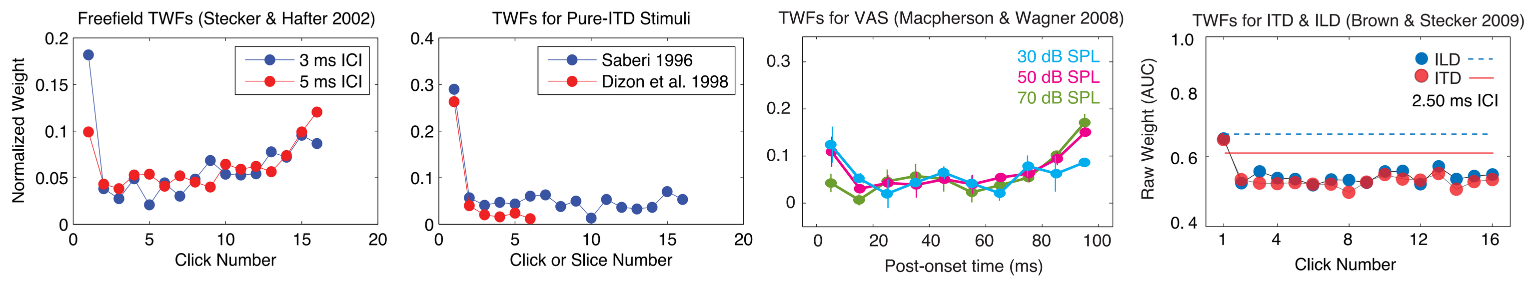
More modeling of temporal weighting functions for interaural time and level differences

G. Christopher Stecker - *Department of Speech and Hearing Sciences, University of Washington, Seattle WA, USA*

Background: Temporal Weighting and Binaural Adaptation

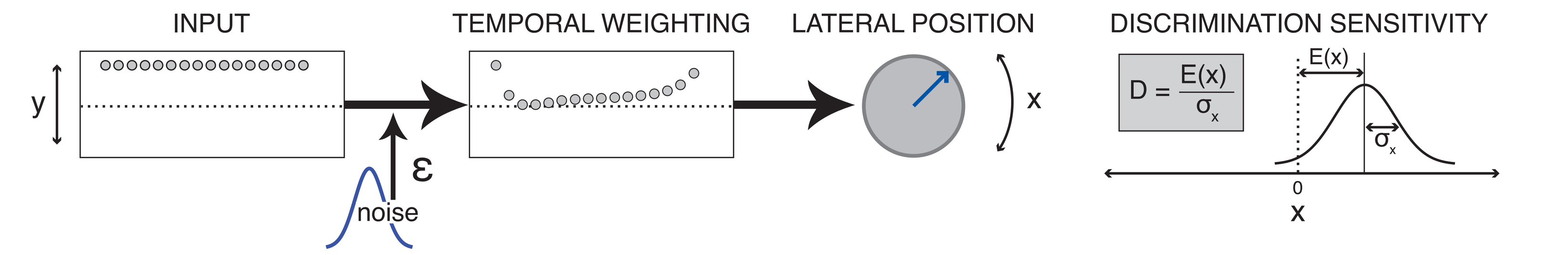


Abstract:

Numerous studies have investigated the time-course of binaural cue processing by estimating temporal weighting functions (TWFs) that describe spatial-cue sensitivity over the durations of brief stimuli. TWFs have been estimated variously by measuring threshold interaural differences for a brief “probe” stimulus embedded in a longer diotic “fringe” (Zurek 1980, Akeroyd and Bernstein 2001), by measuring improvements in discrimination with duration (Hafter and DYe 1983, Hafter and Buell 1990), and by multiple regression of localization responses onto spatial variation applied independently to multiple temporal divisions of the sound (Saberi 1996, Dizon et al. 1998, Stecker and Hafter 2002, 2009, van Hoesel 2008, Macpherson and Wagner 2008). For both broadband and narrowband, rapidly modulated, sounds, TWFs have revealed varying degrees of onset dominance (revealed by high onset weight and reduced weight for later parts of the stimulus) and “upweighting” (increased weight near offset). These effects are stimulus dependent, and may reflect contributions of multiple physiological mechanisms. In a previous presentation (Stecker 2009), we investigated those contributions by estimating TWFs on the basis of auditory peripheral processing, binaural coincidence detection, and temporal integration.

