Trading of interaural time and level differences in modulated high-frequency stimuli

G. Christopher Stecker
Dept. of Speech and Hearing Sciences, University of Washington, Seattle

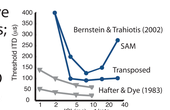
UNIVERSITY OF WASHINGTON

Background

Envelope ITD at high carrier frequency

Good sensitivity to envelope ITD of impulsive stimuli (filtered impulses, transposed tones; Bernstein & Trahiotis 2002).

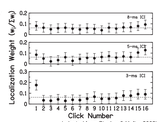
Limited availability of ongoing envelope ITD at high modulation rate (>200 Hz; Hafter & Dye 1983, Bernstein & Trahiotis 2002).



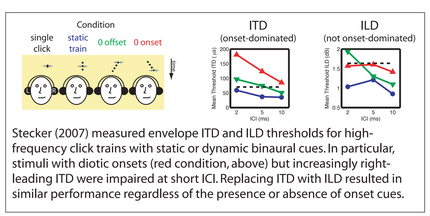
Onset dominance in high-rate stimuli

Shift to onset strategy at high rate consequent to reduced ongoing sensitivity (Hafter & Dye 1983); affects both envelope ITD and ILD (Hafter et al. 1983, 1990).

Onset strategy reflected in temporal weighting functions for ITD (Saberi 1996), freefield azimuth (Stecker & Hafter 2002).



Removal of onset cue impairs envelope ITD discrimination *but not ILD discrimination* (Stecker 2007).



Stecker (2007) measured envelope ITD and ILD thresholds for high-frequency click trains with static or dynamic binaural cues. In particular, stimuli with diotic onsets (red condition, above) but increasingly right-leading ITD were impaired at short ICI. Replacing ITD with ILD resulted in similar performance regardless of the presence or absence of onset cues.

Question

Does reduced sensitivity to ongoing envelope ITD increase the relative influence of ILD on localization at high rates?

If so, then ITD/ILD "trading ratios" (Hafter & Jeffress 1968) should increasingly favor ILD at modulation rates above ~200 Hz.

References

Bernstein LR & Trahiotis C (2002). *JASA* **112**:1026-1036.
Freyman RL, Clifton RK & Litovsky RY (1991). *JASA* **90**:874-884.
Hafter ER & Dye RHJ (1983). *JASA* **72**:644-651.
Hafter ER, Dye RHJ, & Wenzel E (1983). *JASA* **73**:1708-1713.
Hafter ER, Dye RHJ, Wenzel E, & Knecht K (1990). *JASA* **87**:1702-1708.
Hafter ER & Jeffress LA (1968). *JASA* **44**:563-569.
Krumbholz K & Nobbe A (2002). *JASA* **112**:654-663.
Rakerd B & Hartmann WM (1985). *JASA* **78**:524-533.
Saberi K (1996). *Percept. Psychophys.* **58**:1037-1046.
Stecker GC (2007, abstract). *ARO Abstracts* **30**:910.
Stecker GC & Hafter ER (2002). *JASA* **112**:1046-1057.
Trahiotis C & Kappauf WE (1978). *JASA* **64**:1041-1047.

Methods

Stimuli

Trains of 16 Gaussian impulses ("clicks")
4 kHz carrier frequency
2 ms nominal duration (~300 μs/σ, BW ~900 Hz) per click

Whole-waveform Interaural Time Difference (ITD)
−225 to 225 μs (50 μs steps)
Interaural Level Difference (ILD)
-5 to +5 dB (2 dB steps) or under subject control
Inter-click interval (ICI) 2, 5, or 10 ms
(modulation rate 500, 200, or 100 pps)
Stimulus level: 61-68 dB SPL (A, Leq)

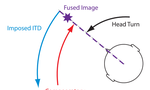
Task 1: closed-loop adjustment

Diotic reference stimulus alternates with dichotic test stimulus (ISI = 500 ms including stimulus duration).

