Electrophysiological correlates of attentional cueing and auditory spatial discrimination

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INTRODUCTION

Attention facilitates processing of objects, events, or locations in complex scenes. The Line Motion Illusion (FIG. 1) illustrates stimulus-driven attentional modulation in vision (Shimojo et al., 1992).

Very few studies looked at
- the effect of attention on sound localization,
- whether the effect is modality-dependent,
- whether there is a difference for exogenous vs endogenous attention.

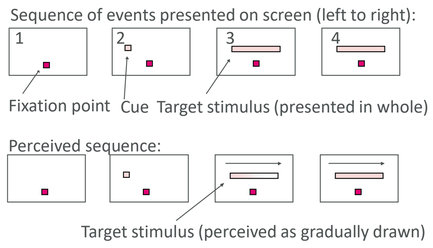

Figure 1 Line Motion Illusion - Cue enhances perception of nearby visual stimuli.

Previous studies found:
- cueing improves reaction times (Spence and Driver, 1994),
- small (Sach et al., 2000) 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, but not when cue was auditory (Maddox et al., 2014).
- lateralized sound elicited an enlarged contralateral positive potential in the interval of 200–450 ms after sound onset localized in visual cortex.
- this auditory evoked contralateral occipital positivity (ACOP) reflects the orienting of attention toward the cued location, which improves perceptual discriminations at that location (McDonald et al., 2013)

CURRENT STUDY

Examine the effect of **exogenous attention** on **spatial discrimination** for:
- **visual** vs **auditory central and peripheral** cues,
- **gaze fixed** at a neutral location.
  In fully simulated virtual auditory environment. Also measure EEG to examine neural correlates.

Hypothesis and predictions:
Automatic attention attracted by the cue, not only by gaze direction, affects spatial discrimination.
- **valid cues** will result in improved performance,
- **valid visual** cues will be more helpful than **valid auditory** cues (even without gaze changes), because of higher visual spatial acuity.

The typical auditory-evoked N1 component peaking at 100–110 ms will be observed in the fronto-temporal ERP waveforms elicited by the lateralized sounds under all conditions.
- we predict N1 amplitude will be larger over the hemisphere contralateral to the sound location
- we predict there will be no contralateral vs ipsilateral difference in N1 amplitudes between correct trials and incorrect trials and valid and invalid trials
(we predict that the N1 will not be associated with better performance of validly cued stimuli)

The ACOP will be predictive of target discrimination accuracy on valid trials.
- there will be significant contralateral vs ipsilateral amplitude difference at occipital sites over the time window 300–400 ms on valid-correct trials
but no difference in valid-incorrect trials (based on Feng et al, 2014)

METHODS

SUBJECTS, STIMULI AND SETUP

- 14 subjects (9 male),
- 2 sessions + initial practice,
- 1 **session** divided into 20 **blocks** of 40 **trials** (FIG. 2A), each block with fixed Fixation point and cue modality, varying target location, target shift direction (T1 vs T2), and cue validity (FIG. 2B),
- **Target**: two 100-ms 170-Hz click trains (T1,T2), presented w/o gap at 0° or 25° (T1) and 0°±4.2° or 25°±8.4° (T2),
- **Cue**: auditory (like T1) or visual (100-ms white dot), valid (same location as T1), or invalid (25° - T1 location), cue validity 50%,
- **Task**: "Discriminate whether T2 was to the left or to the right of T1. Cue will indicate correct or incorrect location."
- auditory stimuli simulated using non-individualized HRTFs and ER1 headphones,
- visual stimuli presented on computer screen (head fixed at a constant distance from screen),
- auditory and visual stimuli presented through DataPixx system and a computer screen,
- responses on computer keyboard,
- ERPs recorded during sessions using 32-channel Biosemi ActiveTwo system at 4096 Hz,
- EOGs recorded for eye-tracking.