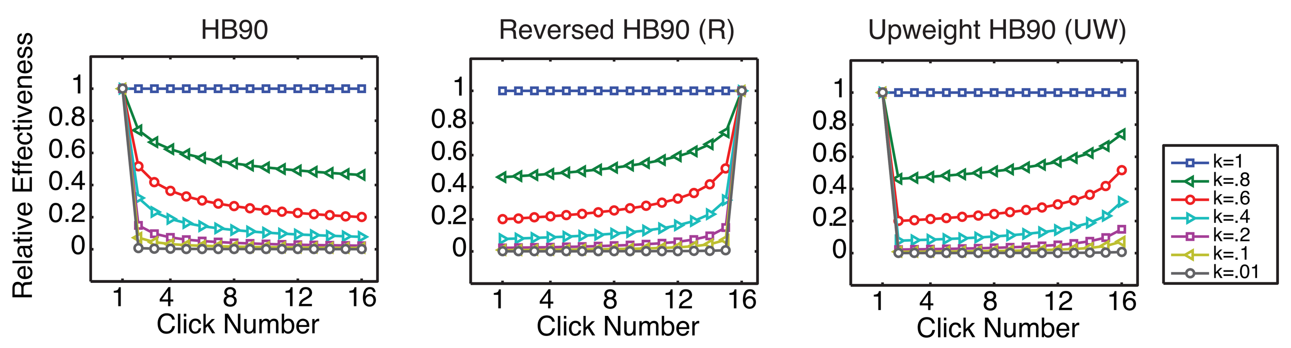
In the current study, we apply various forms of empirically and theoretically derived TWFs to generate predictions for binaural discrimination and lateralization tasks with stimuli varying in duration and binaural cue content. The results of this modeling suggest that multiple forms of TWF may be consistent with any given set of behavioral data, and that conclusions regarding the underlying dynamic mechanism may depend strongly on the analytical assumptions used to derive the TWF.

Approach

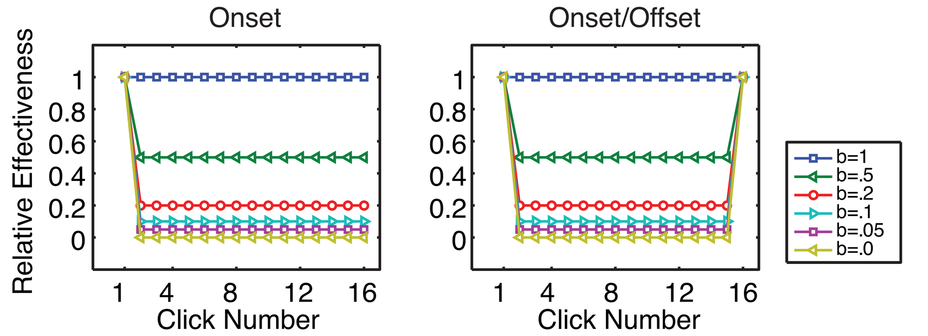


1. Stimuli represented as series of discrete cue values (y) ranging -1 to +1. (Model ITD or ILD). Appropriate for impulse trains, etc. Gaussian noise ε (amplitude 0.1) added independently to each y value.
2. Temporal Weighting Function (TWF) applied (multiplication) to stimulus values.
3. Lateral position variable computed by averaging weighted values over time: $x = \sum w_i(y_i + \varepsilon_i) / \sum w_i$
4. Discrimination sensitivity, $D = E(x) / \sigma_x$, where E = expected (mean) value of x and σ_x = std. deviation, over 1000 Monte Carlo estimates of x.
5. Discrimination sensitivity D expressed relative to single-click discrimination sensitivity D_1 for plotting across TWFs and stimuli.

