Cueing vs. Distracting Effects of Attentional Orienting on Auditory Spatial Discrimination

Norbert Kopčo, Yeganeh Modaresnia, Udbhav Singhal, René Šebeňa
Institute of Computer Science, P. J. Šafárik University, Košice, Slovakia

INTRODUCTION

Attention facilitates processing of objects, events, or locations in complex scenes. However, very few previous studies looked at attention in **sound localization** and:
- whether it is **cue modality-dependent**,
- whether **endogenous** attention **enhances** localization,
- whether **interference** arises when **cue** provides incorrect information.

PREVIOUS FINDINGS

Behavioral studies:
- cueing **improves reaction times** (Spence and Driver, 1994),
- **small** (Sach et al., 2000), **location-specific** (Maier et al., 2009), or **no** (Kopco et al., 2001) **improvements in localization** accuracy,
- enhancement of auditory **discrimination** based on **ILD** or **ITD** when the listener's **gaze** was directed to stimulus visually, but not when cue was auditory (Maddox et al., 2014).

Related EEG studies:
- **attentional networks** engaged more when space simulated using **HRTFs** (Deng. et al., 2019),
- lateralized **cue** sound elicited an enlarged contralateral positive potential (**Auditory-evoked Contralateral Occipital Positivity, ACOP**) 250-450 ms post-sound onset in visual cortex,
- ACOP reflects attentional orienting to the cue, improving discrimination (McDonald et al.,2013), however, it is not clear whether it is represented in the visual (eye-centered) or auditory (head-centered) reference frame (Groh et al., 2021).

CURRENT STUDY (EXTENSION AND FOLLOW-UP TO SEBENA et al., 2022)

Behavioral and EEG experiment (Sebena et al.):
- to examine the effect of **exogenous** attention on spatial auditory discrimination using HRTFs to simulate sound locations,
- compare cuing by **visual** vs **auditory** cues,
- **gaze fixed** at a neutral location,
- measured **EEG** to examine **neural correlates** of attentional control.

Follow-up:
- examine whether cue-target dissimilarity reduces distracting effects of invalid cue.

HYPOTHESIS AND PREDICTIONS

- **automatic attention** attracted by the cue, not only gaze direction (Maddox et al., 2014), **affects spatial discrimination**, by either:
  - **enhancing** the processing at **cued** locations, or
  - **interfering with** the processing at **un-cued** locations.
- the cuing effect will be **modality-dependent** (cf. Maddox et al., 2014) even without gaze changes.
- **Event-related potentials (ERPs)** to **targets (N1 to P3)** and/or to **cues (ACOP)** will correlate with behavioral effects.
- **ACOP** to **cue** may be represented in **head-centered or eye-centered** coordinates.
- Follow-up: the **distracting effect** is due to **spatial attentional shifts** and **cue-target similarity**.

