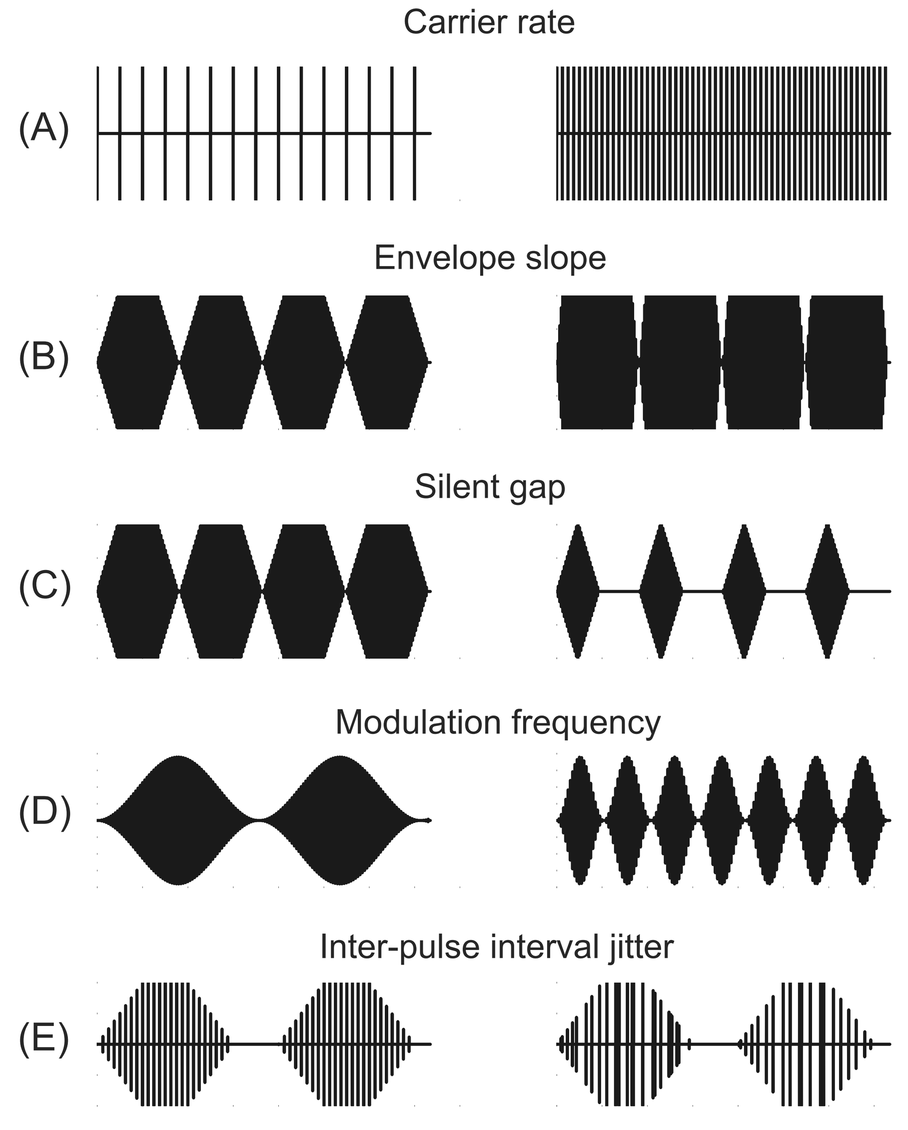

Figure 3 Illustration of stimuli used in the current study, showing the variation in carrier rate **(A)**, variation in envelope defined using envelope slope **(B)** or duration of the silent gap between the envelope bursts **(C)**, variation in sinusoidal modulation frequency **(D)** and jitter of the inter-pulse-intervals **(E)**.

