The reference frame of the electrophysiological correlates of attentional cueing in auditory spatial discrimination

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Intro

Attention facilitates processing of objects, events, or locations in complex scenes.

Very few previous studies looked at attention in **sound localization** and:
– whether it is **cue modality-dependent**,
– whether there is a difference for **exogenous** vs **endogenous** attention.

Past behavioral studies found:
– 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 results:
– **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 towards cue, improving discrimination (McDonald et al.,'13)
– visual space is referenced in eye-centered frame, auditory in head-centered (Groh et al., 2021)

Current study

Behavioral and EEG experiment:
- examined 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.

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** (like in Maddox et al., 2014) even without gaze changes.

ERPs to **targets (N1/P2)** and/or to **cues (ACOP)** will correlate with behavioral effects.

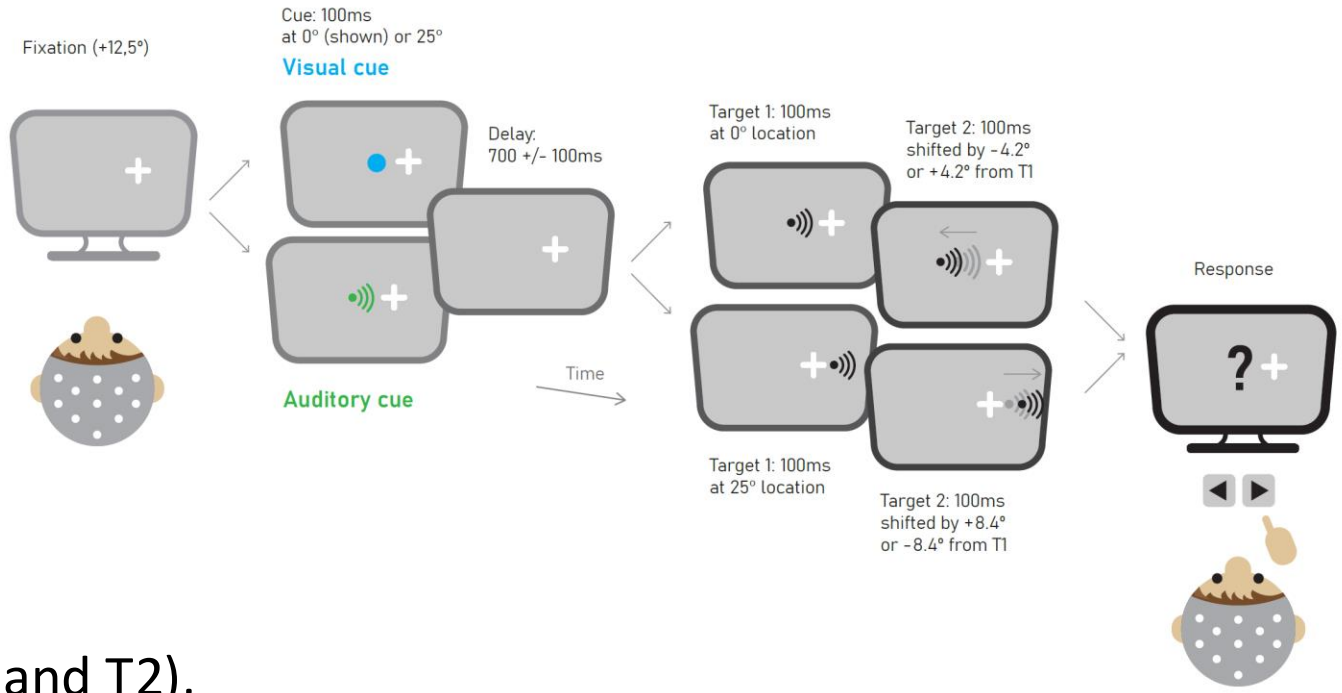
Is **ACOP** to **cue** represented in head-centered or eye-centered coordinates?

Experimental setup

Virtual AV environment: anechoic HRTFs

Eyes: fixated at 12.5°
(fixed within a block)

Cue: - auditory (100-ms 170-Hz click train, identical to target)
or visual (100-ms white dot),
- at 0° or 25°, valid (predicting target location), or invalid,
- cue validity 50%.