EXPERIMENTAL SETUP

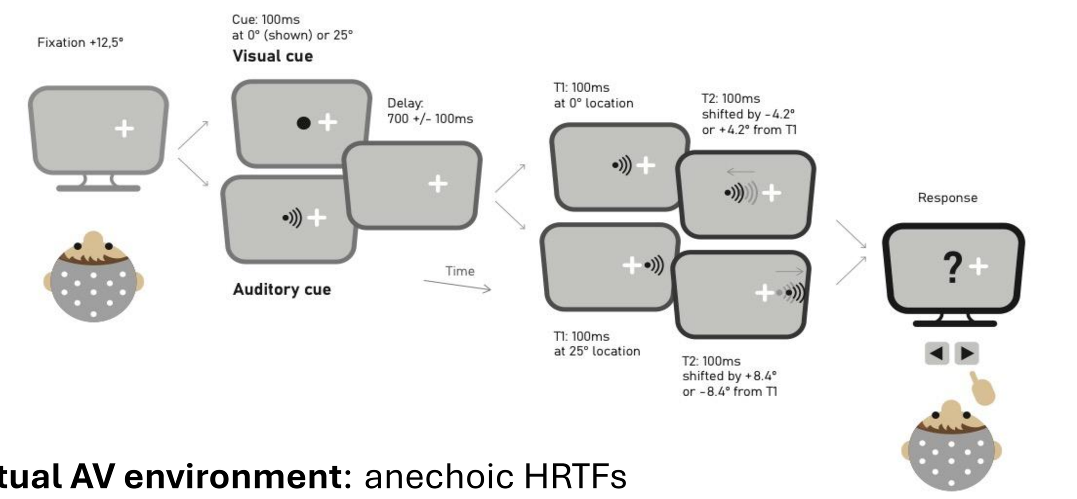


Figure 1 original experimental setup and trial structure. Each trial began with an FP, followed by a cue (visual/auditory) and a target (T1 & T2). In a half of trials, setup was mirror-flipped (FP at -12.5°). Follow-up: setup similar, but left-right symmetrical.

Virtual AV environment: anechoic HRTFs

Eye fixation:
- fixed at **±12.5°** (follow-up: always **0°**)

Cue:
- **auditory** (100-ms, 170-Hz click train **buzz**, identical to target) or **visual** (100-ms white dot)
- follow-up: only **auditory** cue (100-ms, 170-Hz **buzz** or broadband **noise**)
- presented at **±12.5°** re. fixation point (FP) (follow-up: **-25°, 0°, or 25°**), valid or invalid
- cue validity: **50%** (follow-up: **33.3̄%**)

Target:
- two 100-ms 170-Hz click trains / **buzz** sounds (T1 and T2),
- presented w/o gap with T1 at **±12.5°** re. FP (follow-up: **-25°, 0°, or 25°**), T2 shifted by ±4.2° or ±8.4°

Task: "Discriminate whether T2 was to the left or to the right of T1", while ignoring the cue.

ERPs:
- recorded during sessions using **32-channel Biosemi ActiveTwo system**.

RESULTS: Behavioral

Original experiment:

SENSITIVITY INDEX *d'* ANALYSIS

– pattern similar for central (0°) and peripheral (25°) targets (symbols).

Auditory cue affects discrimination more than visual cue, mainly due to distraction when cue is invalid.

CRITERION BIAS *c* ANALYSIS

Criterion Bias placement re. FP:
- visual: slightly shifted towards FP, uninfluenced by cue validity,
- auditory: unbiased for valid cue, strongly biased toward FP for invalid.

For auditory invalid cue (identical to target), this bias is consistent with direction from cue to target -> interference from cue location.

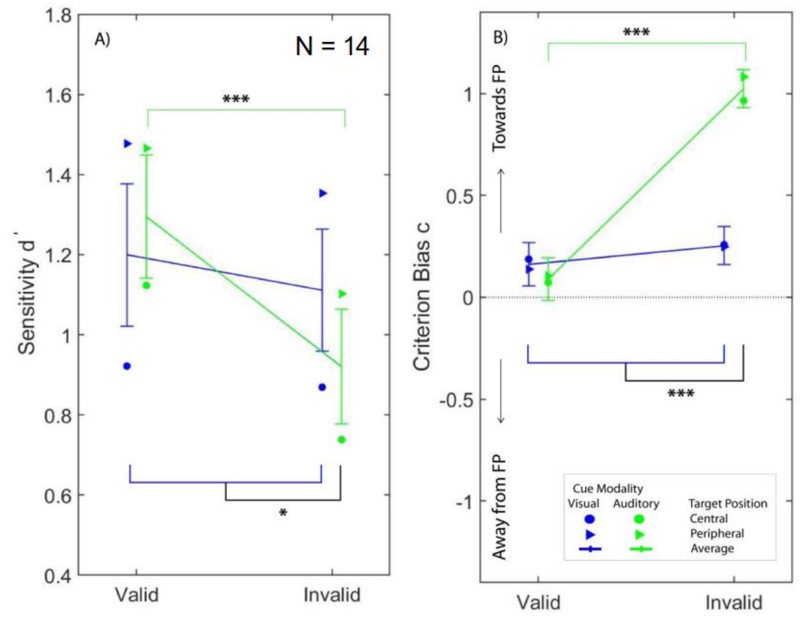


Figure 2 Mean (±SEM) sensitivity (d') and criterion bias (c) across subjects by cue validity for visual and auditory cues. Data are shown for central vs. peripheral target locations, averaged across left and right fixations. Significant differences are marked (** p < 0.01, *** p < 0.001).