Neurometric analysis

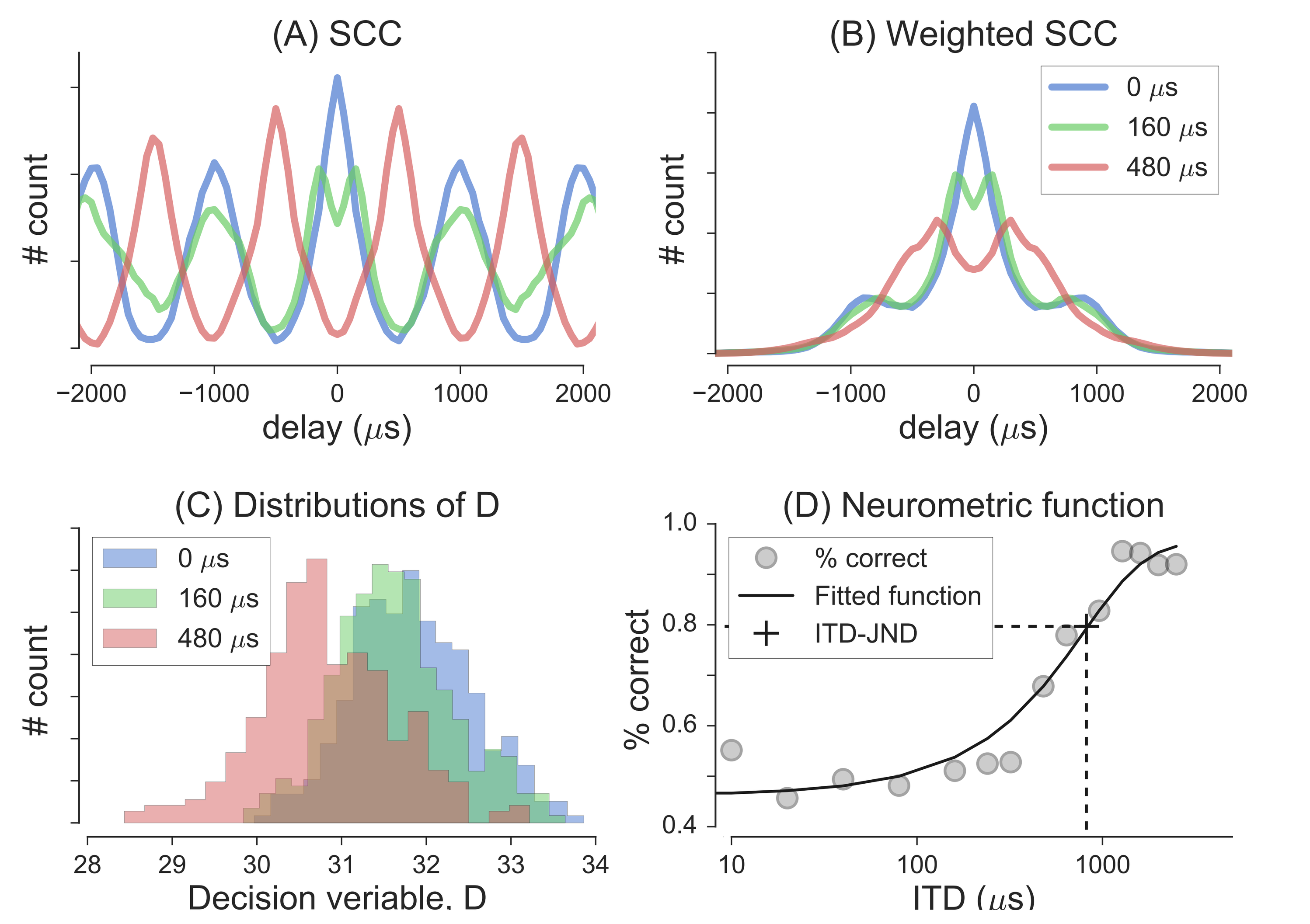

Figure 4 Examples of the SCC functions for a pulse train of 1000 pps with an imposed ITDs of 0 μs (blue line), 160 μs (green line) and 480 μs (red line) are shown in **A**. Corresponding centrality-weighted correlograms are shown in **B**. The resulting distributions of decision variables for the three ITDs based on 100 repetitions of the model simulations are shown in **C** for each of the three ITD values. The distributions of D show that the is highest for ITD = 0 μs and decreases with increasing the ITD. An example of the neurometric function fitted to the percent discrimination as a function of the value of imposed ITDs is shown in **D**.