Test stimulus ITD imposed by experiment; ILD under subject control via tracked head turn. Compensatory ILD values from polynomial fit to published measurements (Gulick et al. 1989).

Subject adjusts test-stimulus ILD (via head turn) to match perceived location of reference stimulus (~"centering" test stimulus; Hafter & Jeffress 1968), indicates match of fused or left-most image by button-press.

$$\text{Trading ratio (μs/dB)} = \frac{\text{Imposed ITD}}{\text{- Compensatory ILD}}$$



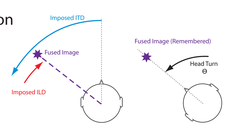
Task 2: open-loop head-pointing

Single presentation of test stimulus with combination of ITD & ILD.

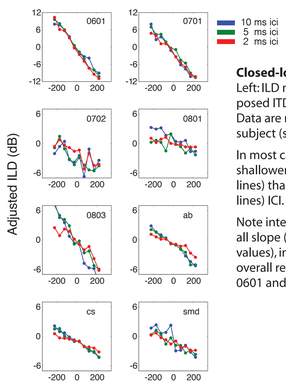
Subject turns head toward direction of fused or left-most image, indicates response by button press.

Response azimuth fit by regression on ITD, ILD.

$$\text{Trading ratio (μs/dB)} = \frac{\theta \text{ / ITD slope (deg/μs)}}{\theta \text{ / ILD slope (deg/dB)}}$$



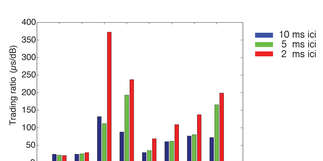
Results: Closed-Loop Adjustment



Closed-loop trading functions. Left: ILD necessary to offset an imposed ITD in the closed-loop task. Data are means across runs for each subject (separate panels).

In most cases, ILD-ITD functions had shallower slopes at 2 ms ICI (red lines) than 5 (green) or 10 ms (blue lines) ICI.

Note intersubject variability in overall slope (range of adjusted ILD values), indicating relatively greater overall reliance on ITD for subjects 0601 and 0701 than others.



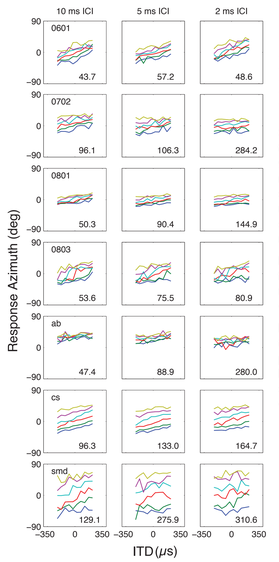
ITD/ILD trading ratios obtained via closed-loop adjustment favor ILD at high modulation rates. Above: bar height plots mean trading ratio, obtained by linear fit of ILD adjustment data to imposed ITD, across ICI for each subject. Trading ratios correspond to the slopes of ILD-ITD functions in the previous figure. Note consistent trend for trading ratios to be greatest at 2 ms ICI and (typically) least at 10 ms ICI, despite large intersubject differences in overall trading ratio. Greater trading ratios indicate increased sensitivity to ILD at high modulation rates. Effects of ICI were least apparent among those subjects with the lowest overall trading ratios (i.e., subjects applying greater weight to ITD cues tended to be less affected by modulation rate).

Contact

Chris Stecker, Dept of Speech & Hearing Sciences
University of Washington
1417 NE 42nd St, Seattle WA 98105

email: cstecker@u.washington.edu
web: http://faculty.washington.edu/cstecker

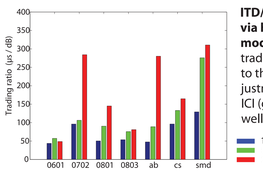
Results: Open-Loop Head Pointing



Open-loop lateralization functions. Left: mean orienting responses (y-axis, in degrees azimuth) are plotted as a function of imposed ITD (x-axis) and ILD (different colored lines) for each combination of subject and ICI (separate panels).

