CLICK VS. CLICK-CLICK: INFLUENCE OF A PRECEDING STIMULUS ON SOUND LOCALIZATION

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1. Abstract

Previous studies of sound localization have observed spatial interactions between sound objects presented simultaneously or with very small inter-stimulus delays. For stimuli presented in rooms, we have observed such interactions at much longer delays (up to 300 ms). The aim of the current study was to better characterize how preceding stimuli influence sound localization over these time scales.

We examined the localization of two-ms-long target clicks presented with or without an identical preceding click. The clicks were presented from loudspeakers located in the frontal horizontal plane in a moderately reverberant room. Preceding and target clicks had angular separations of up to 90° and temporal separations of up to 500 ms. The preceding click had two main effects: (1) it increased the variance in target localization responses and (2) it shifted the mean response, especially for large angular separations (greater than 50°) where the mean was shifted towards the location of the preceding click. Both effects decreased with increased temporal separation.

Analysis of interaural cues for the click-pair stimuli suggest that acoustic interactions between the reverberant tail from the preceding click and the direct sound of the target click cannot explain the observed effects. We hypothesize that neural dynamics in spatial processing, operating over longer time scales than many other known spatial-processing mechanisms (such as the precedence effect), contribute to the observed phenomenon.

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2. Introduction

Two sounds can perceptually interact even when they do not overlap in time or frequency.

In a previous study of "cuing" (Kopco et al., 2001, 2003), we found that a preceding sound had a strong effect on the perceived location of a target.

The current study was designed to examine these interactions in detail, and to determine if these interactions were due to neural processing effects or acoustic effects of the room.

We measured azimuthal localization performance for a click target stimulus when preceded by another identical click:
- presented with a short onset asynchrony
- from a different azimuthal location
- in either an anechoic chamber or an ordinary classroom

Performance was compared to that in a control in which there was no preceding click.

We hypothesize that many factors may contribute to spatial interactions
- acoustical interactions between reflections of the first click and the target click waveform
- peripheral interactions in the neural representation of the energy from the first click and that of the second click
- "sluggishness" of the neural representation
- precedence-like mechanism that actively suppress first-click reflections, altering the representation of the second click

3. Methods

TASK

On each trial, subjects pointed to the heard location of a target click presented from a random loudspeaker.

On most trials, a "distractor" click preceded the target (see top panel of Figure 1).

On control trials, the target was presented alone.

Each click was presented at 62 dB SPLA.

The distractor-target Stimulus Onset Asynchrony (SOA) was either 25, 50, 100, 200, or 400 ms.

EXPERIMENTAL PROCEDURES

Two experiments in different environments
- reverberant room (5 m x 4 m; T_{60}=500ms; background noise of 40 dB SPLA)
- anechoic space

Seven normal-hearing subjects (three in both environments)
- 6 in the room
- 4 in anechoic space

Seven target loudspeakers and two distractor loudspeakers positioned in the subjects' right (or left) frontal quadrant (see bottom panel in Figure 1)

Runs blocked by distractor location (frontal or lateral) and listener orientation (left or right quadrant)

Four 1/2-hour sessions per experiment per subject

Each session was 4 runs of 168-trials (random order)

DATA ANALYSIS

Assumed left/right symmetry (collapsed across orientation)

For each subject, calculated
- mean perceived azimuth
- standard deviation in perceived azimuth