Target: - two 100-ms 170-Hz click trains (T1 and T2),
- presented w/o gap at 0° or 25° (T1) and 0°±4.2° or 25°±8.4° (T2)

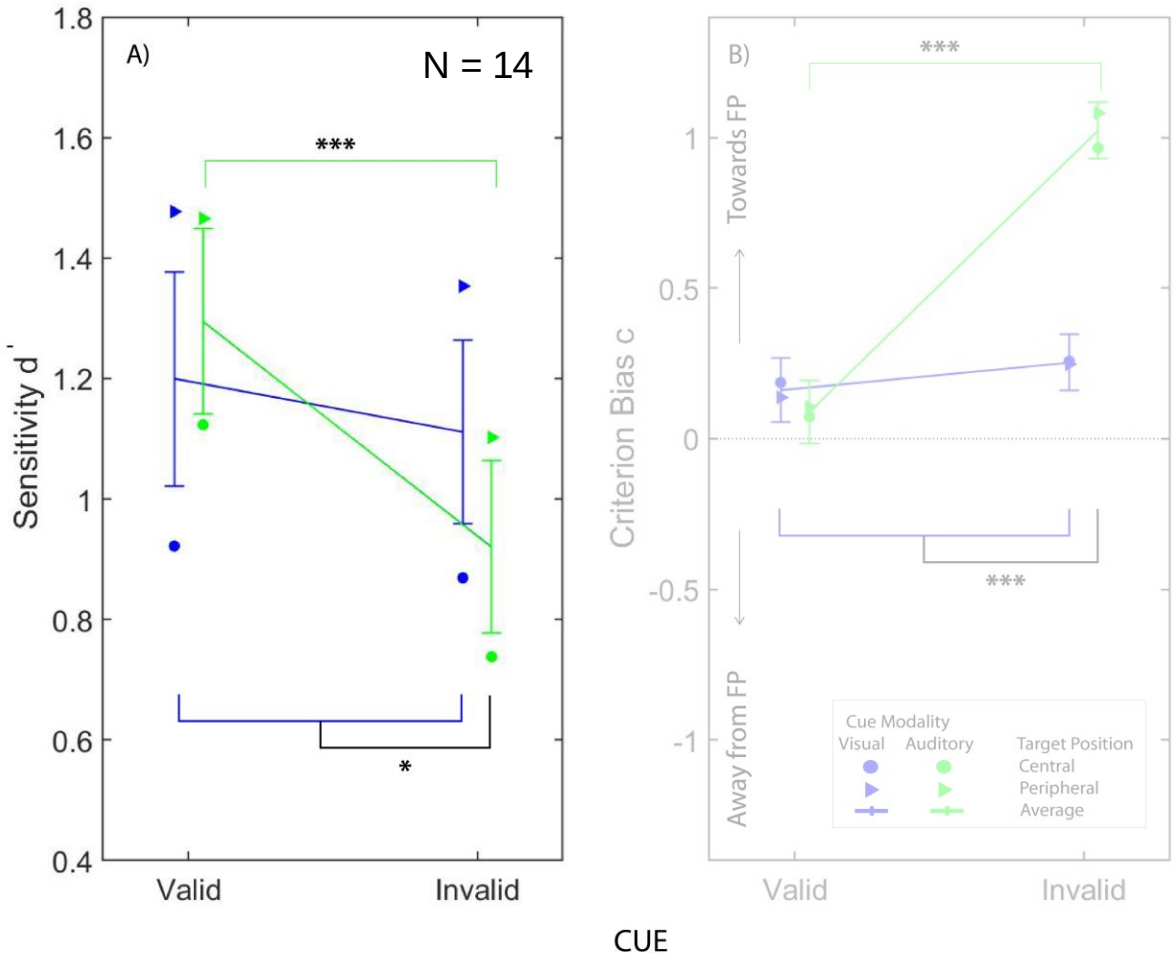
Task: "Discriminate whether T2 was to the left or to the right of T1."

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

In half of experiment, blocks were mirror-flipped to the left hemifield.

Results Presentation Outline:
- **behavioral**, **ERPs** to **targets**, **ERPs** to auditory **cues**.