Results

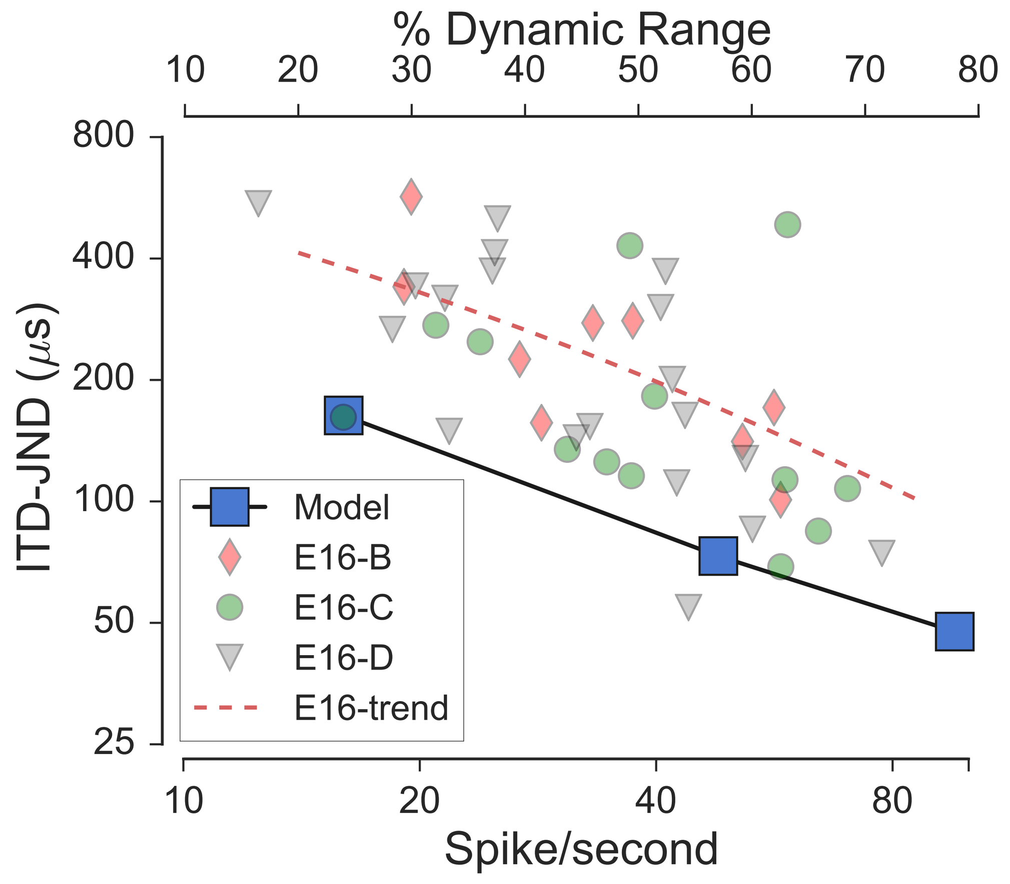

Figure 5 Predicted ITD-JNDs (squares) as a function of spike-rate for 100 pps pulse train. The corresponding behavioral data from Egger et al (2016) are indicated with different symbols as a function of percent dynamic range indicated on the top axis. The dashed line indicates a trend-line through the data.

