Interaural Time Differences in Ongoing and Gating Signal Portions in Acoustic and Electric Hearing: Model Results

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Introduction

The relative contributions of interaural time differences (ITDs) in the ongoing and gating signal portions to lateralization discrimination were studied in three cochlear implant (CI) subjects and five normal hearing (NH) subjects listening to a simulation of electric stimulation. The first and last pulse of rectangularly gated pulse trains represented the gating portions (onset/offset) and the remaining pulses the ongoing signal. Experiment I studied the effects of the ITD type and of the pulse rate (100-800 pulses per second, pps). Experiment II examined the effect of signal duration at 100 pps. A multiple looks cross-correlation model is proposed, in which ITD information is integrated across time after applying a rate-dependent onset-weighting function. It accounts well for the effects in the NH listeners, but only for some of the effects in the CI listeners.

Experiment I

Methods

The effect of ITD on lateralization discrimination was measured using a 2-interval 2-AFC procedure. Just notice-able differences (JND) in ITD were determined by the me-thod of constant stimuli (6 ITD values, 60 repetitions each).

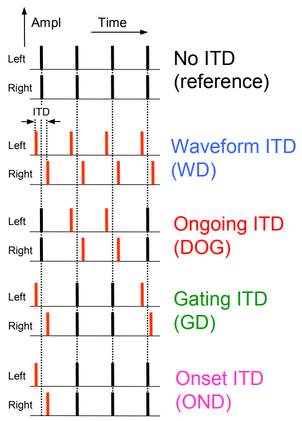

Fig. 1: ITD conditions tested in the experiments

Five NH listeners were presented with bandpass-filtered (3900-5400 Hz) acoustic pulses via headphones. Three CI listeners (*CI40+, MED-EL*) were presented with biphasic current pulses, at an interaurally loudness balanced and pitch matched electrode pair. JNDs were measured for the independent variables ITD type (see Fig. 1) and pulse rate (100, 200, 400, and 800 pps). A constant number of four pulses was used at all rates.

Results

For the average NH listener (Fig. 2, left), the JNDs for ongoing ITD (DOG) increase with the pulse rate, showing an upper rate limit of 200-400 pps. The JNDs for gating ITD (GD) are constant and for onset ITD (OND) decrease with the pulse rate. The CI listeners show less homogeneous results and the results are shown exemplarily for CI1 and CI8 (left panels of Figs. 3 and 4, respectively). Ongoing ITD (DOG) contributes up to 800 pps for CI8 and CI3 and at 100 pps only for CI1. For all CI listeners, the contribution of onset ITD increases with the pulse rate.

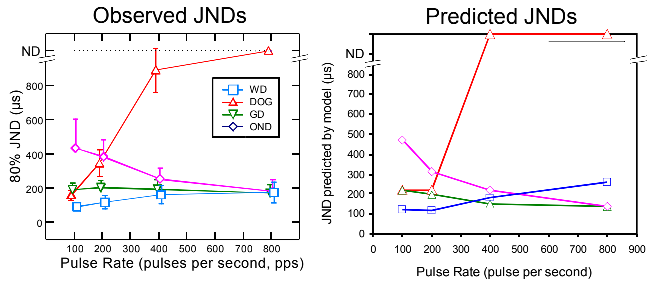

Fig. 2: Mean of observed results (left) and model predictions (right) of experiment I for NH listeners (n=5). JNDs are plotted as a function of pulse rate. The parameter is the ITD condition, as depicted in Fig. 1. Non-determinable JNDs are plotted at an arbitrary value, indicated as “ND”.

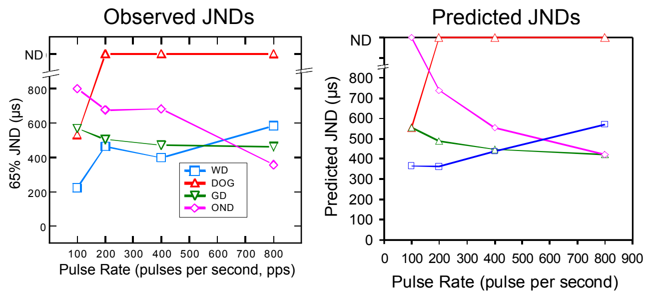

Fig. 3: As in Fig. 2, but for CI listener CI1.

Experiment II

Methods

The effect of the number of pulses (4, 8, 16, 24, 32, and 40) was tested for the ITD types DOG, GD and WD, using a pulse rate of 100 pps. All other aspects of stimuli and methods were the same as in experiment I.

Results

For the NH listeners (left panel of Fig. 7, empty symbols connected by lines), the JNDs for ongoing ITD decrease with increasing pulse number up to about 24 pulses (240 ms), which is consistent with the temporal integration effect [1]. The JNDs for gating ITD increase with the pulse rate.

For the CI listeners, the data were more homogeneous than in experiment I, thus mean results are shown (right side of Fig. 7, empty symbols connected by lines). The effects are similar to the effects observed for the NH listeners.