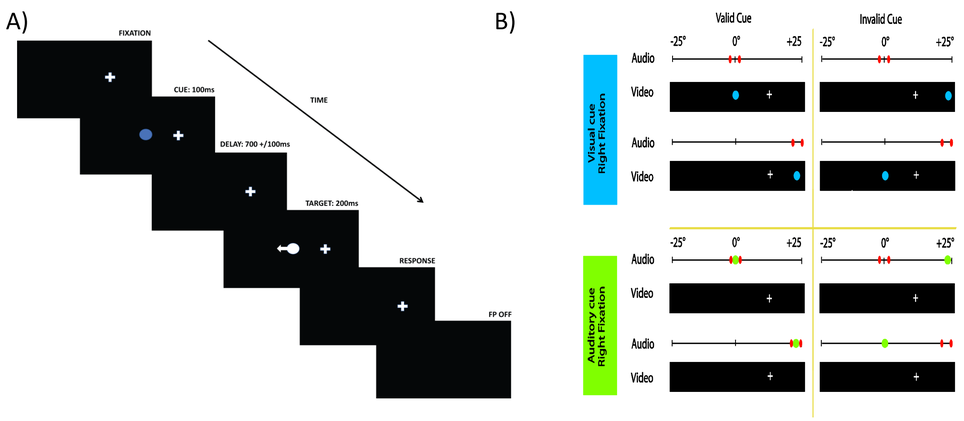

Figure 2 Experimental setup. A) Temporal structure of a single trial. B) Spatial arrangement of stimuli in different experimental conditions for FP on the right (mirror-flipped setups were used with FP on the left).

DATA ANALYSIS

- statistical significance assessed using repeated-measures ANOVA, only significant effects shown,
- figures plot across-subject mean +/- standard error of the mean.

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RESULTS: Behavioral

PERCENT CORRECT

Overall visual cue performance better than auditory cue performance.

Validity of cue (FIG. 3A) has:
- little impact for visual cue (n.s.),
- large impact for auditory cue:
  invalid cue acts as a distractor (valid cue has a small effect re. visual).

When data divided by target shift direction re. FP (FIG. 3B, C):
Independent of cue validity, visual cue responses always slightly biased away from FP.
Auditory valid-cue resps not biased.
Auditory invalid-cue resps biased strongly away from FP (i.e., from cue to target).

Figure 3 Percent correct responses as a function of cue validity plotted separately for the visual and auditory cues, and for data averaged across target shift direction (A), or separately for targets moving towards FP (B) and away from FP (C).

Visual cue has very small effect. Invalid auditory cue acts as distractor.
Discrimination responses are asymmetrical, dependent on FP. When auditory cue is presented, that asymmetry is suppressed: for valid cue there's no bias, for invalid cue (identical to target), there's bias away from cue.

RESULTS: ERPs elicited by cue sounds

N1 results

N1 amplitude was larger over the hemisphere contralateral to the sound location (contralateral vs ipsilateral Fronto-temporal amplitudes over 90–150 ms ($F(1,12)= 6.798$, $p = 0.023$); and larger for lateral cue then for central ($F(1,12)= 7.325$, $p = 0.019$) (Figure 4a).

Laterality x cue position interaction was also found to be highly significant ($F(1,12) = 9.508$, $p= 0.009$). Specific comparison showed that this interaction was the result of the N1 difference amplitude between lateral and central cue being larger contralateral than ipsilateral to fixation (Figure 4b).