Behavioral Results: Sensitivity



Sensitivity d':

Overall visual cue performance slightly better than auditory.

Validity of cue has:

– little impact for visual cue (n.s.),

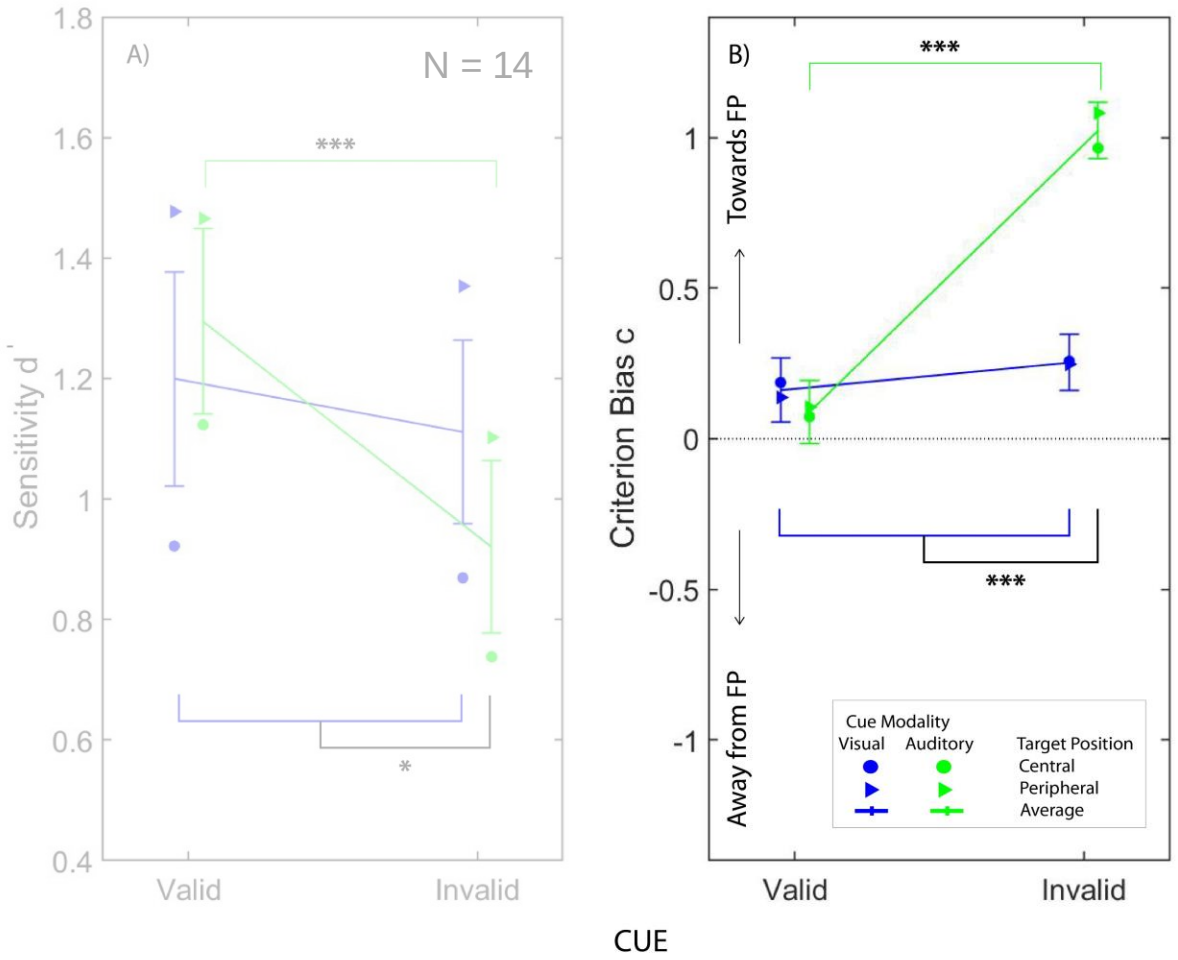
– large impact for auditory cue: strongest effect: invalid cue reduces performance,

– 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.

