Visual vs. auditory 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).

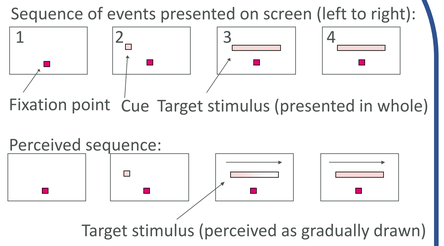

Figure 1 Line Motion Illusion - Cue enhances perception of nearby visual stimuli.

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.

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).

CURRENT STUDY

Examine the effect of **exogenous attention** on **spatial discrimination** for:
- **visual** vs **auditory** cues,
- **gaze fixed** at a neutral location.

In fully simulated virtual auditory environment. Also measure EEG to examine neural correlates.

Hypothesis:
Automatic attention attracted by the cue, not only by gaze direction, affects spatial discrimination.

Predictions:
- **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,
- invalid visual and auditory cues similarly distracting.

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.

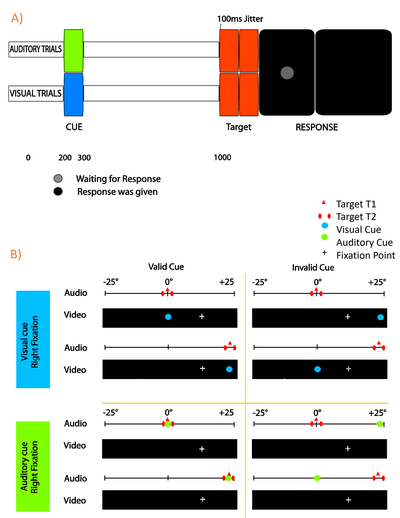

Figure 2 Experimental setup. A) Temporal structure of a single trial. B) Spatial arrangement of stimuli in different experimental conditions for FP on the right (mirror-flipped setups were used with FP on the left).

DATA ANAYLSIS

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

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).

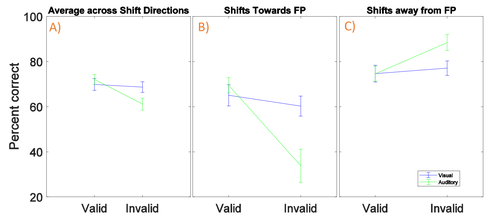

Figure 3 Percent correct responses as a function of cue validity plotted separately for the visual and auditory cues, and for data averaged across target shift direction (A), or separately for targets moving towards FP (B) and away from FP (C).

SENSITIVITY ANALYSIS

Sensitivity d' (FIG. 4A) is:
- uninfluenced by visual cue validity,
- slightly influenced auditory cue validity (better for valid).

Criterion placement (FIG. 4B) is:
- slightly biased towards FP, uninfluenced by visual cue validity,
- unbiased for valid auditory cue,
- strongly biased toward FP for invalid auditory cue.

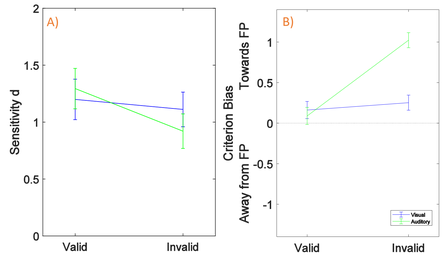

Figure 4 Sensitivity d' (A) and criterion bias (B) in responses as a function of cue validity plotted separately for the visual and auditory cues analyzed with respect to the FP.

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.

REACTION TIMES (FIG. 5)

Reaction Times measured from end of previous trial
- uninfluenced by cue validity,
- uninfluenced by cue modality,
- influenced by target shift direction: faster for targets moving away from FP.

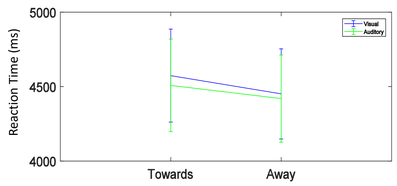

Figure 5 Reaction times in responses as a function of target shift direction re. FP, plotted separately for the visual and auditory cue.

Reaction times depend on gaze direction – faster for targets moving away.
Valid cues do not make responses faster.

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RESULTS: EEG

EVENT-RELATED POTENTIALS

Maxima and minima of grand averaged potentials (FIG. 6) are referenced to the onset of target T1. Therefore, the P2, N2, and P3 components coincide with target T2 N1, P2 and N2 components.

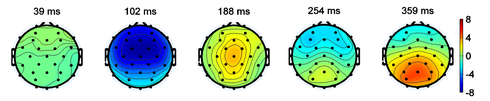

Figure 6 Topographic distribution of grand average potentials at P1, N1, P2, N2, P3 re. onset of target T1.

CUE VALIDITY (FIG. 7)

Cue validity and target N1:
- auditory cue modulates target N1: N1 smaller for valid cue,
- visual cue does not modulate N1,
- target N1 after visual cue much larger than after auditory cue.

Cue validity and later components:
- no effect of visual cue,
- auditory cue ERPs differs 200-300ms post-T1 (100-200ms post-T2)

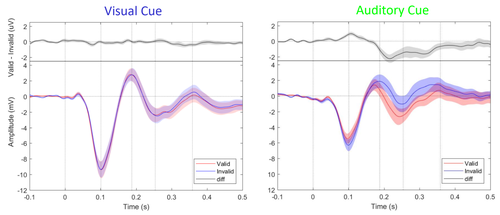

Figure 7 Cue-modality-specific and cue-validity-specific responses averaged across electrodes Cz, Fc1, Fc2, Fz. Vertical dotted lines indicate timing of components P1, N1, P2.

N1 modulation likely result of spatially-specific adaptation, not attention.
Later components likely a correlate of behavioral interaction cue modality x validity for auditory cue.

SHIFT DIRECTION

Target shift direction re. FP averaged across cue validity (FIG. 8)
- Away-response more positive than towards-response 300-500ms post-T1 (200-400ms post-T2), independent of cue modality.

N2/P3 response is a cue-modality-independent correlate of behavioral bias away from FP.

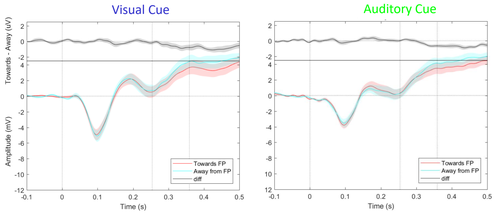

Figure 8 Cue-modality-specific and target-direction-specific responses averaged across 7 electrodes around Pz. Vertical dotted lines indicate timing of components N2 and P3.

ERP LATENCIES

No significant latency-differences found. Closest-to-significance P2 difference for valid vs. invalid auditory cue (FIG. 7); $p > 0.05$.

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. No effect of cuing on reaction ties.
These effects correlate well with P2-N2 ERP components.

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 at all not for valid auditory cue,
- by responding faster to targets shifting away from FP (re. shifting towards).

This effect is also reflected in late ERP components N2/P3.

Both modality-specific automatic attention and eye-gaze direction influence discriminability of auditory target locations. These behavioral effects have neural correlates in late ERP components.