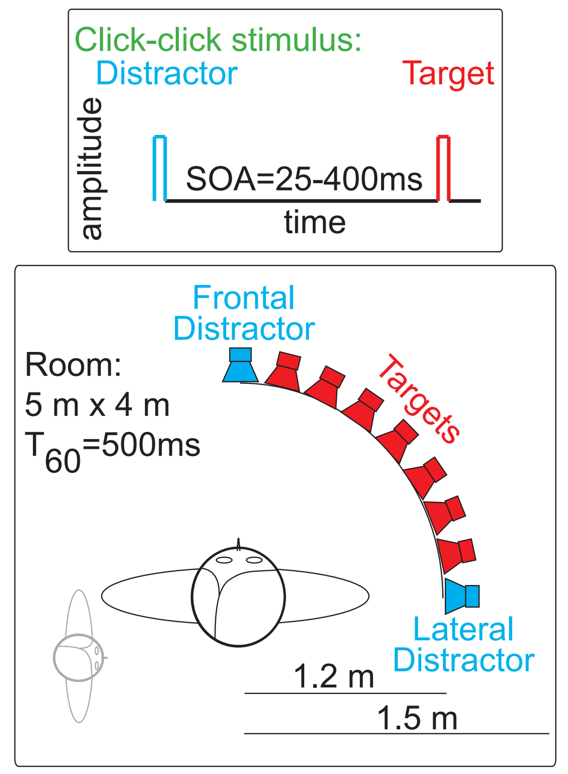

Figure 1 Experimental stimuli and setup

4. Results: Mean Perceived Azimuth

Control: no distractor
(* in Figure 2 A,B):
- large lateral bias in blocks with distractor in front (left-hand panels)
- small medial bias near distractor speaker, followed by small lateral bias far from distractor speaker when distractor on side (right-hand panels)

There is a contextual effect: subjects tend to respond away from the distractor location, even in the no-distractor control trials in both environments.

Effect of frontal distractor
(left-hand panels in Figs 2,3):
- up to 5° medial bias (attraction by distractor) for middle separations (20-40°) and middle SOAs (*,*), in both environments
- in anechoic space (left-hand panel A), up to 4° lateral bias (away from distractor) for large separation (67°) and larger SOAs (*,*)

Effect of lateral distractor
(right-hand panels in Figs 2,3):
- in both environments
  - targets near distractor (>67°) are perceived more medially (up to 6°)
  - targets in the middle (45°) are perceived more laterally (effect grows with shorter SOAs)
- in the room (panel B), there is up 12° lateral bias for frontal target (<22°) with short SOA (<100 ms)

Reverberation influences localization bias: the lateral distractor attracts frontal targets at short SOAs in the room, but not in anechoic space.
In both environments, there is a complex pattern of biases caused by the distractor that depends on target azimuth and SOA.