* $p < 0.05$, *** $p < 0.001$

Behavioral Results: Criterion



Criterion Bias placement re. fixation (FP):

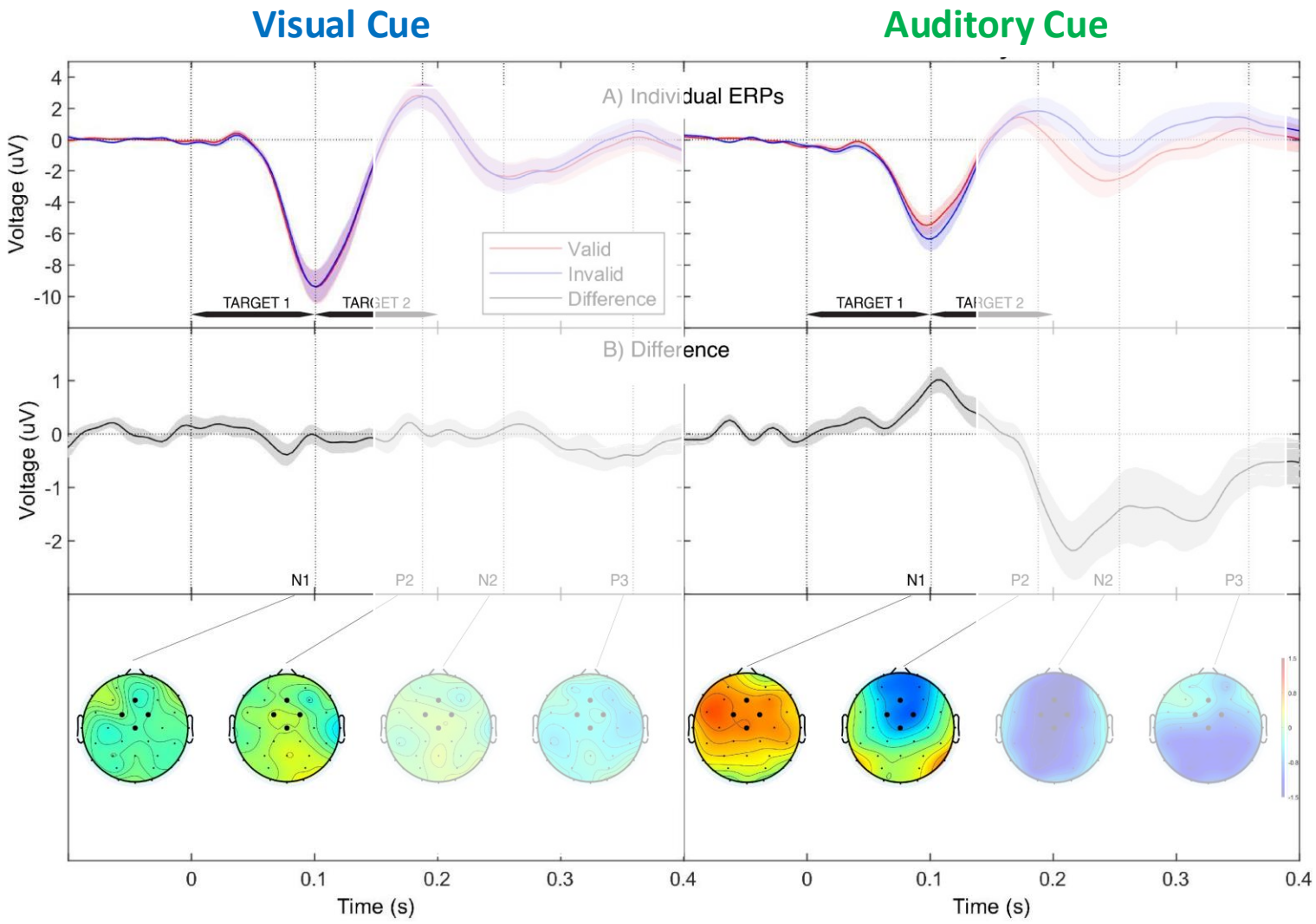
- visual: slightly biased towards FP, uninfluenced by cue validity,
- auditory: unbiased for valid cue, strongly biased toward FP for invalid.