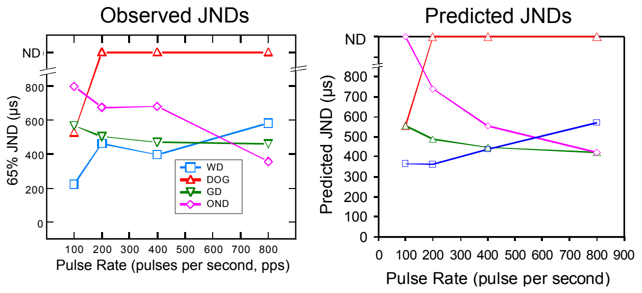

Fig. 4: As in Fig. 2, but for CI listener CI8.

"Multiple Looks" Lateralization Model

To model the effects, the classical cross-correlation model is not satisfying since it explains neither the rate-dependent onset dominance nor the temporal integration effect. A new "multiple looks" lateralization model (Fig. 5) is proposed to account for the effects.

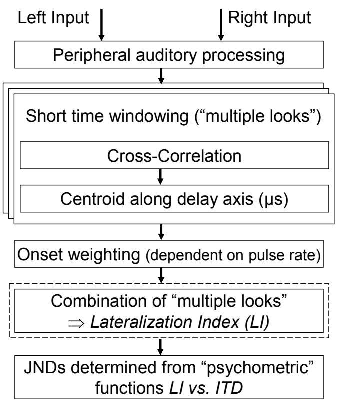

Fig. 5: Outline of "multiple looks" lateralization model.

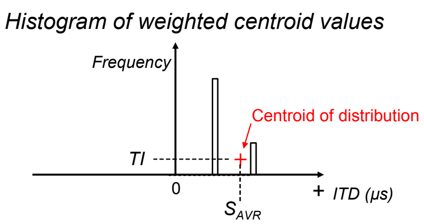

Fig. 6: Histogram of weighted centroid values (in µs), derived from the "multiple looks" model. The calculation of the lateralization index *LI* is based on the x and y coordinates of the centroid of this distribution (S_{AVR} and *TI*, respectively).

Short rectangular windows are centered at the temporal centers of each interaural pulse pair. For each window, the cross-correlogram and its centroid along the delay axis is calculated. The output of the first window is weighted, depending on the pulse rate, according to [2]. The lateralization index (*LI*) is based on the centroid of the distribution of weighted centroid values (see Fig. 6):

$$LI = S_{AVR} \cdot TI^{k} \qquad (1)$$

S_{AVR} corresponds to the centroid along the ITD values and models the average sidedness; *TI* is the centroid along the frequency and models temporal integration. The exponent k determines the efficiency of temporal integration (set to the optimal value: 0.5). Finally, JNDs are determined from the "psychometric functions" *LI* vs. ITD.

Model Evaluation

The acoustic stimuli were used to model the data of the NH and CI listeners. Two model parameters were optimized on the NH data of experiment I (results in parentheses): a) onset weighting function (increasing from 1 at 100 pps to 4 at 800 pps), b) window duration (1.25 ms). These parameters were also applied to predict experiment II.

Figs. 2-4 (right side) show the model predictions for experiment I (NH listeners, CI1, and CI8, respectively). For the NH listeners, 89% of the variance in the observed data are acounted for. For the CI listeners, only 68% (CI1), 63% (CI3), and 45% (CI8) of the variance are explained. In case of experiment II, the model explains 98% of the variance for the NH listeners and 90% for the CI listeners (Fig. 7, indicated with crosses).

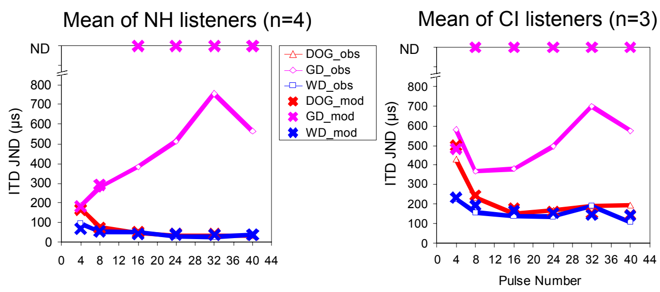

Fig. 7: Results of experiment II (empty symbols connected by lines) and model predictions (crosses). Left side: Mean for four NH listeners; right side: mean for three CI listeners. JNDs are plotted as a function of the number of pulses in the train.

Discussion and Conclusions

The finding that CI listeners are senstive to ongoing ITD indicates that the timing of the pulses ("fine structure") should be considered in CI stimulation strategies. Current CI strategies encode information solely via the envelope.

The proposed "multiple looks" lateteralization model accounts well for the effects observed with the NH listeners, i.e., the dependencies on the parameters ITD type, pulse rate, and duration. The predictions of the CI listeners' results for experiment I were less accurate: in particular, the model failed to predict the higher upper rate limit for ongoing ITD for CI3 and CI8 (800 pps) compared to the NH listeners (200-400 pps). In contrast, temporal integration of ongoing ITD was accurately predicted for all CI listeners.

Literature

[1] Discrimination of interaural differences of time in the envelopes of high-frequency signals: integration times. J. Acoust. Soc. Am. 84, 2063-2066.

[2] Observer weigthing of interaural delays in filtered impulses. Perception & Psychophysics 58, 1037-1046.