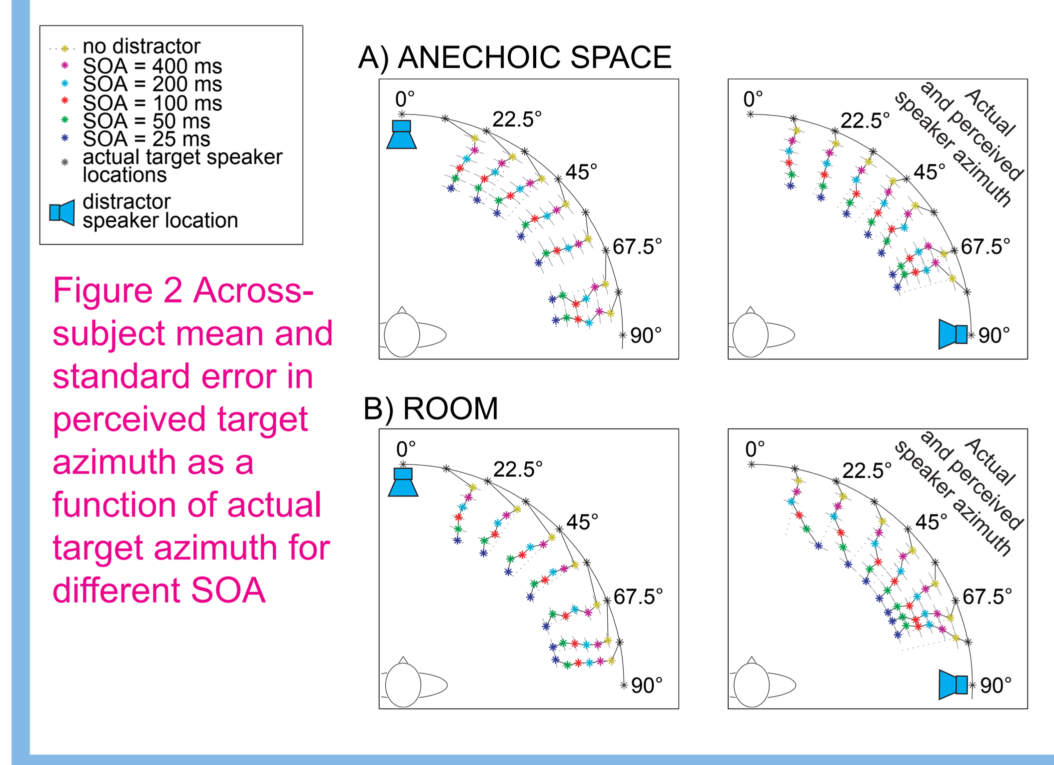

Figure 2 Across-subject mean and standard error in perceived target azimuth as a function of actual target azimuth for different SOA

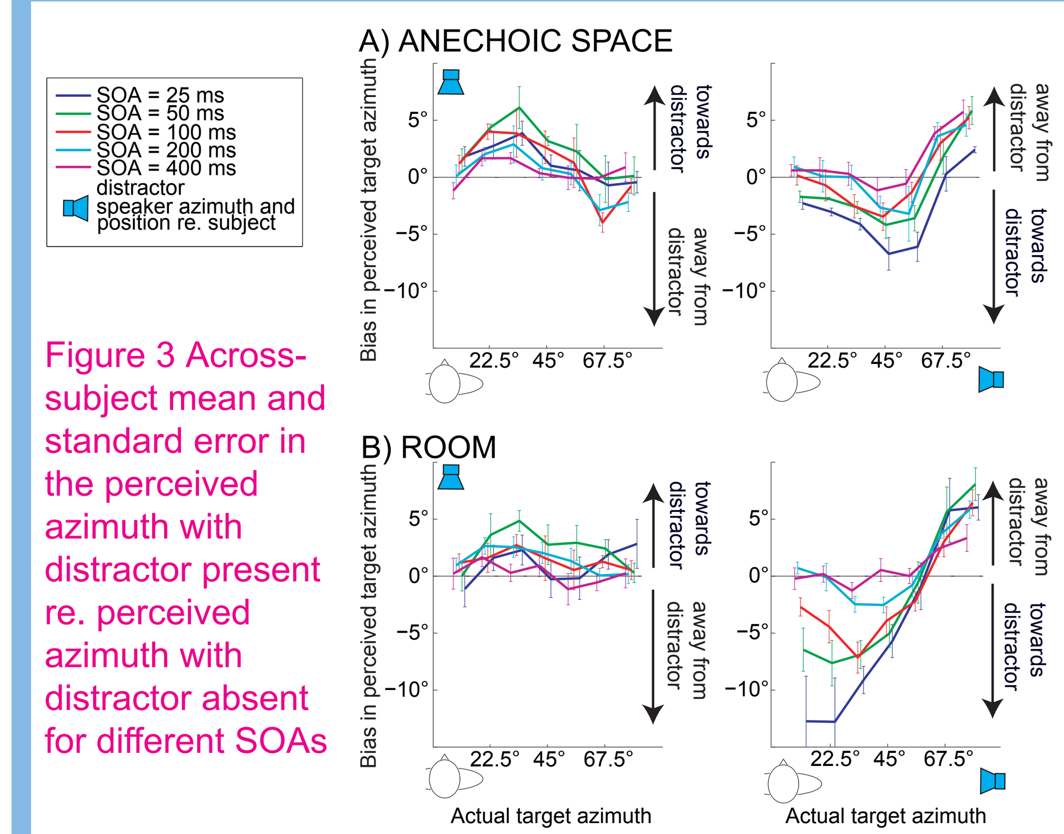

Figure 3 Across-subject mean and standard error in the perceived azimuth with distractor present re. perceived azimuth with distractor absent for different SOAs