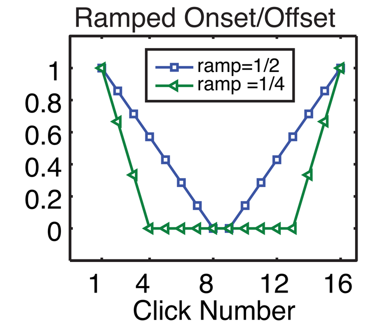
Model Temporal Weighting Functions (TWFs)



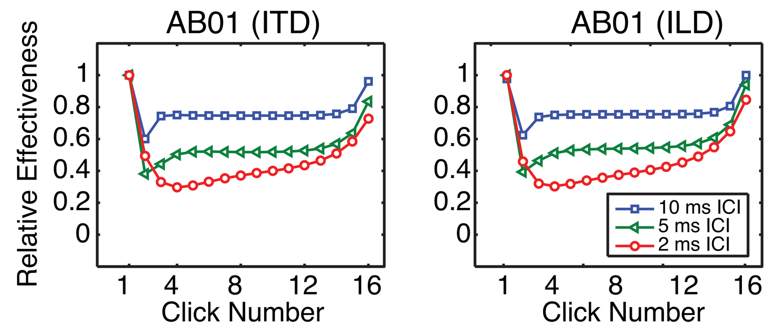
Far left: TWFs computed using the relative effectiveness model of Hafter & Buell 1990 (HB90). Developed to account for ICI-dependent improvement in discrimination with click-train duration, the model assumes monotonic decreasing weight over time. Parameter k controls the rate of decrease: k≈1 produces static weighting while k≈0 produces strong onset dominance. Center left: reversing the TWFs in time changes sensitivity to dynamic, but not static cues. Near left: a similar reordering of weights that includes both onset dominance and mild upweighting.



Far left: TWFs generated by assuming a high weight on the onset click. Other clicks recieve a static “body” weight (parameter b) that provides sensitivity to ongoing cues. Near left: onset/offset TWFs constructed similarly to onset TWFs, with the addition of high weight on offset click. Right: ramped onset/offset TWFs, consisting of symmetric weights that emphasize onset and offset. Middle clicks receive 0 weight.Parameter: ramp duration as proportion of total stimulus duration.



Right: TWFs computed using the model of Akeroyd & Bernstein 2001 (AB01). Model combines post-onset weighting (Houtgast & Aoki 1994) responsible for onset dominance, and a sliding window of binaural temporal integration (Bernstein et al. 2001) responsible for ongoing-cue sensitivity and upweighting near offset. Model was developed to account for variation in listener’s sensitivity to ITD of brief noise bursts as a function of a burst’s temporal placement within a longer diotic “fringe” (Zurek 1980). Here, we adapt the model to generate TWFs for click trains. Parameters are identical to those used by Akeroyd & Bernstein (2001) to account for ITD (left) or ILD (right) discrimination in their data. Note significant body weight, consistent with ongoing sensitivity in broadband noise.

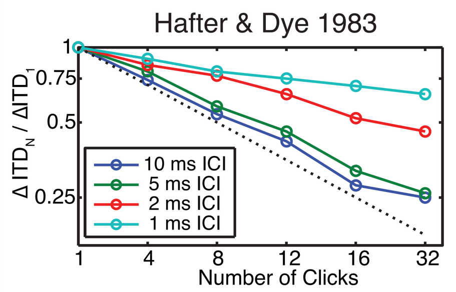


1. Change in Sensitivity with Duration

The Stimuli:

Trains of 1-32 Gabor clicks (4000 Hz cf) with static ITD or ILD. Measure improvement in discrimination with duration N across values of ICI.

The Data:



Discrimination threshold strongly ICI-dependent for long trains. Improves as power function of train duration,

