2aPPb3: Localization judgments are sensitive to late-arriving sound

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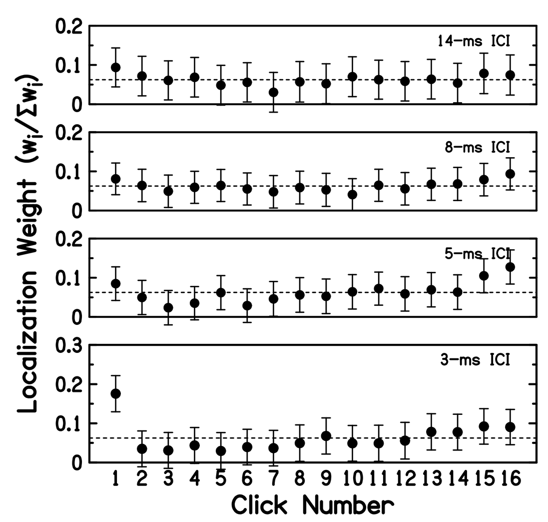
Spatial cues in late-arriving sound are more effective than earlier sound

In studying the temporal weighting of spatial cues in click-train localization, Stecker and Hafter (in press) found the initial click in a train to be more effective than later clicks when the interclick interval (ICI) was less than about 5 ms. This finding is consistent with previous research on the precedence effect (Wallach et al 1949, Litovsky et al 1999, Saberi 1996, Dizon et. al 1998).

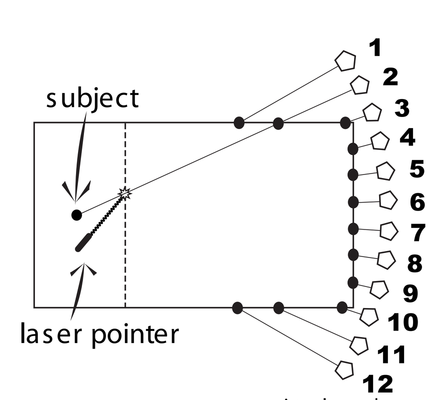


An additional finding was that over a wider range of ICI, clicks near the end of a train received elevated weight, indicating increased effectiveness of late-arriving sound in the localization of such stimuli in the free field.

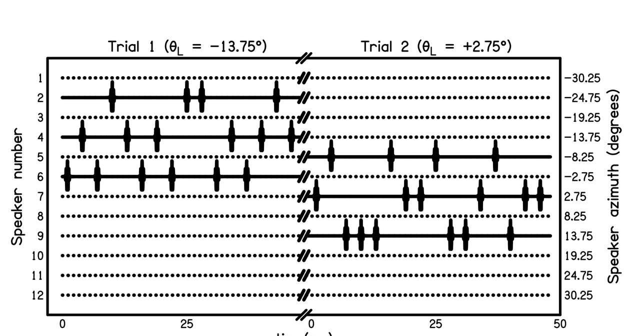
For lack of a better term, we will refer to the finding of increased weight near stimulus offset as "upweighting," and one possible explanation for the effect is that the effectiveness of spatial cues following onsets recovers after a temporary reduction due to transient suppression. The goal of the current study is to test this possibility.

Methods

Stimuli were trains of band-limited clicks (gaussian-windowed pure tones of 4 kHz cf, 2-ms total window duration, and ~900 Hz bandwidth) with ICI ranging from 3 to 14 ms. Subjects included the first author and four paid listeners.



An 8-by-5 meter anechoic chamber was arranged as depicted at right. The listener faced an array of loudspeakers spanning +/- 30.25 deg of azimuth in 5.5 deg. increments. Although arranged along the chamber walls, electronic signal processing simulated a circular array of loudspeakers of 240-inch radius. The listener's view of the loudspeaker array was blocked by an acoustically-transparent white curtain hung 42 inches in front of the listener's position.



On each trial a train of 2-32 clicks was presented from one of the loudspeaker locations. Each click in the train was presented from a randomly-selected location within +/- 11 degrees of the overall train location (as depicted at left). Following the stimulus, listeners looked toward the perceived location (avoiding head movement) and used a laser pointer to mark the direction of their gaze.

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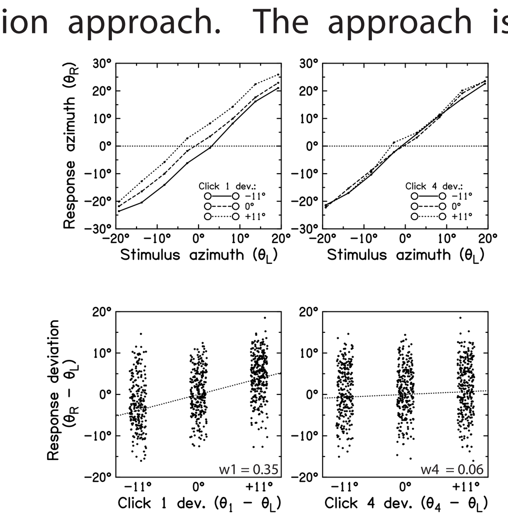
Analysis