Follow-up experiment:
- for invalid cues, there is a strong bias away from the cue (stronger for lateral targets),
- for valid cues performance slightly biased with lateral target, not for central target,
- cue type mostly affects the valid lateral-target data (noise responses biased more away from FP), but also for invalid central-target data.

Cue-target similarity only has a modulatory effect on attentional cuing, affecting mainly the valid cue performance with lateral target. This is unexpected, likely also influenced by the eye-gaze direction.

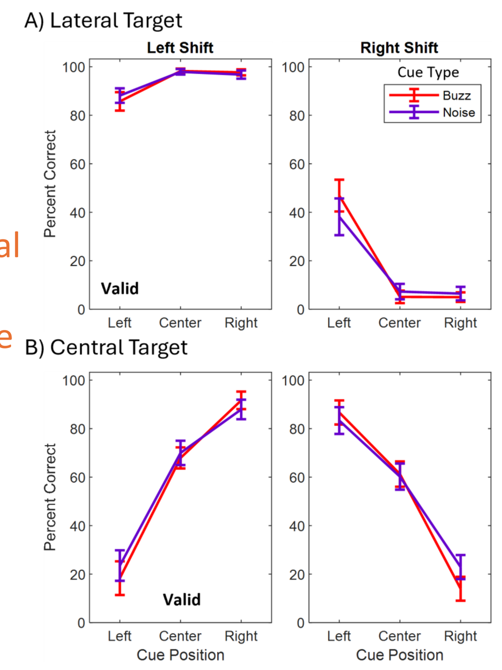


Figure 3 Percent correct (±SEM) responses as a function of cue location for the lateral and central targets (plotted separately for the left and right shifts). A) Lateral target data combined across ±25°. B) Central target data.

RESULTS: Target-Elicited ERPs (Sebena data only)

CENTRAL ELECTRODES

Cue validity and target N1:
- auditory cue modulates target N1: smaller for valid cue,
- target N1 after visual cue much larger than after auditory,

N1 effects likely a result of spatially specific adaptation/refractoriness (auditory cue identical to target), not attention.

Cue validity and later components:
- auditory ERP differs strongly 200-300 ms post-T1 (100-200 ms post-T2).

Later components N2/P3 of ERP responses are likely correlates of behavioral interaction modality x validity elates in d'.

OCCIPITAL ELECTRODES

Shift direction re. FP:

For both visual and auditory cue, away-response more positive than towards-response 300-500 ms post-T1 (200-400 ms post-T2).

For auditory cue, effect also modulated by cue validity (inset in panel A).

P3 - possible cue-independent correlate of behavioral bias away from FP. However, it does not match the auditory-cue validity-dependence.