Discrimination responses asymmetrical with respect to FP: most responses in direction away from FP.

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

* $p < 0.05$, *** $p < 0.001$

Target-elicited ERPs, Central Electrodes

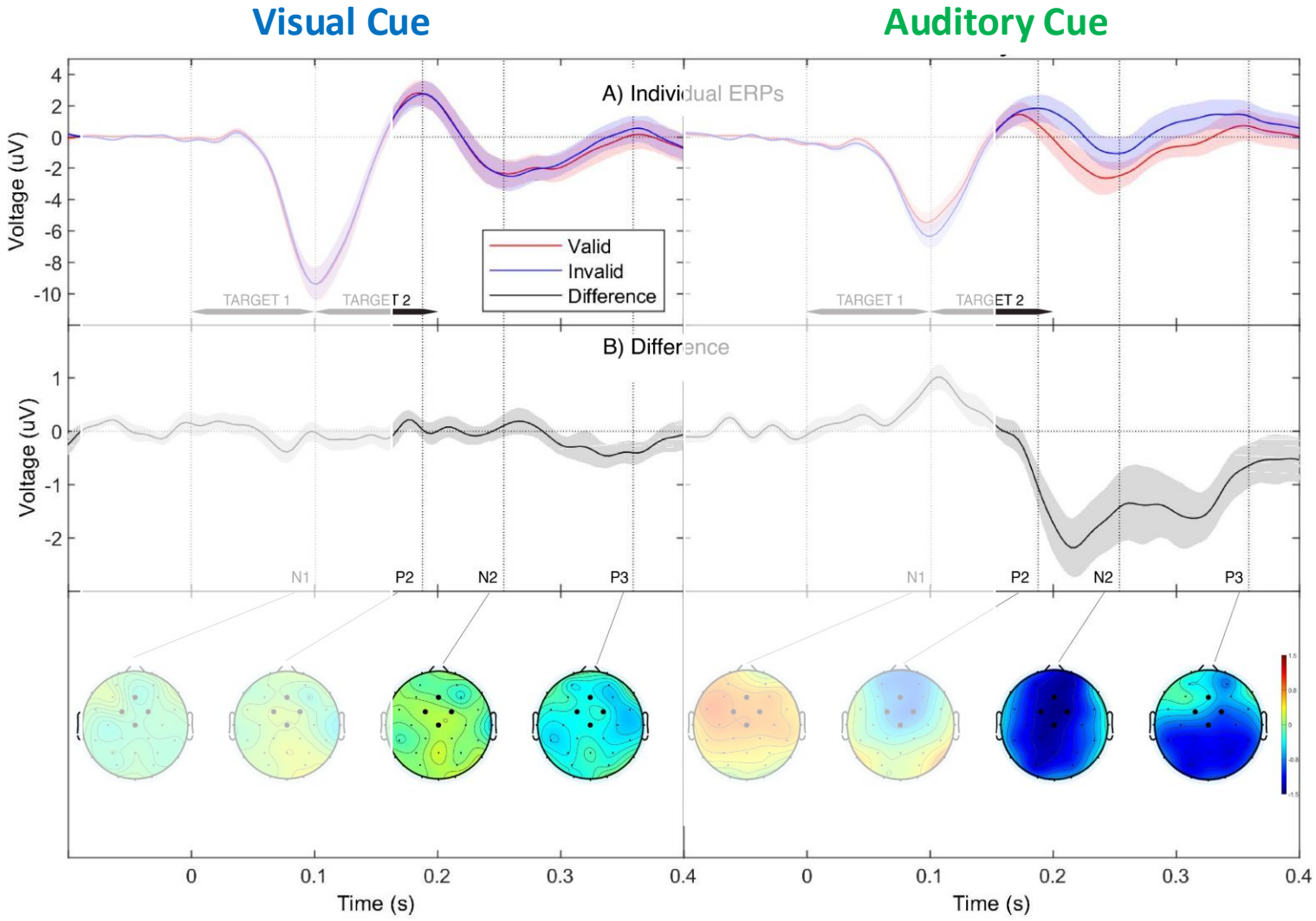


Cue validity and target N1

- auditory cue modulates target N1: smaller for valid cue,
- visual cue does not,
- target N1 after visual cue much larger than after auditory,

