Binaural interference with dynamic interaural cues

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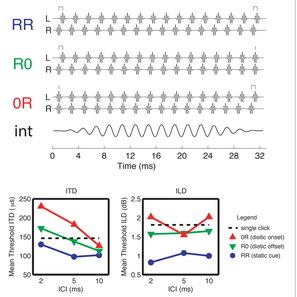
Background

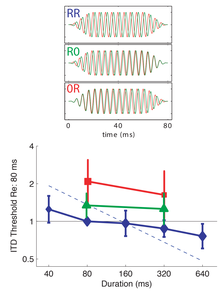
Onset dominance: binaural cues present at sound onsets dominate spatial perception of sounds with dynamic cues

Envelope ITD at 4000 Hz
(Stecker and Brown 2010)



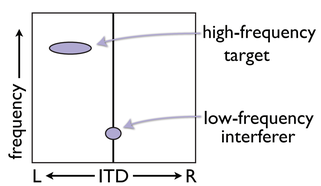
Top: stimuli used by Stecker and Brown (2010) to measure discrimination of binaural cues distributed statically (RR) or dynamically (R0, 0R) over sound duration. Interferer waveform the current expement also shown. Bottom: eliminating onset ITD (condition 0R) dramatically impaired discrimination at short interclick interval (ICI). ILD exhibited less temporal asymmetry.

Fine-structure ITD at 500 Hz
(Stecker and Bibee 2014)



Top: stimuli (not to scale) used to measure dynamic fine-structure ITD thresholds. Interaural frequency difference in conditions R0 and 0R results in dynamic ITD peaking at onset or offset of sound. Diotic gating reduces "envelope" cues. Bottom: as for high-rate click trains (Stecker and Brown 2010), better discrimination of low-frequency ITD is obtained with cues present at onset. Consequently, static-cue thresholds improve only shallowly with sound duration.

Binaural interference: cues in salient frequency regions dominate spatial perception when cues differ across frequency

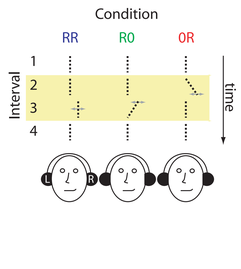


Binaural Interference depends on salience of target and interferer cues
- Low-frequency tones interfere with ITD in high-frequency SAM tones (McFadden & Pasanen 1976)
- High frequencies interfere with low-frequency ILD (Heller and Richards 2010)
- Slow "transposed" tones (salient envelope ITD) partly immune to BI (Bernstein and Trahiotis 2004)

Questions:

Are filtered impulse trains susceptible to binaural interference?
Are (salient) onset cues less susceptible than less-salient cues?

Approach



Targets were trains of 16 Gabor clicks
- CF = 4 kHz, ICI = 2 ms, 80 dB peSPL, 32 ms

Interferer: diotic 500 Hz pure tone
- 32 ms dur incl. 10 ms rise/fall, 80 dB peSPL

ICI/freq rove (±10%) sync. to target & interferer

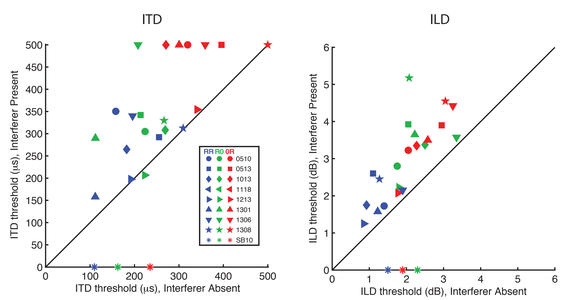
Binaural cues (ITD or ILD) applied to target:
- RR: static cue
- R0: peak cue at onset, linear fade to 0 at offset
- 0R: diotic onset, peak cue at offset

Discrimination threshold for peak cue measured
- 4I2AFC procedure with diotic reference (left)
- Two interleaved adaptive tracks (2d/1u)
- Peak cue range 0-500 µs ITD or 0-10 dB ILD
- Thresholds averaged 8 reversals

Subjects (8 normal-hearing young adults)
- completed min 4 runs (8 tracks) per condition
- "no threshold" if 3/8 or 4/10 tracks at ceiling

Results

Binaural discrimination thresholds

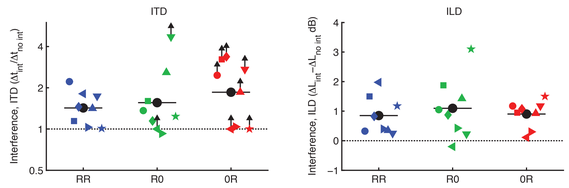


Discrimination thresholds for ITD (left) or ILD (right) obtained by individual subjects (symbols) in each cue condition (blue = RR, green = R0, red = 0R). Horizontal axes indicate thresholds in absence of 500 Hz interferer. For comparison, group-average data from identical conditions in Stecker and Brown (2010) are plotted by asterisks (*) along the axis. Vertical axes plot thresholds measured in the presence of 500 Hz interferer. Error bars indicate bootstrapped 95% confidence intervals. Symbols plotted at y=500 µs correspond to conditions in which fewer than 6 tracks converged below the ceiling value of 500 µs. This mainly occurred for ITD thresholds in condition 0R when the interferer was present.