$\Delta ITD_N = \Delta ITD_1 / \sqrt{(N^k)}$,

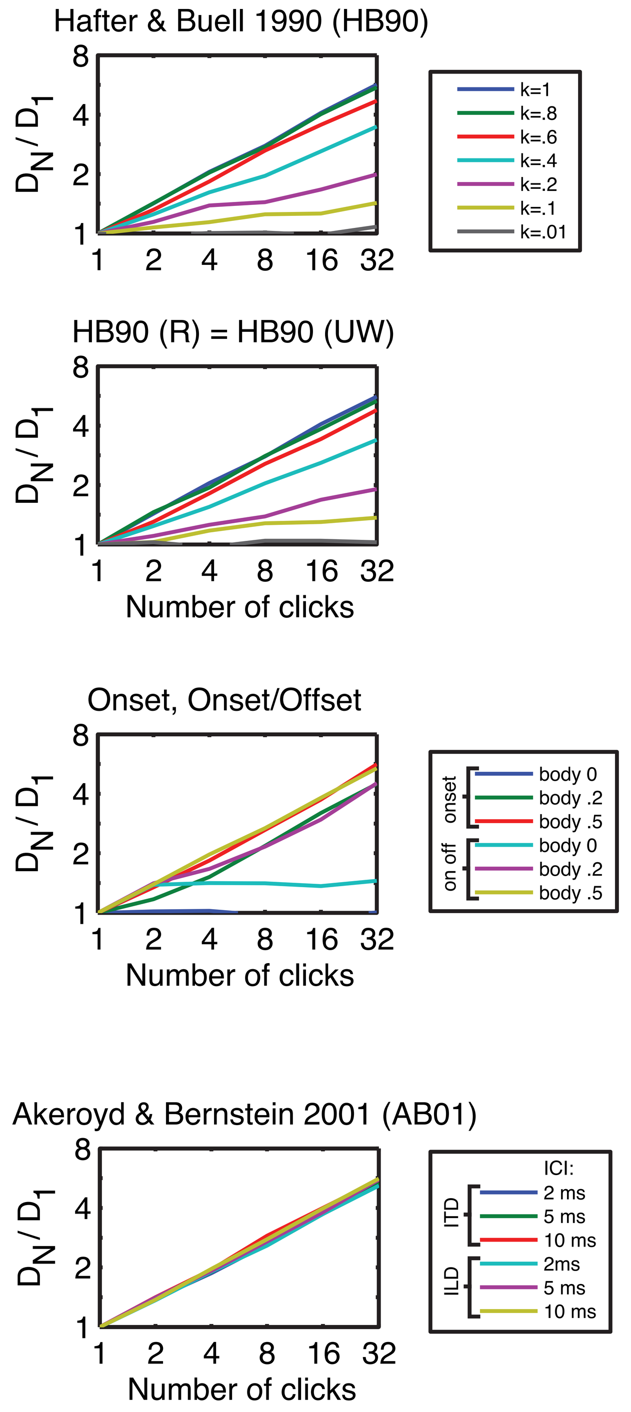
where the parameter k controls the degree of improvement with N. For k≈0, performance is independent of N, whereas k≈1 indicates optimal improvement with N.

The parameter k is ICI-dependent. For ITD discrimination, Hafter & Dye (1983) found best fitting k = [.27, .44, .75, .81] for ICI = [1, 2, 5, 10 ms]. Hafter et al. (1983) reported a similar relationship for ILD discrimination.

The Model:

Model sensitivity (right) computed from posiiton variable x, across 1000 Monte Carlo simulations:

$D = E(x)/\sigma_x$



In figures, D is plotted relative to single-click sensitivity D_1 against number of clicks N.

Top panels: TWF computed using relative effectiveness model of Hafter & Buell 1990 (HB90) and Reverse- or Upweight-modified HB90 model. Note that predictions are identical regardless of ordering of weights over time. Third panel: TWFs generated with onset or onset/offset weighting and variable degree of “body” weight applied to remaining clicks. Bottom panel: TWFs computed using model of Akeroyd & Bernstein 2001 (AB01). Note that relatively high body-weighting in the AB01 model leads to near-optimal improvement in sensitivity with duration, a better fit for broadband stimuli (as used by AB01) than narrowband (HB90) stimuli.

Acknowledgments

Erv Hafter and Andrew Brown, significantly shaped this project through critical discussions and through the experiments that led to this work. Shiboney Dumo, Julie Stecker, Andrew Brown, Anna Mamiya, and Jennifer Ostreicher assisted with data collection stages of the supporting experiments.

This work was funded by NIDCD R03-DC009482 (GCS).

