Nonuniform temporal weighting of interaural time differences in low frequency tones presented at low signal-to-noise ratio

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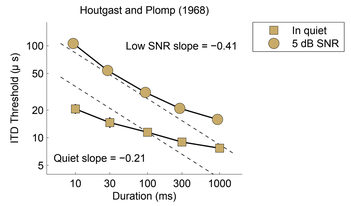
Background

Temporally nonuniform weighting of interaural-time differences (ITD) (for example, dominance of onset cues) has been demonstrated across a wide range of sound frequency, and may benefit sound localization by reducing the perceptual effects of late-arriving sound in echoic environments.

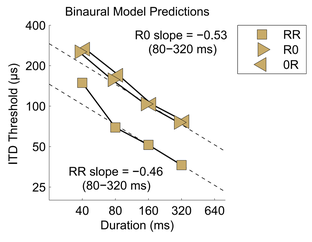
Suboptimal improvement in ITD threshold with sound duration is one well-documented consequence of such nonuniform weighting. First noted for 500 Hz noise band carriers by (Houtgast & Plomp, 1968), the slope of threshold improvement with duration appears shallower than expected if listeners use all of the available information for discrimination. Similar results have been obtained for modulated high-frequency sound (Hafter & Dye 1983) and for 500 Hz pure tones (Diedesch, Bibee, and Stecker 2012).

Effects of masking noise on temporal weighting of ITD. Several observations suggest that masking noise might alter the pattern of temporal weighting, so that later parts of a sound contribute more strongly. Most critically, Houtgast & Plomp (1968) noted close-to-optimal improvements in ITD threshold with duration, when the signal-to-noise ratio was low (5 dB, see Figure below).

In this study, we measured fine-structure ITD thresholds for 500Hz pure tones in the presence of a continuous 500Hz octave band masker, at a 5dB signal-to-noise ratio (similar to the conditions tested by Houtgast & Plomp, 1968), to investigate the temporal weighting of ITD for tones presented in noise.



ITD thresholds improve suboptimally with sound duration in quiet, but close to optimally at low SNR. ITD thresholds (vertical axis) are plotted against duration (horizontal axis). Data replotted from Houtgast and Plomp (1968), for 500 Hz octave band noise targets presented in quiet (squares) or in the presence of a 500 Hz octave band continuous noise at 5dB SNR (circles). Dashed lines plot expectations based on optimal integration of ITD across duration (a slope of 1/√T, or -0.5 on this log-log plot).

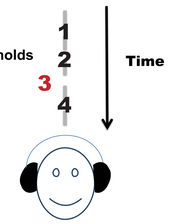


Simulated data for the conditions of the current study. Individual trials of the current study were simulated by comparing the frequency- and time-averaged output of binaural cross correlation (Akeroyd 2001) for a diotic reference and ITD-bearing target carrying independent, binaurally uncorrelated noise. Left/right decisions were used to simulate 100 adaptive tracks per condition. Except for the shortest durations, thresholds in all conditions improve at the optimal rate (dashed line) of -0.5 in log-log coordinates. The pattern is not dependent on SNR.

Methods

Task:

- **4 interval, 2 alternative forced choice (4I2AFC)**
- **Target in either the 2nd or 3rd interval**
- **Right leading ITD**
- **Headphones used to measure lateralization thresholds**
- **2 down, 1 up Levitt tracker**

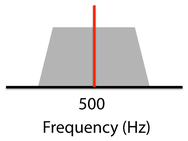


Stimulus:

- **Frequency:** **500 Hz pure tone**
- **Intensity:** **60 dB SPL**
- **Duration:** **40 – 640 msec (RR)**
  80 & 320 msec (R0 & 0R)
- **Ramp:** **20 msec, diotic**
- **Freq. Rove:** **± 10%**

Masker:

- **Frequency:** **500 Hz**
- **Bandwidth:** **Octave**
- **Intensity:** **55 dB SPL (5 dB SNR)**
- **Duration:** **Continuous**



Stimulus Conditions:

1. **"RR" - Constant ITD throughout the duration**
2. **"R0" - No offset ITD**
3. **"0R" - No onset ITD**

Pure tone target stimuli used in this experiment are depicted above, not to scale. Targets in all conditions carried a right leading ITD cue. The temporal profile of ITD sensitivity was measured using three test conditions. The "RR" condition provided a constant binaural cue throughout the duration of the pure tone stimulus, while the "0R" and "R0" conditions progressed linearly to eliminate the cue from either the beginning or the end of the tone, eliminating the onset or offset cue (respectively). Not shown is the continuous 500 Hz masking noise.

