Exploiting envelope fluctuations to enhance binaural perception

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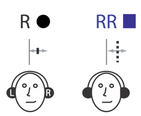
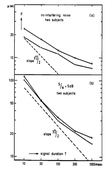
Approaches

Temporal Integration



Measure binaural discrimination across sound duration.

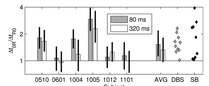


Houtgast & Plomp, 1968

-Onset dominance evidenced by shallow threshold-duration slope
Used in:
-Discrimination (Stecker & Bibee, 2014)
-Lateralization (Houtgast & Plomp, 1968)

Dynamic Cues

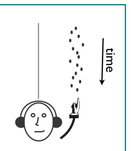
Measure binaural discrimination for sounds with cue at onset vs later.



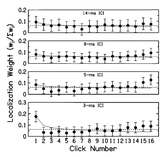
Stecker & Bibee, 2014

-Onset dominance evidenced by threshold difference 0R > R0
Used in:
-Discrimination (e.g. Stecker & Brown, 2010, Stecker & Bibee, 2014)
-Lateralization (Dietz et al., 2013)

Temporal Weighting



Measure relative sensitivity to cues present at each moment in time.



Stecker & Hafter, 2002

-Onset dominance evidenced by increased click - 1 weight
Used in:
-Discrimination (Brown & Stecker, 2010)
-Lateralization (Stecker et al., 2013)

References

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Tobias & Schubert, 1959, *JASA*, 31: 1595-160

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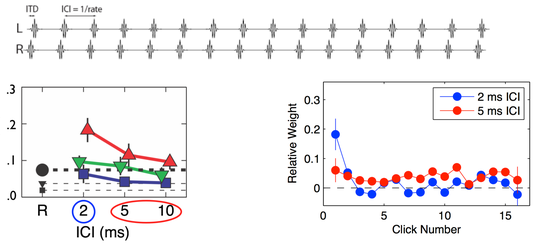
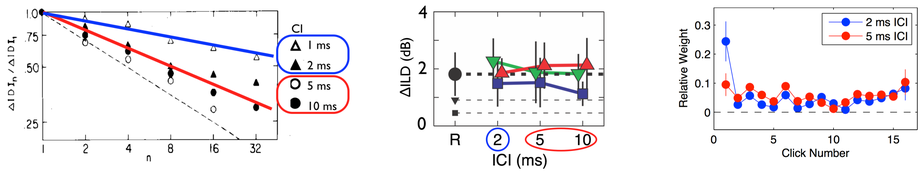
Rate-dependent onset dominance for interaural time difference (ITD) in periodically modulated high-frequency tones



Hafter & Dye, 1983, *JASA* | Stecker & Brown, 2010, *JASA* | Stecker et al., 2013, *JASA*

1. At **high modulation rates** (> 200 Hz, ICI < 5 ms), all approaches reveal onset dominance for (envelope) ITD at high frequencies. For example, the first click in a train dominates the lateral impression.
2. At **low modulation rates** (ICI ≥5 ms), ongoing information contributes more. *Each click* contributes as much binaural information as the first.

Rate-dependent onset and offset dominance for interaural level difference (ILD) in periodically modulated high-frequency tones

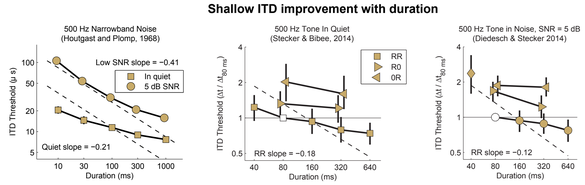


Hafter, Dye, & Wenzel, 1983, *JASA* | Stecker & Brown, 2010, *JASA* | Stecker et al., 2013, *JASA*

1. At **high modulation rates** (> 200 Hz, ICI < 5 ms), the ILD cue present at sound onset is more heavily weighted than that of the ongoing sound. Sound offset additionally contributes.
2. Similiar to ITD, at **low modulation rates** (ICI ≥5 ms), ongoing information contributes more. *Each click* contributes nearly equally, although late-arriving ILD may still receive increased weight.