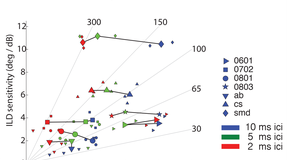
Note that in most cases, the influence of ITD was reduced (shallower line slopes) at 2 ms vs 5 or 10 ms ICI.

ILD sensitivity (indicated by vertical separation of lines in each plot) was minimally affected by ICI, although large intersubject differences in ILD sensitivity were clearly apparent.



ITD/ILD trading ratios obtained via head-pointing favor ILD at high modulation rates. Left: open-loop trading ratios followed a similar pattern to those obtained with closed-loop adjustment, both in terms of the effect of ICI (greater trading ratios at 2 ms ICI) as well as specific differences between subjects that showed greater or lesser reliance on ILD or ITD.

Trading-ratio shift due to reduced influence of ITD, not enhancement of ILD. Open-loop trading ratio reflects combination of ITD and ILD slopes obtained through multiple regression. Right: ILD slope (y-axis, in degrees per decibel) is plotted against ITD slope (x-axis, in degrees per microsecond) for each combination of subject (symbol) and ICI (color). Larger symbols connected by dark lines indicate means across runs; smaller symbols indicate data from individual runs. Except for subject 0601, mean values progress roughly parallel to the x-axis, indicating reduced ITD sensitivity but unchanged ILD sensitivity with decreasing ICI. Light gray lines and associated values indicate contours of equivalent ITD/ILD trading ratio.



Discussion

1) ITD/ILD trading ratios favor ILD at high modulation rates.

Reflects reduced influence of envelope ITD at high rate.

Suggests stimulus-specific weighting of onset vs ongoing, ITD vs ILD cues (cf. Rakerd & Hartmann 1985).

2) Large intersubject differences in overall trading ratio.

"Time" vs "intensity" image? - but consider different effects of ICI.

3) Trading ratios for 4000 Hz click trains consistent with high-pass clicks, exceed ratios for tones, broadband clicks.

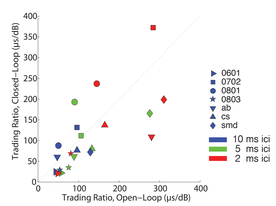
High-pass clicks: 75-150 μs/dB for "intensity" image;
< 50 μs/dB for "time" (Hafter & Jeffress 1968).

4) Effects of method: do open-loop trading ratios favor ILD more strongly than do closed-loop ratios?

Inconsistent with expectation that adjustment favors the adjusted dimension (i.e. expect larger ratios when adjusting ILD than ITD; Trahiotis & Kappauf 1978);

-Orientation to remembered location in open loop?
-Repeated presentation in closed loop? (cf. buildup of precedence; Freyman et al. 1991, Krumbholz & Nobbe 2002).
-Greater conflict in closed-loop?

Open-loop trading ratios favor ILD more strongly than do closed-loop ratios. Right: trading ratios obtained by the two methods are plotted together (x-axis: open-loop, y-axis: closed-loop). Across subjects and conditions, open-loop trading ratios tended to exceed closed-loop ratios.



Future Questions

Reduced sensitivity to ongoing envelope ITD forces listeners to use other cues at high modulation rate: onset ITD, ILD, etc. How do these cues combine over time? What does each cue contribute to temporal weighting functions measured in the free field? Where (in time) do spectral cues come in?

How do high-frequency envelope ITD and ILD interact with low-frequency ITD information in complex stimuli? Does "binaural interference" alter the relative weighting of binaural cues available at high frequencies?

Acknowledgments

Students Shiboney Dumo and Andrew Brown provided invaluable assistance running this study.

Personal conversations with Erick Gallun, and at the Binaural Bash, helped develop this study and its interpretation.

Support by NSF IOB-0630338 and the University of Washington.