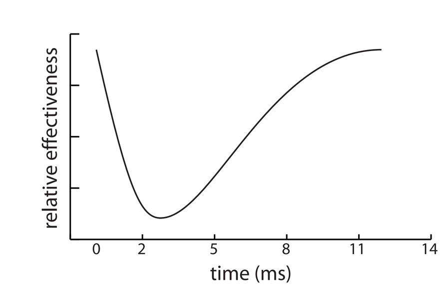
Localization weights were estimated for each click in a train by regressing the judged location on the individual click locations, using a standard least-squares multiple-linear regresssion approach. The approach is illustrated for clicks 1 (high weight) and 4 (low weight) in a 16-click train of 3-ms ICI at right. Deviations in the location of click 1 produce measureable deviations in response location, while those of click 4 do not.



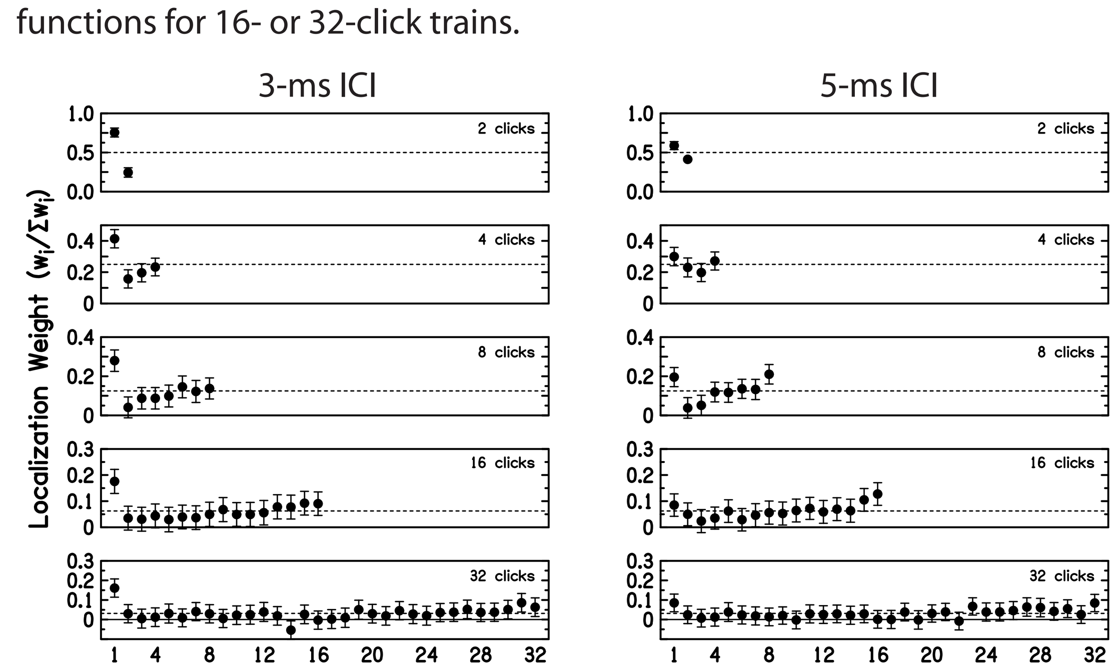
For averaging across subjects, weights were normalized to sum to 1 over an entire train. 95% confidence intervals were calculated for each weight estimate, and the mean (across subjects) confidence intervals are plotted around mean normalized weights in subsequent plots.

Upweighting is not recovery from suppression with fixed duration

Some aspects of the precedence effect point to a mechanism of delayed, onset-triggered inhibition, whereby responses to spatial cues are momentarily suppressed during the period from 1 to approximately 10 ms post-onset. (Zurek 1980, Wickesberg & Oertel 1990, Yin 1994). While such a mechanism cannot account for all aspects of the precedence effect, it suggests an interpretation of the upweighting effect reported by Stecker & Hafter (in press). One prediction of such a model is that if the duration of inhibition is fixed, then recovery should take place at the same time for stimuli of different durations. To test this possibility, we examined temporal-weighting functions for the localization of trains composed of 2 to 32 clicks.



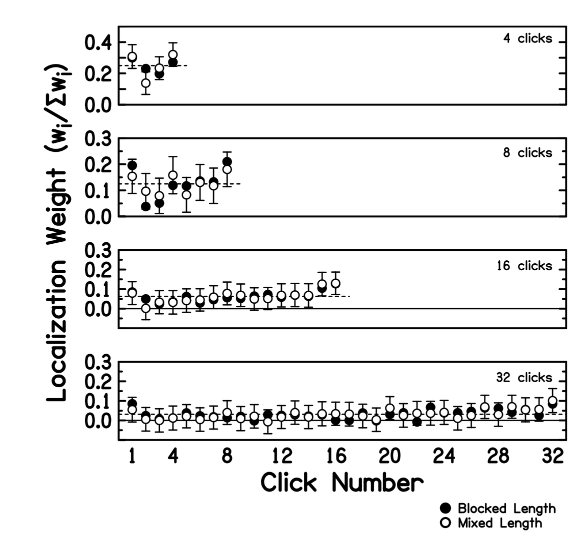
As shown below, the tendency for click weights to increase toward the end of a train persisted for trains of 4 to 32 clicks at ICIs of both 3 and 5 ms. Comparing trains of different length at either value of ICI shows no evidence for recovery from suppression at a fixed post-onset time. 8-click trains with 5-ms ICI, for example, show significantly greater weight on click 8 than click 7. No such increase in the weight of click 8 can be seen in functions for 16- or 32-click trains.