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

Target-elicited ERPs, Central Electrodes

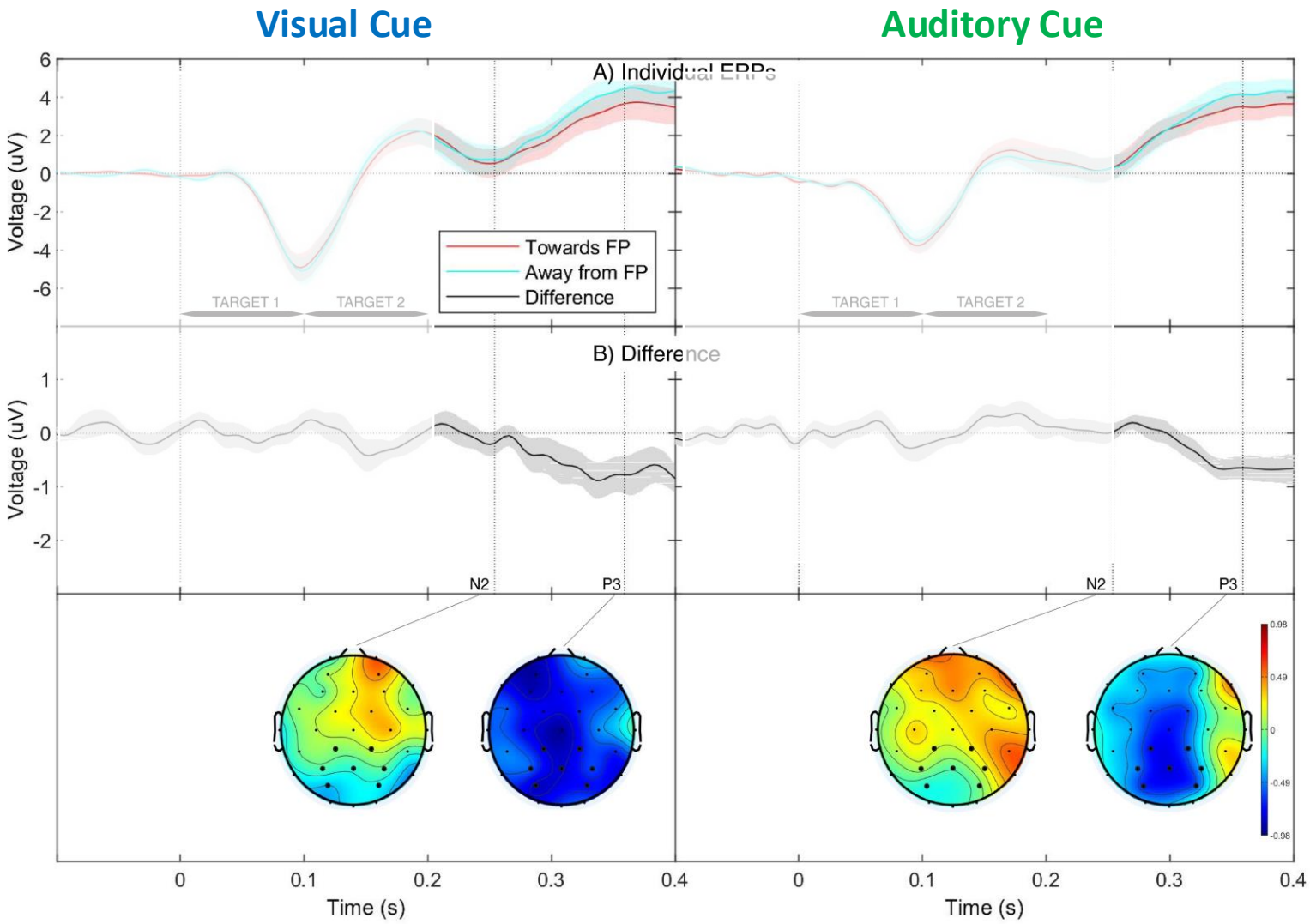


Cue validity and later components:

- No effect of visual cue,
- auditory ERP differs strongly 200-300 ms post-T1 (100-200 ms post-T2).