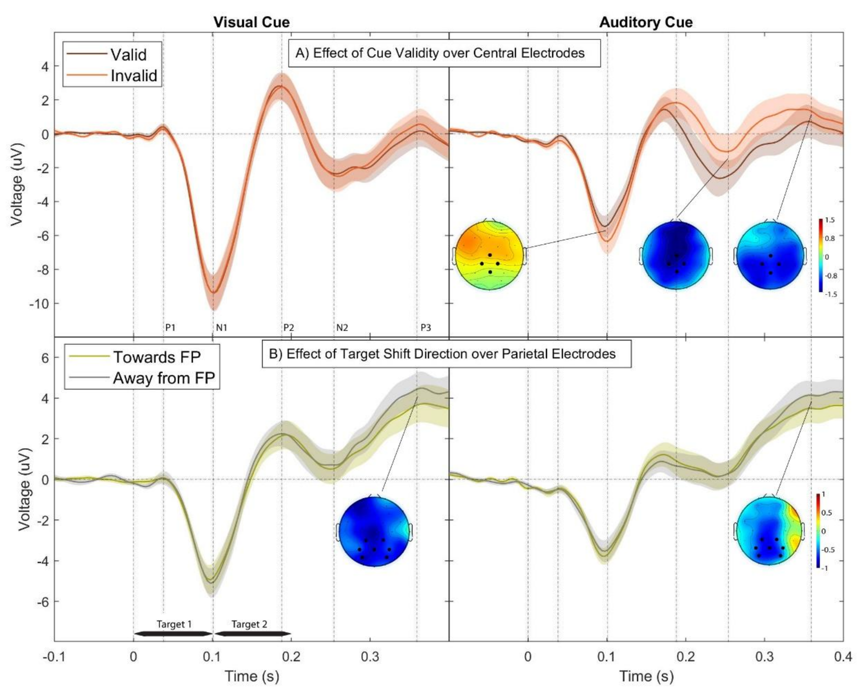


Figure 4 Target-elicited ERPs as a function of time averaged over two scalp regions. A) Across-subject average responses over central electrodes for valid vs. invalid cues and visual vs. auditory relative to the target onset. B) Responses over parietal electrodes plotted separately for the towards vs. away from FP shift directions, using the same layout as in panel A.

RESULTS: Auditory Cue-Evoked ERPs

Responses at occipital electrodes for different combinations of validity and correctness are similar in each hemisphere for t < 300 ms (Fig. 5A, 5B).

The hemispheric difference polarity depends on cue location in mixed HC & EC frame.

Auditory-evoked Contralateral Occipital Positivity (ACOP) in mixed RF (Fig. 5C)

Contra - ipsi hemispheric difference *re.* cue location (in mixed head-centered & eye-centered reference frame) at occipital electrodes:

Correct trials – no effect.

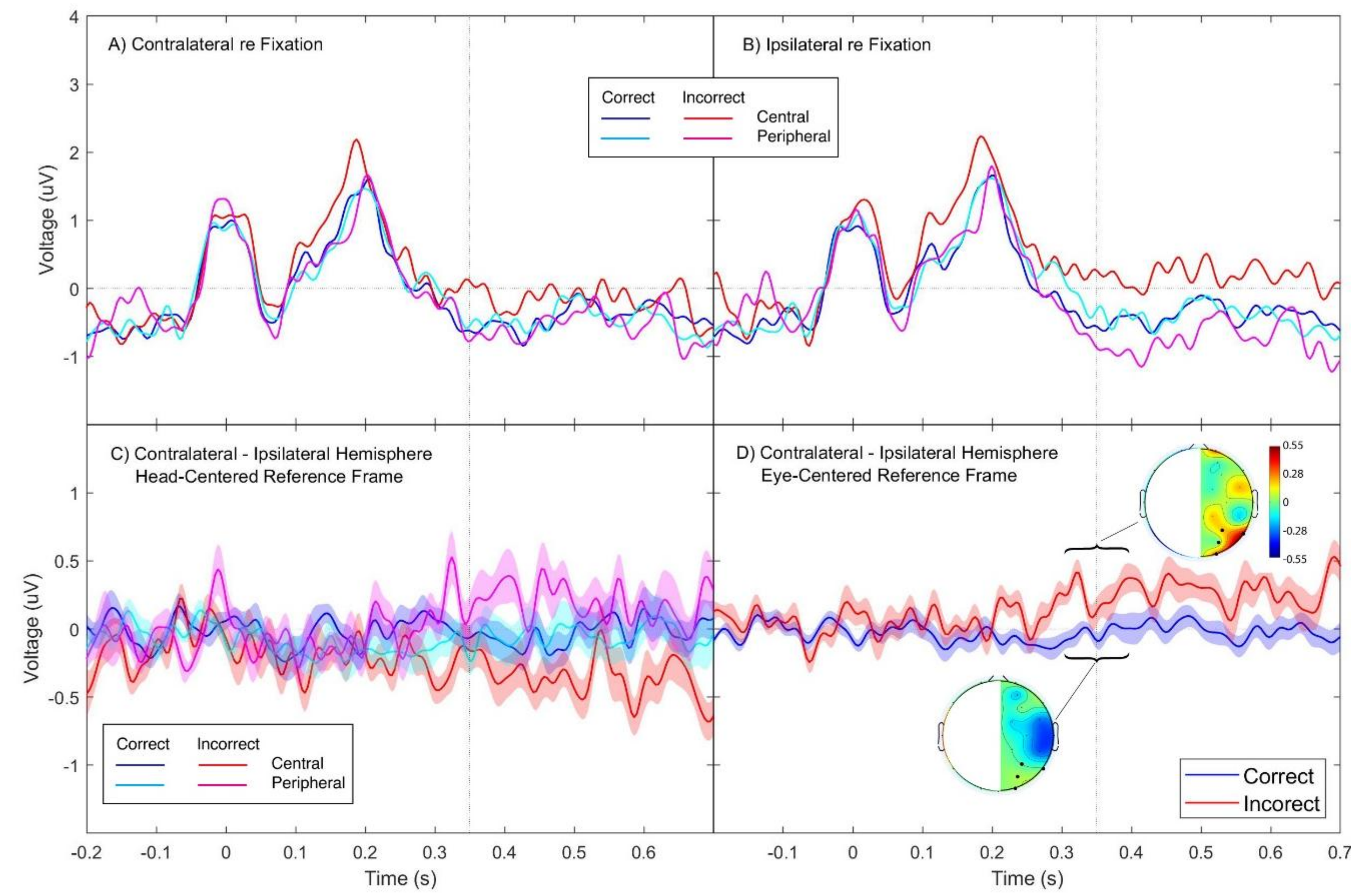
Incorrect trials – positive for central, negative for peripheral cue. Results independent for cue validity.