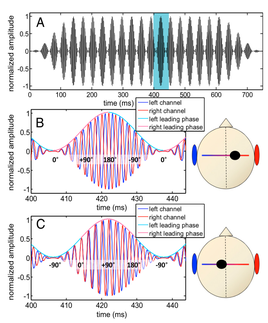
Enhanced sensitivity to low-frequency, fine-structure ITD during positive envelope fluctuations (i.e., onsets, attacks, and modulation periods)

Shallow ITD improvement with duration



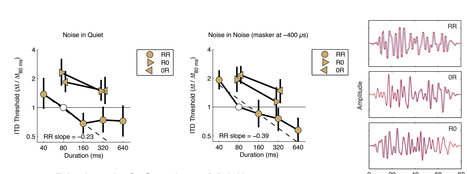
1. Temporal-integration and dynamic-cue studies evaluating **unmodulated low-frequency tones** reveal similar results to rapidly modulated high-frequency tones: Strong onset dominance, even with *diotic* envelopes..

2. For **slowly modulated tones** (~30 Hz, Dietz et al., 2013), *each modulation period* contributes to the lateral impression, via fine-structure ITD present during its *rising portion*

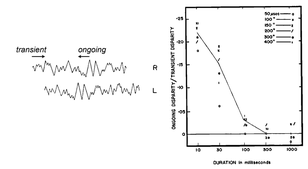


Dietz, et al., 2013, *PNAS*

Little to no onset dominance for "noise"



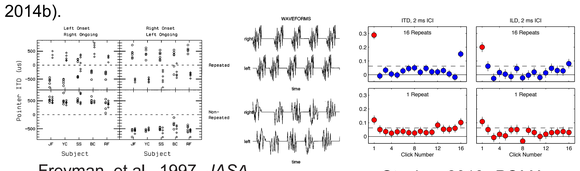
Diedesch & Stecker, 2014b



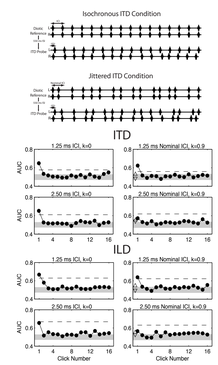
Tobias & Schubert,1959, *JASA*

1. For **stochastic signals**, numerous studies have revealed greater sensitivity to *ongoing* binaural information:

- "fresh" vs. "frozen" noise (Freyman et al., 1997, Stecker, 2013).
- temporally irregular amplitude modulation (Laback & Majdak, 2008, Goupell et al., 2009, Brown & Stecker, 2011).
- lateralization of broadband noise (Tobias & Schubert, 1959).
- ITD sensitivity in noise masking (Houtgast & Plomp, 1968, Diedesch & Stecker, 2014b).



Freyman, et al., 1997, *JASA* | Stecker, 2013, *POMA*



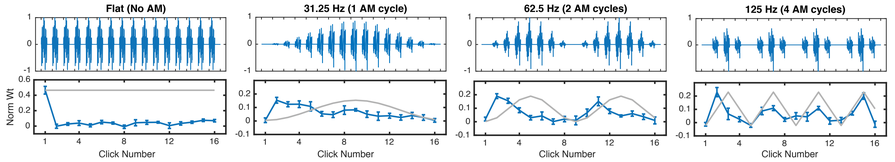
Brown & Stecker, 2011, *JASA*

Conclusions and applications

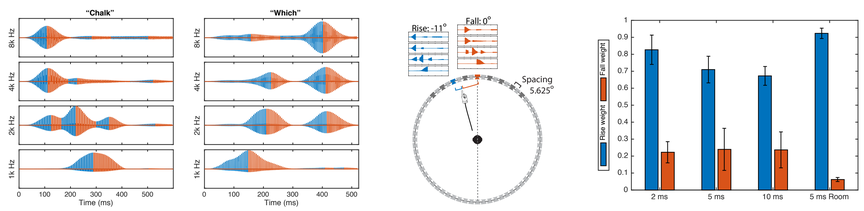
These various results of 30+ years demonstrate good binaural sensitivity at:
a. Sound onsets
b. Each modulation event when the rate is *slow* (<100-200 Hz)
c. When the envelope is irregular (e.g. noise)

In each case, it appears that binaural sensitivity is high when [within-band] envelope fluctuations are present.

Hypothesis: localization will be dominated by moments of positive envelope fluctuation...



Result: temporal weighting functions for amplitude-modulated noise-burst trains (above) reveal strongest weighting of early bursts in each envelope attack. Mean of 5 subjects, 2-ms ICI, periodic.



Applications to spatial audio analysis and synthesis (above):
- Click-train vocoder assigns rising (blue) vs falling (red) envelopes of speech to different locations
- Listeners localize in the direction of rising envelopes (bars), particularly at short ICI or in reverb (right).

Results may inspire envelope-based perceptual "codecs" for spatial features of immersive / virtual audio.