Contact

email: cstecker@uw.edu

web: http://faculty.washington.edu/cstecker

2. Discrimination of Dynamic Interaural Differences

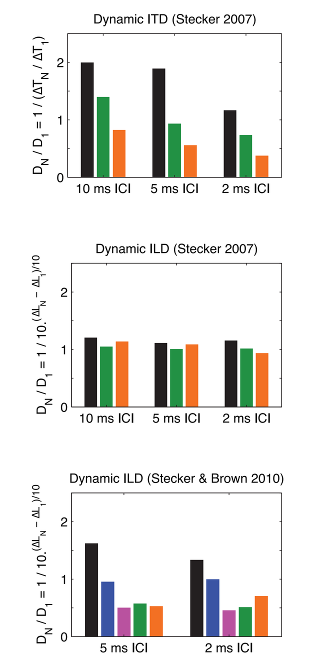
The Stimuli:

Trains of 16 Gabor clicks (4000 Hz cf) with time-varying ITD or ILD. Real thresholds measured at peak cue value across values of ICI.

RR: 16 clicks / static cue
R0: linear decreasing cue
0R: linear increasing cue

RRRR: static cue
R00R: onset+offset cue
0RR0: no on/off cue
R000: onset cue only
000R: offset cue only

The Data:



Discrimination data from two studies, averaged across subjects and expressed relative to single-click performance (inverse ratio) for comparison to model sensitivity (right).

The Model:

Sensitivity to dynamic cues under various TWF assumptions (right). Model performance computed from posiiton variable x, across 1000 Monte Carlo simulations:

$D = E(x)/\sigma_x$

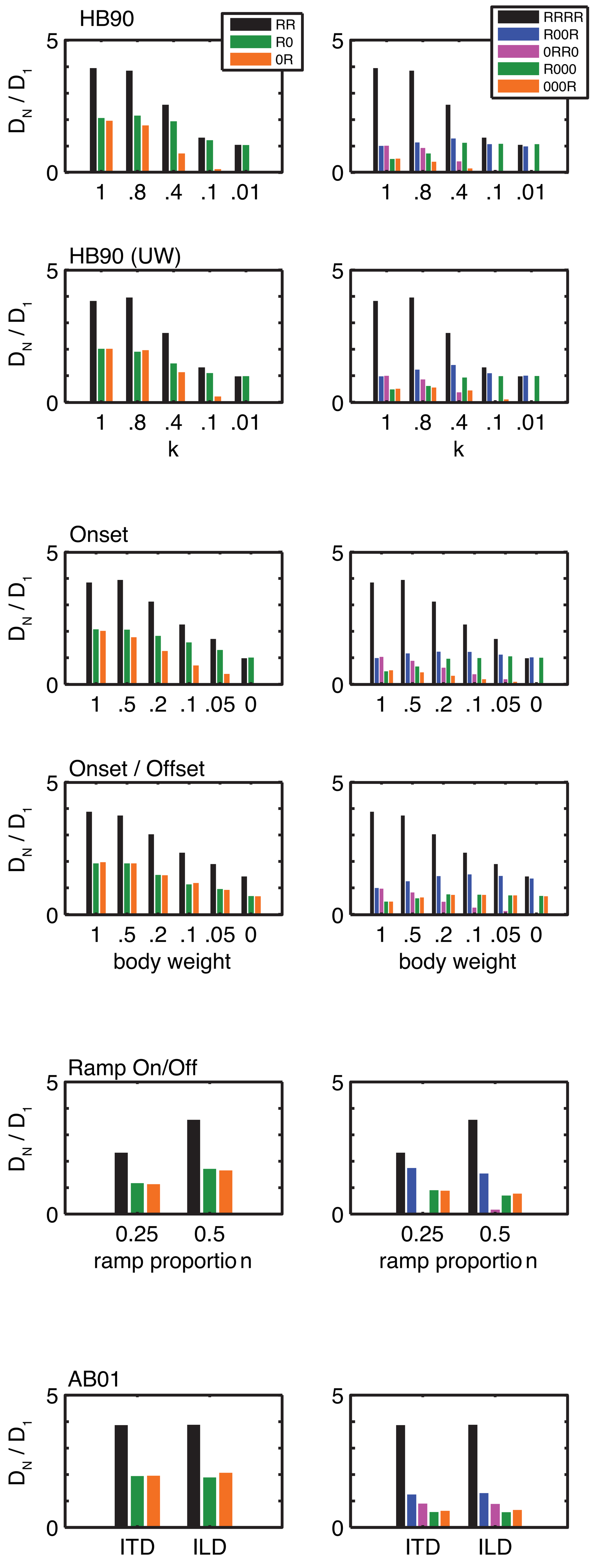
In figures, D is plotted relative to single click sensitivity D_1.