ACOP in eye-centered reference frame

ACOP observed:
- for both central and peripheral cues (= left & right cue re. fixation), independent of fixation, but only for the incorrect trials.

ACOP observed in eye-centered RF, however only for incorrect trials (dependence on correctness different than in Feng et al., 2004).

Figure 5 Auditory cue-elicited ERPs over occipital electrodes, shown separately for the hemisphere contralateral (A) and ipsilateral (B) to fixation, and as hemispheric differences in a mixed head- and eye-centered (C) and eye-centered (D) reference frames. Time referenced to cue onset. Insets highlight electrode locations and topographies



CONCLUSIONS

- **Stimulus-driven automatic spatial attention influences auditory spatial discrimination:**

Valid auditory (but not visual) cue improves performance (re. invalid cue) by increasing sensitivity and reducing criterion bias.

Main effect of cuing is the **distracting** effect of invalid auditory cue, possibly related to the fact that it was identical to the target in original experiment. Follow-up shows a slight reduction for a dissimilar cue, but a stronger bias when the dissimilar cue is valid and lateral.

These effects correlate with **N2/P3 target-evoked** ERP components over central electrodes.

- **Eye-gaze direction influences performance even when subjects do not move their eyes in response to cues/stimuli:**

Subjects were biased to respond away from the fixation point
- slightly for visual cue, strongly for invalid auditory cue, but not at all for valid auditory cue.

This effect is partially reflected **in late target-evoked P3** ERP components over occipital electrodes.

- **ACOP** in response to **cue predicts accuracy** of subsequent **target discrimination, independent** of cue **validity**. **Reference frame** of the activation is mostly **eye-centered**.

REFERENCES

Kopčo, N, A Ler, and B Shinn-Cunningham (2001). "Effect of auditory cuing on azimuthal localization accuracy," J. Acoust. Soc. Am. 109(5), 2377
Maddox RK, Pospisil DA, Stecker GC, et al. (2014) Directing eye gaze enhances auditory spatial cue discrimination. Current Biology : 24: 748-52
Rhodes, G. (1987). Auditory attention and the representation of spatial information. P&P, 42, 1-14.
Sach, AJ, Hill, NI, and Bailey PJ. (2000) Auditory spatial attention using interaural time differences. JEP:HPP. 26(2):717-729
Sebena R, Kopco N (2022) "A cue or a distractor? Automatic attention in spatial discrimination" 21st Aud Perc., Cog., & Action meeting, Boston.
Shimojo, S., Miyauchi, S. and Hikosaka, O. (1992). Visual attention field can be assessed by illusory line motion sensation." IOVS, 33:1354
Spence, CJ and Driver J (1994) Covert spatial orienting in audition: Exogenous and endogenous mechanisms. JEP:HPP. 20(3): 555-574.

[Work supported by EU Horizon Europe HORIZON-MSCA-2022-SE-01 grant N° 101129903 and APVV-23-0054]

More info: pcl.upjs.sk