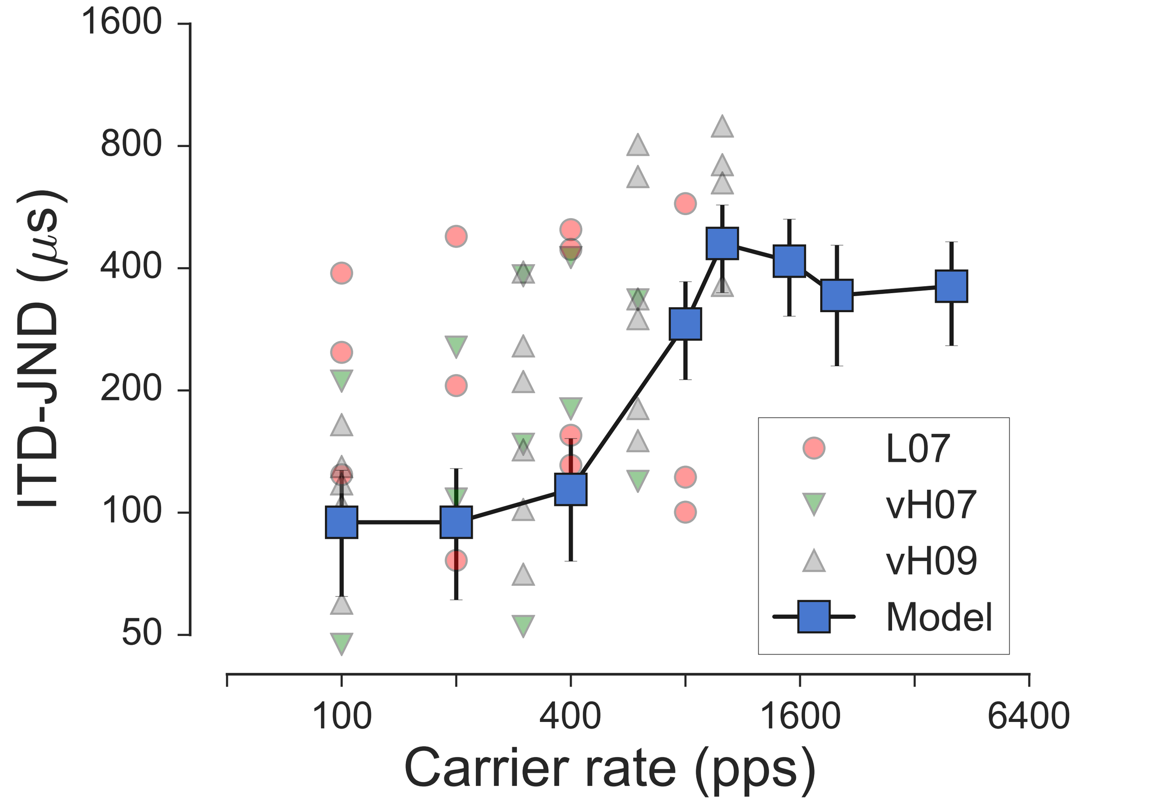

Figure 6 The predicted effect of carrier pulse rate on ITD-JNDs (blue squares), along with corresponding behavioral data from Laback et al. (2007) and van Hoesel (2007) and van Hoesel (2009).

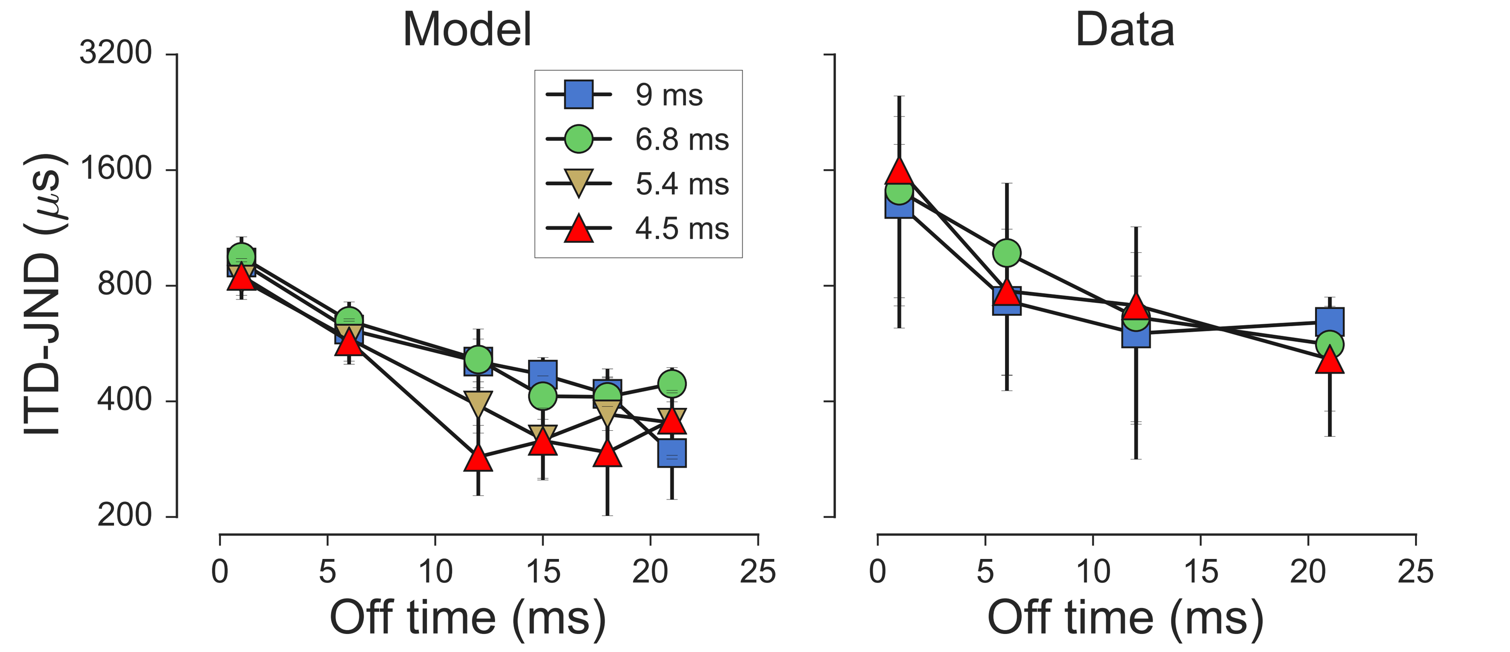

Figure 5 The predicted effect of envelope shape on ITD-JNDs. The ITD-JNDs for the envelope slope of 9 ms (squares), 6.8 ms (circles), 5.4 ms (downward triangles) and 4.5 ms (upward triangles) are indicated as a function of the silent gap duration. The corresponding behavioral data from Laback et al. (2011) is shown for a comparison.