5. Results: Variability in Perceived Azimuth

Standard deviation in localization responses

In anechoic space (Fig. 4A), variability
- increases with target laterality
- is larger when the target is near a lateral distractor
- tends to increase with decreasing SOAs

In the room (Fig. 4B), variability
- is generally larger than in anechoic space
- increases with increasing SOA
- is larger for the lateral distractor than for the frontal distractor
- does not increase monotonically with azimuth (at least for the frontal distractor)

In anechoic space, the distractor's effect on variability in perceived azimuth is relatively small.
In the room, the distractor increases variability dramatically, particularly for a lateral distractor and short SOAs

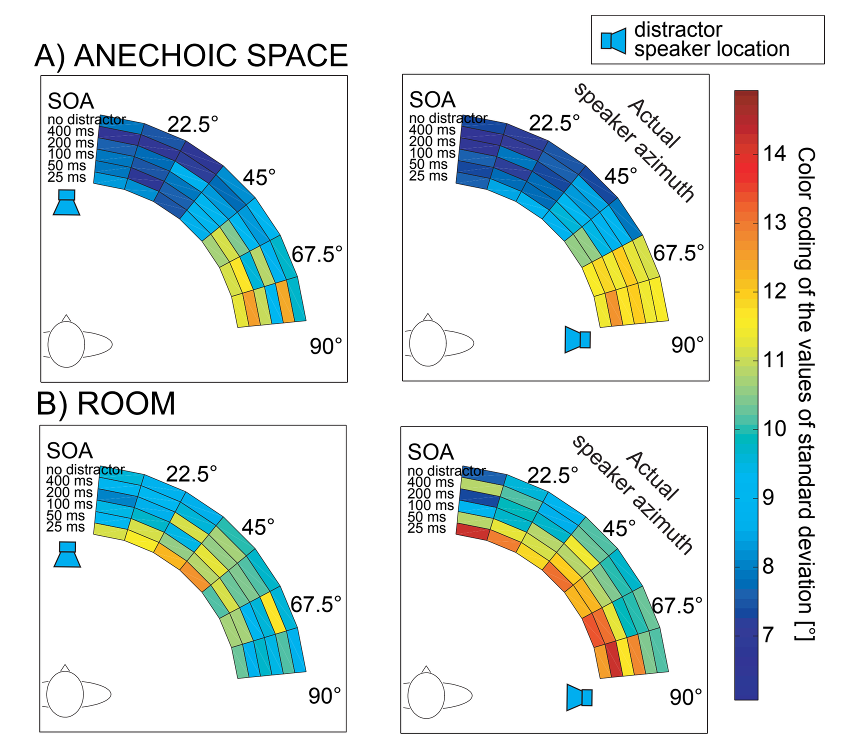

Figure 4 Across-subject mean of the standard deviation in perceived azimuth as a function of actual target azimuth and the SOA

6. Acoustic Analysis (are room effects purely acoustic?)

METHOD

Raw KEMAR recordings of stimuli presented in ROOM
All combinations of:
- target at 10° or 80°
- distractor at 0° or 90°

Recordings had SOA of 400 ms (other SOAs synthesized)
Peak of normalized cross-correlation was computed in a running 5-ms rectangular window

BIAS

No shift in the peak of running cross-correlation was observed, even for the room data (simulation results not shown).

Biases due to presence of distractor observed in Figure 3 cannot be explained by acoustic interaction of the stimuli.

VARIABILITY

If response variability increases with interaural decorrelation, then the peak cross-correlation height should be inversely related to resonse variability.

Behavioral variability (Figure 5 A,B):
- is smaller for frontal (panel A) than lateral distractor (panel B)
- grows with decreasing SOA for 10° targets
- grows less with decrasing SOA for 80° targets

The peak of the cross-correlation (Figure 5 C,D):
- is similar for frontal (panel A) and lateral distractors (panel B)
- is essentially independent of SOA for 10° targets
- grows with increasing SOA for 80° targets

Trends in response variability cannot be explained by the interaural correlation of the stimuli.