Upweighting is not recovery from suppression with adaptive duration

The previous results indicate that upweighting cannot be explained by a mechanism that suppresses spatial information temporarily and recovers with a fixed time-course. If upweighting reflects a recovery of sensitivity to spatial information, this raises the question of how the mechanism "knows" when to turn off. One possibility is that the time-course of suppression is not fixed, but adapts based on the duration of previous stimuli (this could be useful, for example, in "tuning" echo suppression to the effects of different acoustic environments).

Since the previous experiment presented stimuli in a blocked fashion, stimulus duration was perfectly predictable based on the duration of the first few trials, and such an adaptive mechanism would be indistinguishable from a mechanism that specifically influences late-arriving sound. To test this possibility, we modified the method to vary stimulus durations (click-train lengths) randomly between trials. ICI was fixed at 5 ms, but other methods were identical to those described above.



The results, plotted at right, showed no significant differences between weighting functions obtained with blocked and intermixed stimulus durations, indicating that upweighting does not reflect the operation of an adaptive transient suppression mechanism. Since the largest weights (aside from the onset) occur near the end of the train, regardless of train length or its predictability, we conclude that upweighting must reflect a special importance of spatial cues carried by late-arriving sound.

Upweighting reflects a special importance of spatial cues near stimulus offset

At first glance, the increase in effectiveness of late-arriving sound seems to imply a precognitive mechanism that anticipates the end of a stimulus. However, judgments of spatial location are made after the entire stimulus presentation, not as a direct result of strictly feedforward processing, so this need not be the case.

Instead, the results imply that spatial cues contained over the duration of the stimulus are made available to the localization process, and thus that they must be stored in some manner (e.g., in a memory buffer). Stimulus location must be determined *post hoc,* based on this representation.

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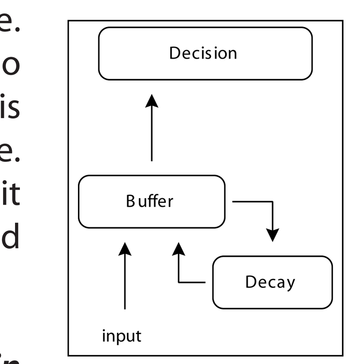
Potential explanations for upweighting

The current experiments have eliminated one possible explanation (recovery from transient suppression) for the upweighting result. A number of other potential explanations remain, however, and will be the subject of future work:

Apparent auditory motion. On some trials, subjects reported the sensation of apparent motion of the stimulus. This is an accurate observation, due to the randomization of click locations; however, the likelihood of coherent motion in a stimulus of up to 32 clicks is quite low. Nevertheless, if differences between the locations of the inital and final clicks produce the perception of apparent motion, and this percept systematically biases the localization judgments, then one would expect to see increased weight assigned to the final clicks.

Response selection. Some readers might entertain the possibility that upweighting reflects the operation of mechanisms involved in response selection, rather than the underlying perception of sound-source location. This possibility is clear, and may be quite likely. Moreover, if a memory-based mechanism is implicated, we cannot yet distinguish the modality involved: auditory, motor, or otherwise. Regardless, the different weights assigned to different parts of a stimulus imply that each part is individually capable of affecting the response. Therefore, if response selection is responsible, it cannot proceed solely from a precomputed auditory location.



Integration of spatial information (recency in sensory memory). Upweighting is reminiscent of recency effects observed in studies of verbal memory (Glanzer & Cunitz 1966); these can be modelled by the interaction of individual long- and short-term memory stores, or alternately by an integration mechansim like that depicted at right. Here, new input is integrated with a decaying representation of previous input and stored in a limited-capacity memory buffer. The form of decay need not (necessarily) be limited to attenuation over time, as in a "leaky" temporal integrator, but the end result is that more recent input tends to dominate the integrated representation, leading (in this case) to increased weights for late-arriving sound.

Differences in time-course of ITD, ILD, spectral cue processing. Finally, while the results of Stecker & Hafter (in press) generally agree with Saberi (1996) and Dizon et. al. (1998), neither of the two latter studies observed any tendency for weights to increase toward the end of a stimulus, raising the issue of procedural differences between the studies. Most obvious is the stimulus: both previous studies employed headphone presentation of stimuli varying only in ITD, while the current study presented stimuli in the free field, where ITD, ILD, and spectral cues for localization are related in a natural manner. Rakerd & Hartmann (1985) have shown that the presence of echoes alters the way in which ITD and ILD are combined. It is conceivable that processing of the different cue-types proceeds along different time-courses, and that upweighting reflects such a difference.

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