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

Target-elicited ERPs, Occipital Electrodes



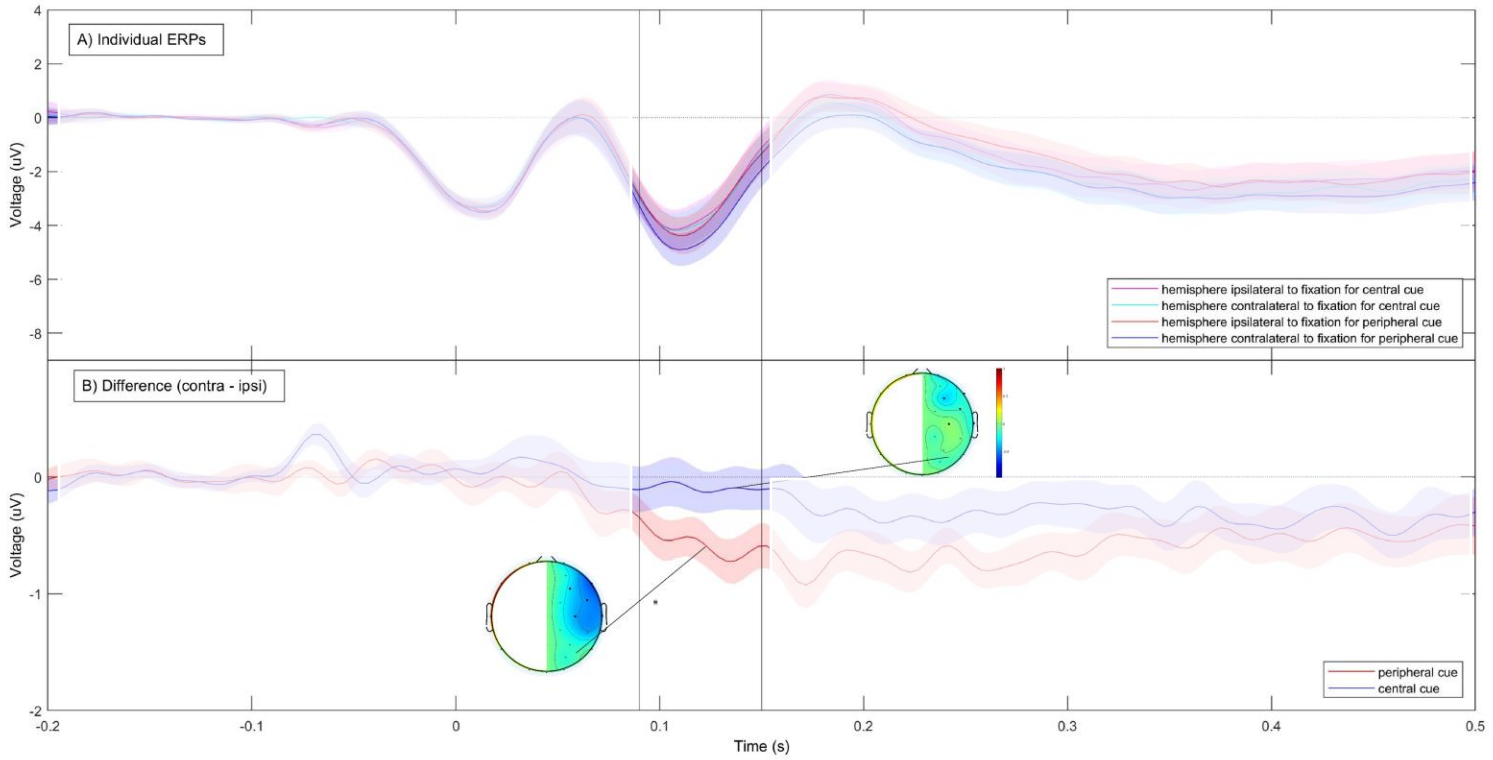
Shift direction re. FP:

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 (not shown).

P3 - possible cue-independent correlate of behavioral bias away from FP.