Thresholds were higher with interferer present, regardless of cue configuration (Wilcoxon signed-rank test, $p<.05$). Independent of interferer condition, ITD thresholds were significantly higher in condition 0R than R0 ($p<.05$), but did not differ between RR and R0. Also regardless of interferer condition, ILD thresholds were lowest in condition RR ($p<.05$) but did not differ between conditions R0 and 0R.

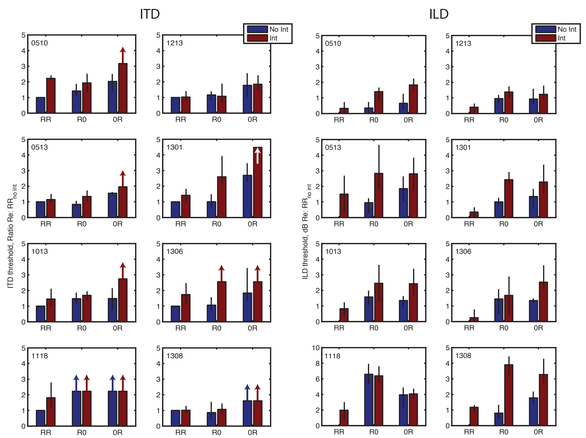
Results

Binaural interference index



Degree of binaural interference, estimated by computing the ratio of ITD thresholds (left), or difference in ILD thresholds (right) between interference and no-interference conditions. Individual-subject data are plotted by symbol type following the previous figure, with vertical black arrows indicating estimates affected by the lack of reliable below-ceiling data (mainly confined to condition 0R, ITD with interferer). Dashed lines indicate expected values for zero binaural interference. Across-subject means (geometric means in the case of ITD ratios) are indicated by large black symbols with horizontal lines, although these are likely biased downward by ceiling effects, as well.

Normalized discrimination thresholds



Normalized thresholds (vertical axes) for individual subjects (separate panels) in each cue condition (horizontal axes), measured in presence (red bars) or absence (blue bars) of diotic 500 Hz interferer. In each panel, thresholds were normalized to the value obtained in condition RR without interferer. Normalization by division for ITD thresholds (left panels) or by subtraction in dB for ILD thresholds (right panels). Arrows indicate conditions in which thresholds could not be estimated due to a large number of threshold tracks finishing at ceiling (500 µs).

Discussion

1. Binaural interference does affect (high rate) filtered impulse trains

For ITD, **magnitude of interference was roughly similar to past reports:** static thresholds nearly double at 4 kHz (McFadden and Pasanen 1976, Heller and Richards 2010).

For ILD, roughly **1 dB of interference was observed in all conditions**, greater than Heller and Richards (2010), who showed only 0.2 dB for a 4000 Hz target. Here, a group of 4 subjects (0610, 1213, 1301, 1306) showed about the same effect, while others showed more interference. Note that Heller and Richards used bands of noise for both stimuli.

2. Were interference effects greater for 0R than R0 targets?

Difficult to answer statistically due to ceiling effects: mean threshold elevations hardly differed across condition. ITD: 1.9x for 0R vs 1.6x for R0; 1.4x for RR, no significant differences; ILD: 0.9 dB for 0R vs 1.1 dB for R0; 0.9 dB for RR, no signifiant differences.

Ceiling effects (failure to measure thresholds within tracker range) were clearly more common in ITD interference condition 0R than any other. This suggests that in most cases listeners were quite strongly affected by the interferer when target carried a diotic onset, to the extent that they simply *could not do the task*.

Suggests that binaural interference has its greatest effect on *post-onset* ITD cues.

3. Does the type of cue (ITD or ILD) matter?

In general, **interference was observed regardless of cue type** or configuration.

However, consistent with past studies, ILD thresholds were overall similar between R0 and 0R conditions, as was the amount of binaural interference observed. This suggests that ILD discrimination at high rates does not require the cue to bepresent at sound onset. This is consistent with past studies that show ILD near sound offset to be similar salient to ILD near onset (Stecker and Brown 2012; Stecker et al. 2013).

A few additional considerations

Note that interferer envelope should allow "clean" access to target onset and offset here.

Bernstein and Trahiotis (2004) showed "immunity" to interference at 5-8 ms ICI, stimuli shown to carry more salient ongoing cues than at 2 ms ICI (Stecker and Brown 2010).

Here, target and interferer share a harmonic relationship (2 ms ICI = 500 Hz) not present in studies employing noise bands.

Acknowledgments

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