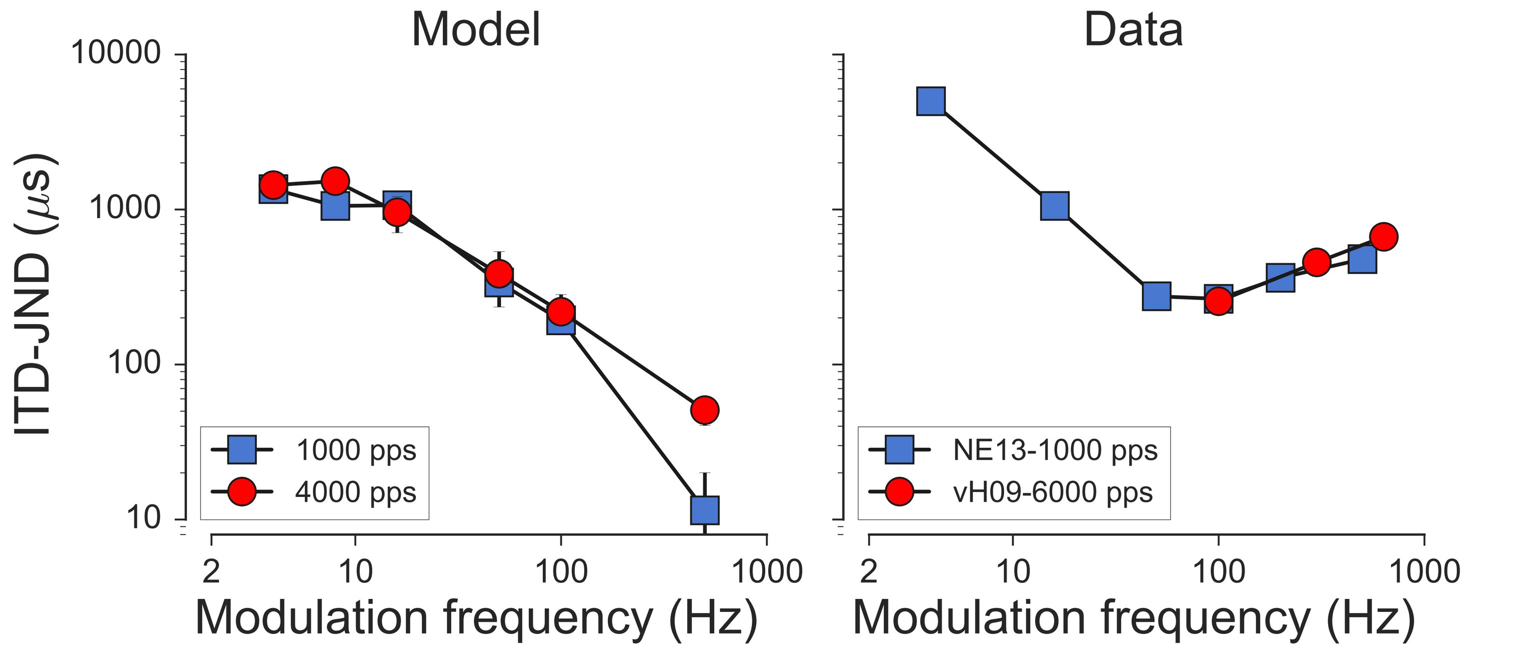

Figure 6 The predicted effect of modulation frequency on ITD-JNDs for carrier rates of 1000 pps (squares) and 4000 pps (circles). The corresponding behavioral data from Noel and Eddington (2013) and van Hoesel et al. (2009) are shown for a comparison. The model can predict reasonably accurate trends for the modulation frequencies up to 100 Hz.