Top panels: TWFs computed using the relative effectiveness model of Hafter & Buell 1990 (HB90) or Upweight-modified HB90 model. Parameter (k) controls degree of onset emphasis.

Second set from top: TWFs generated by weighting single onset click (upper) or both onset and offset clicks (lower). Parameter (b) indicates “body” weight assigned to remaining clicks.

Third set from top: TWFs generated by linear ramps at onset and offset (0 weight assigned to middle clicks). Parameter is the proportion of stimulus duration taken for each ramp (i.e. 4 or 8 clicks).

Bottom panels: TWFs computed from model of Akeroyd & Bernstein 2001 (AB01) for 5 ms ICI. Model parameters as described by AB01 for ITD or ILD.



3. Lateral Position with Opposed Onset and Body Cues

The Stimuli:

Continuous stimuli (or click trains) with onset cue delivered to one side, body cue delivered to opposite side. Vary the proportion of stimulus receiving onset cue (”onset duration”) and measure lateral position of combination.

The Data:

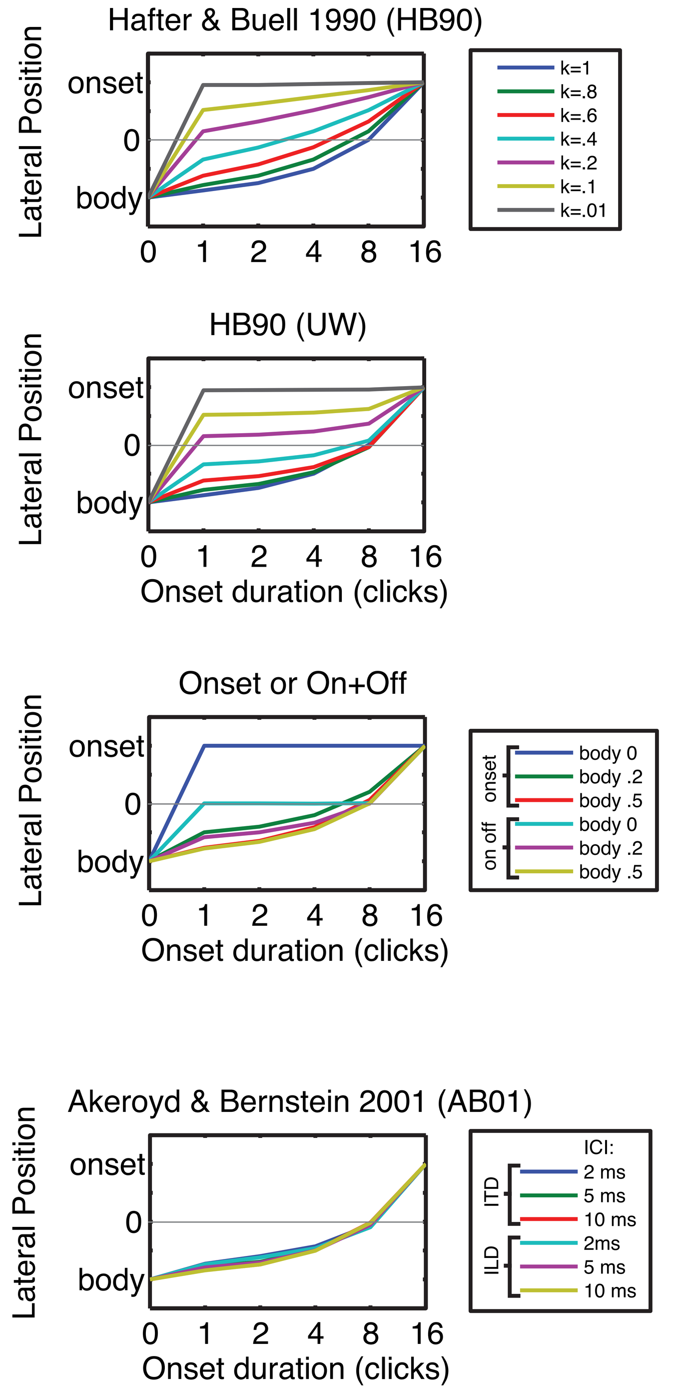
Houtgast & Aoki (1994) measured lateral position for octave-band noise varying in total duration, cue type (ITD, ILD, or interaural cross-correlation), and fractional duration receiving onset cue.