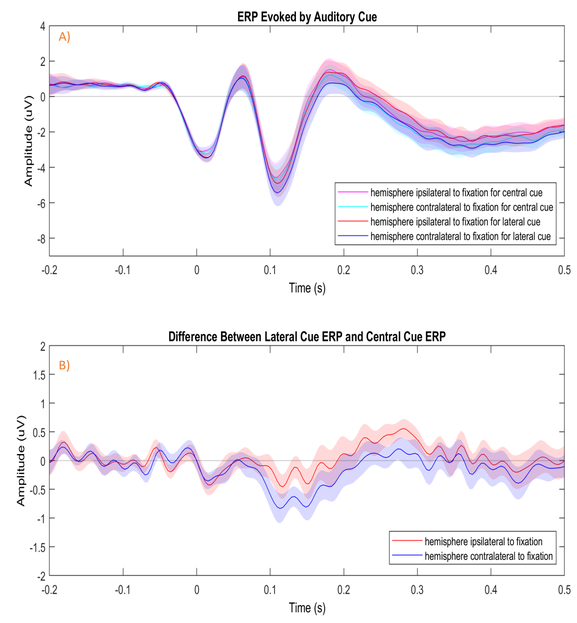

Figure 4 A)ERP waveforms elicited by lateralized and central sounds averaged over five pairs of fronto-temporal electrodes ipsilateral and contralateral to the fixation
B) Difference between lateral cue and central cue ERP.

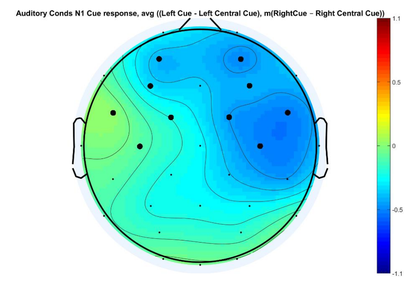

Figure 5 Topographical distributions of difference between lateral and central cue over 90–150 ms with fixation fixed on the left side.

ACOP preliminary results

- We found main effect of cue position ($F(1,12)= 14.37$, $p = 0.003$) with lower amplitude for peripheral cue stimuli, main effect of fixation ($F(1,12)= 15.537$, $p = 0.002$) and their interaction ($F(1,12)= 14.96$, $p = 0.002$),
- validity x laterality x cue position interaction was also found to be significant ($F(1,12)= 6.558$, $p = 0.025$) (Figure 6)

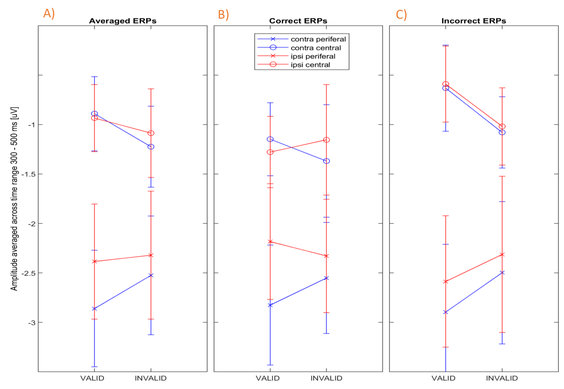

Figure 6 Mean ACOP amplitudes within the time window of 300-500ms averaged over a cluster of four occipital electrodes averaged across correctness(A), or separately for correct (B) and incorrect responses (C).

- there is a contralateral versus ipsilateral amplitude difference between valid correct and valid incorrect for peripheral cue, but no difference between invalid correct and invalid incorrect
- for peripheral cue there is no difference between correct and incorrect responses on contralateral hemisphere
- central cue correct responses have lower amplitude compare to incorrect responses (regardless of validity).

CONCLUSIONS and DISCUSSION

Stimulus-driven automatic spatial attention influences auditory spatial discrimination:
Valid auditory cue improves performance (re. invalid cue) by increasing sensitivity and reducing criterion bias. Valid and invalid visual cue results in performance comparable to valid auditory cue.
Main effect of cuing is the distracting effect of invalid auditory cue, possibly related to the fact that it was identical to the target.

N1 on contralateral vs ipsilateral hemisphere was affected by target location. These asymmetries were not associated with the enhanced discriminability of validly cued targets, not modulated by attentional mechanisms.
In 300 -500ms ACOP time window, peripheral cue resulted in lower amplitude on contralateral hemisphere, with contralateral minus ipsilateral difference associated with better discriminability for valid cues.

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