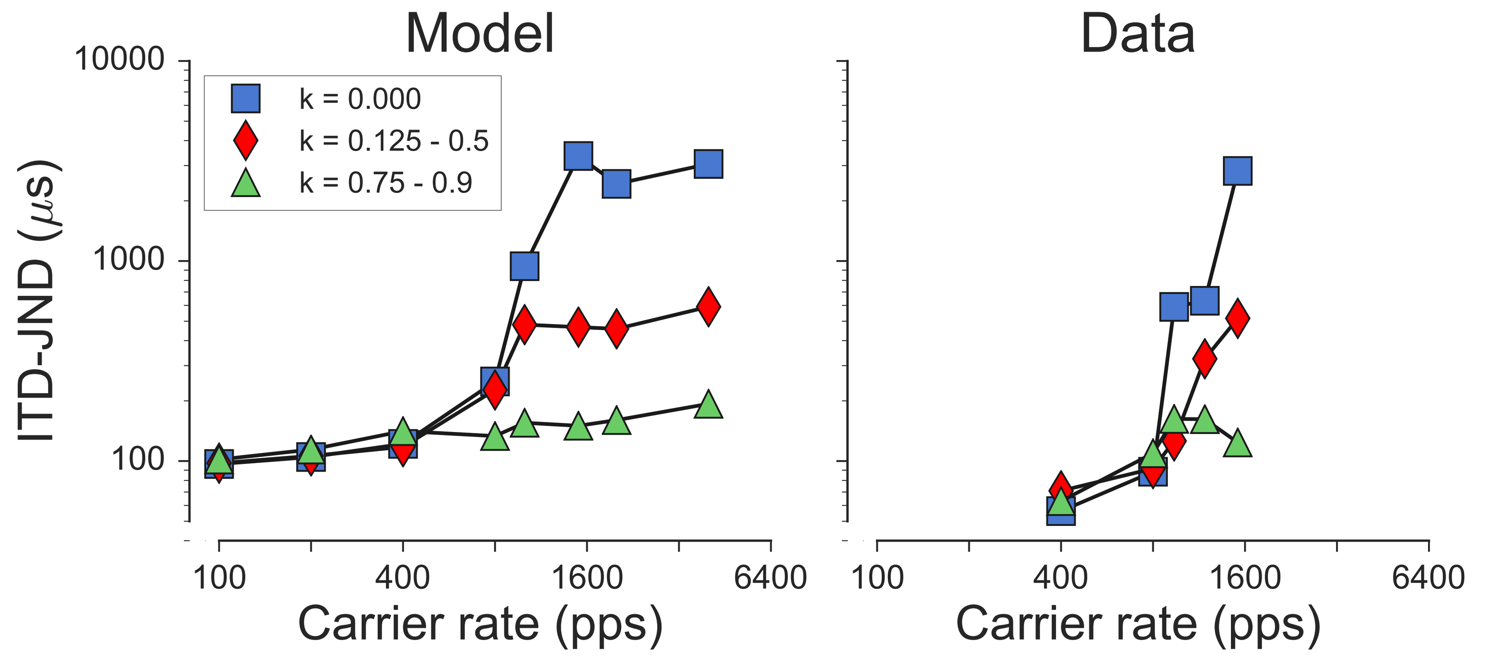

Figure 7 The predicted effect inter-pulse-interval jitter on the ITD-JNDs indicated as a function of the carrier rate along with corresponding data from Laback and Majdak (2008).

Discussion

- A physiologically inspired phenomenological model of ITD coding in bilateral CI listeners is presented and the model predictions were compared with behavioral data from several studies.
- The model can successfully account for the effect of various stimulus parameters such as the stimulus level, carrier pulse rate, envelope shape, modulation frequency and the inter-pulse-interval jitter on the ITD-JNDs observed in the data.
- In case of the amplitude modulated pulse train, the model can account for the effect of modulation frequencies up to 100 Hz. Beyond 100 Hz, the model predicts lowering in the ITD-JND whereas the data shows a slight increase.
- The model can be used to study the effect of various stimulus and auditory nerve fiber related parameters on the coding of neural coding and perception of ITDs.

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References: Joshi et al (in press), JARO; Joris (2003) JNeurosci 23(15); Shackleton et al (1992). JASA, 91(4); Egger et al (2016) JARO 17(1); Laback et al (2007) JASA, 121(4); Laback & Majdak (2008) PNAS 105(2); Van Hoesel (2007) JASA, 121(4); van Hoesel et al (2009) JARO, 10(4); Noel & Eddington (2013) JASA, 133(4)