“Equal-weight ratio” obtained for centered image found for onset ≈ 0.3–0.6 of total duration (2000 Hz octave band, ILD, 20-40 ms total duration). Roughly equivalent to 5-10 clicks in 16-click train.

The Model:

Figures (right) plot mean lateral position E(x), computed across 1000 Monte Carlo simulations, against onset duration (in clicks). Total stimulus duration was 16 clicks for all simulations. Onset duration specifies the number of clicks (starting at onset) to be assigned the cue value +1 (labeled “onset” in the figures); remaining clicks were assigned cue value -1 (”body”). For onset duration = 16, all clicks were assigned +1, and for onset duration = 0, all clicks were assigned -1. In all cases, lateral position shifts from body to onset as onset duration changes from 0 to 16.

Top: TWFs computed using model of Hafter & Buell 1990 (HB90) or Upweight-modified HB90 model. Note that low values of k correspond to lateralization near the onset cue, while moderate and high values correspond to lateralization near the body cue. Third panel: TWFs generated with onset or onset/offset weighting combined with variable degree of “body” weight applied to remaining clicks. Moderate values of body weight greatly reduce the effects of onset cues, especially when offset cues are also strongly weighted. Bottom panel: TWFs computed using model of Akeroyd & Bernstein 2001 (AB01). Note, again, that relatively high body-weighting in the AB01 model results in lateralization near the body cue, consistent with previous studies demonstrating no onset-dominance for broadband sound (recall that the AB01 model was based on measurements in broadband noise).



References

Akeroyd MA and Bernstein LR (2001). *J. Acoust. Soc. Am.* **110**:2516-2526.
Bernstein LR and Trahiotis C (2002). *J. Acoust. Soc. Am.* **112**:1026-1036.
Bernstein LR, Trahiotis C, Akeroyd MA, and Hartung K (2001). *J. Acoust. Soc. Am.* **109**:1604-1615.
Brown AD and Stecker GC (2009). *Assoc. Res. Otolaryngol Abs.* **32**:310.
Dizon RM, Culling JF, Litovsky RY, Shinn-Cunningham BG, and Colburn HS (1998). *Assoc. Res. Otolaryngol Abs.* **21**:42.
Hafter ER and Buell TN (1990). *J. Acoust. Soc. Am.* **88**:806-812.
Hafter ER and Dye RH (1983). *J. Acoust. Soc. Am.* **72**:644-651.
Hafter ER, Dye RHJ, and Wenzel EM (1983). *J. Acoust. Soc. Am.* **73**:1708-1713.
Houtgast T and Aoki S (1994). *Hear. Res.* **72**:29-36.
Macpherson EA and Wagner (2008). *Assoc. Res. Otolaryngol Abs.* **31**:882.
Stecker GC (2007). *Assoc. Res. Otolaryngol Abs.* **30**:910.
Stecker GC (2009). *J. Acoust. Soc. Am.* **125**:2523.
Stecker GC and Brown AD (2010). *Assoc. Res. Otolaryngol Abs.* **33**:828.
Stecker GC and Hafter ER (2002). *J. Acoust. Soc. Am.* **112**:1046-1057.
Stecker GC & Hafter ER (2009). *J. Acoust. Soc. Am.* **125**: 3914-3924.
van Hoesel RJM (2008). *J. Acoust. Soc. Am.* **124**:3861-3872.
Zurek PM (1980). *J. Acoust. Soc. Am.* **67**:952-964.