References

Akeroyd MA (2001). "Binaural toolbox for MATLAB" http://www.ihr.mrc.ac.uk/products/index.php?page=matlab

Diedesch, A.C., Bibee, J., & Stecker, G.C. Temporal weighting for interaural time differences in low-frequency pure tones. Poser presented at the Acoustical Society of America conference, Kansas City, MO, October, 2012.

Hafter ER and Dye RH (1983). Detection of interaural differences of time in trains of high-frequency clicks as a function of interclick interval and number J. Acoust. Soc. Am. 72:644-651

Houtgast, T. & Plomp, R. (1968). Lateralization threshold of a signal in noise. J. Acoust. Soc. Am. 44:807-812.

Acknowledgements

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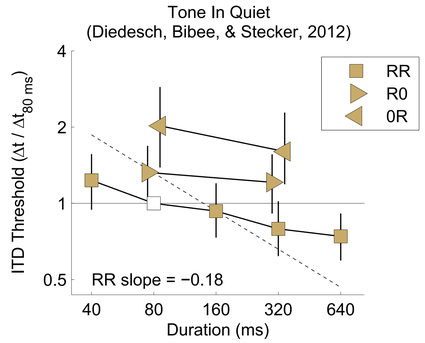
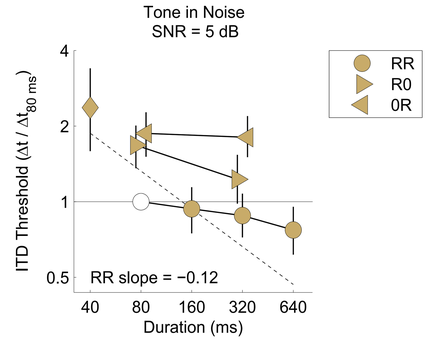
Results

Suboptimal improvement with duration in quiet...

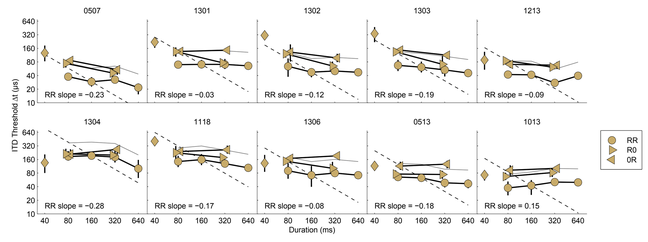


Mean normalized ITD thresholds (vertical axis) versus duration (horizontal axis) for 500 Hz pure tones presented in quiet. ITD cues were constant throughout the tone duration in condition RR (squares), peaked at sound onset in condition R0 (rightward-pointing triangles), or peaked at sound offset in condition 0R (leftward-pointing triangles). Thresholds were normalized to the RR 80ms condition (white square) prior to averaging across subjects. Error bars represent bootstrapped 95% confidence intervals on the group mean. Dashed line indicates the optimal improvement slope of 1/√T (-0.5 in log-log coordinates).

...and at low SNR



Mean normalized ITD thresholds (vertical axis) versus duration (horizontal axis) for 500 Hz pure tones presented in continuous masking noise. As in the previous study, ITD cues were constant throughout the tone duration in condition RR (circles; diamond plots discrepant data at 40 ms) or peaked at sound onset (R0, rightward-pointing triangles) or offset (0R, leftward-pointing triangles). Thresholds were normalized to the RR 80ms condition (white circle) prior to averaging across subjects.



Individual subject data for the tone-in-noise experiment. For each subject (panels), ITD thresholds, in microseconds (vertical axis) are plotted against duration (horizontal axis). Light gray line represents two times the RR threshold at each duration, one estimate of the "ideal" R0 and 0R thresholds. Symbols and other elements as in the previous figures.

Summary & Discussion

1) For 500 Hz tones in quiet **and at 5 dB SNR**, ITD thresholds improve shallowly (suboptimally) with tone duration, consistent with temporally nonuniform ITD weighting.

2) Dynamic-ITD thresholds are lower for ITD carried early than late in a tone, consistent with onset dominance for fine structure ITD at low frequencies, as for envelope ITD at high frequencies.

3) The difference in duration effects on ITD threshold noted by Houtgast and Plomp (1968) for sounds presented in quiet vs low SNR **was not replicated in this study**. May be related to differences in target stimulus (noise band vs pure tone), or the result may not be particularly robust.

4) ITD discrimination at the shortest duration (40 ms) was substantially impaired by masking noise. This may relate to the similar binaural configurations of masker and reference stimuli.