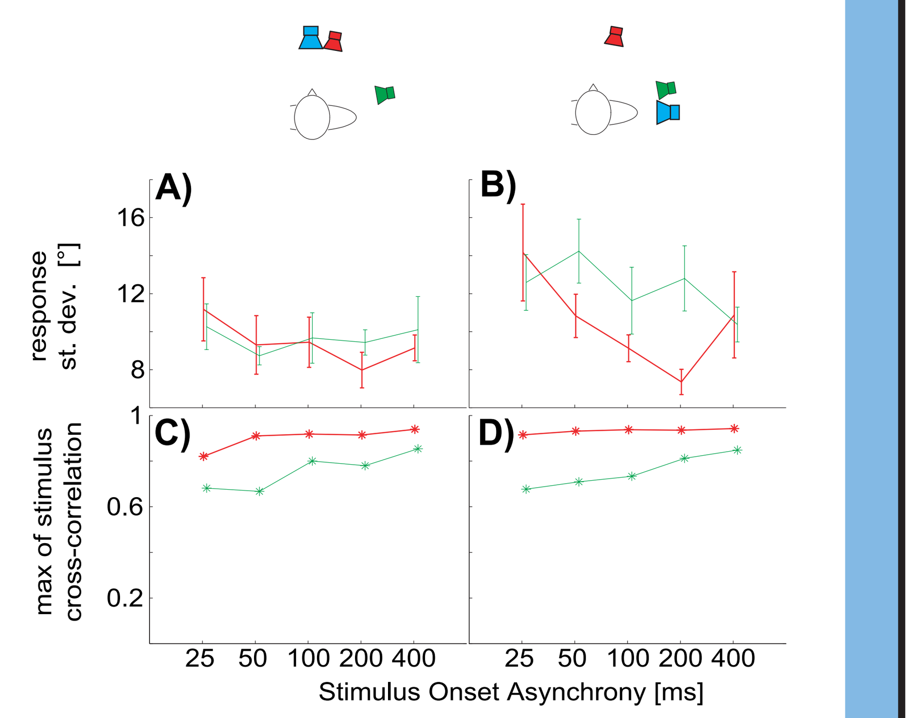

Figure 5 Comparison of the variability in perceived location to the interaural correlation in the received stimuli. Data plotted as a function of the SOA for two target locations (10° and 80°) and two distractor locations (0° in panels A,C, 90° in panels B,D). Panels A,B: Across-subject mean and standard error of the within-subject response standard deviation. Panels C,D: Peak in running cross-correlation of the stimuli.

7. Summary and Discussion

A preceding distractor has a complex effect on azimuthal localization of a target click stimulus.

There were three main effects observed, none of which could be explained by purely acoustic interactions between the stimuli:

CONTEXT BIAS

The presence of a distractor in a block of trials influenced localization on control trials, biasing judgments away from the distractor loudspeaker.

This context bias may be a consequence of subjects either adapting to a stimulus that is presented often (the distractor) or using the distractor loudspeaker as a perceptual anchor.

DISTRACTOR-INDUCED BIAS

In reverberation, the lateral distractor caused a large lateral bias for frontal stimuli at smaller SOAs.

This might be related to the large increase in response variance for these configurations.

In both environments, the lateral distractor caused large repulsion for nearby stimuli.

As localization is poor for targets in this region, the distractor may serve as an anchor that biases judgments in this way.

In both environments, all distractors caused attraction of targets at central locations at smaller SOAs.

Interactions within neural representations of space might be involved in this effect, as discussed by Best et al., 2005; Carlile et al., 2001; Kashino et al., 1998.

DISTRACTOR-INDUCED VARIABILITY

In reverberant space overall standard deviation was large, and grew strongly with decreasing SOA

The mechanisms hypothesized to underlie the precedence effect might be responsible for these effects (and possibly also other effects observed in this study). If this is the case, it would suggest that such mechanisms operate at much larger time scales (up to 100 ms) than traditionally assumed.

8. References and Acknowledgement

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