Auditory Cue-elicited early ERPs



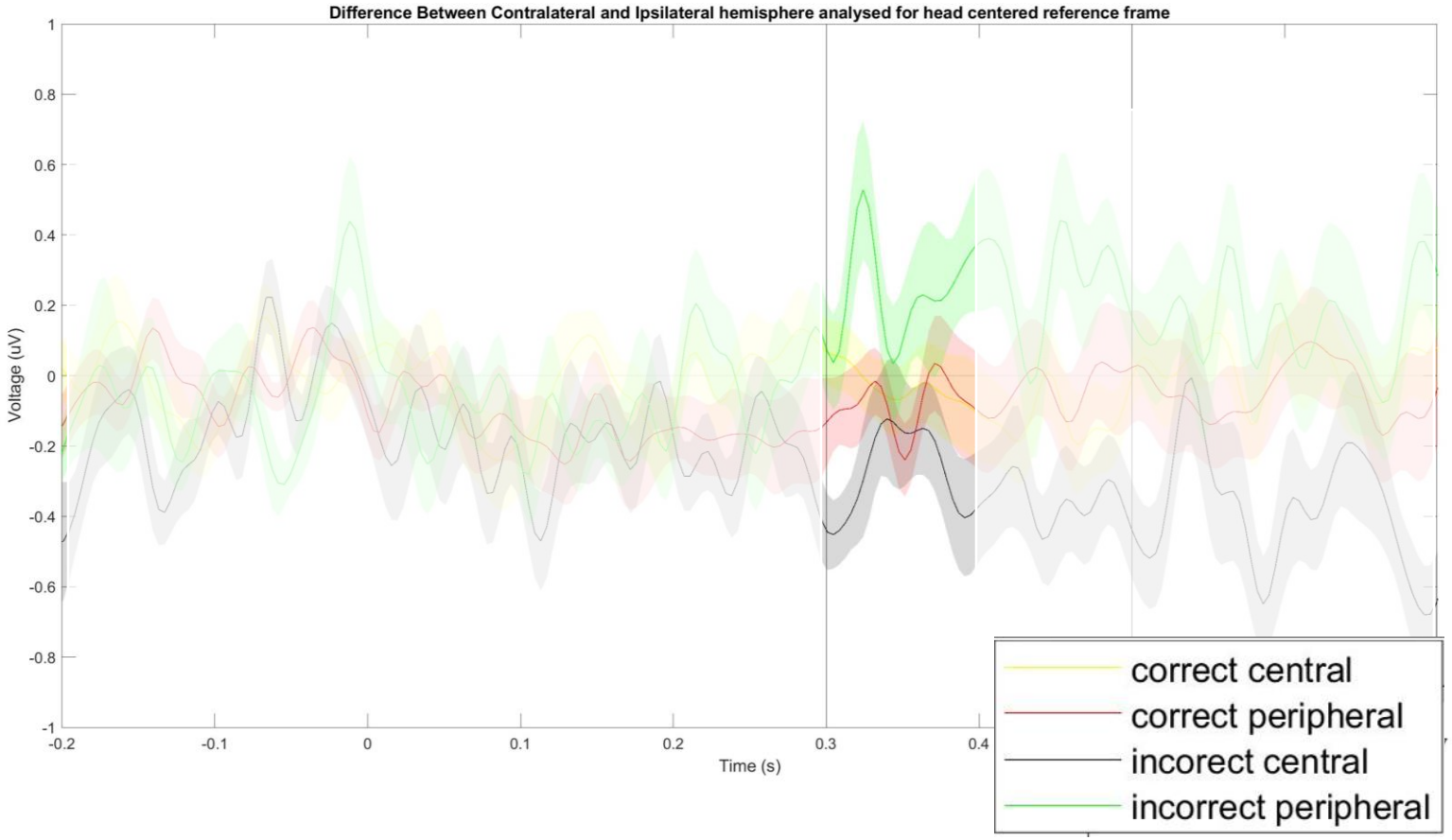
Contra - ipsi hemispheric difference *re*. fixation at fronto-temporal electrodes:

Peripheral cue causes N1 that is more negative in the contralateral hemisphere.

No such difference for central cue.

For N1 component there is larger hemispheric difference for peripheral than central auditory cue position, likely a result of early sensory processing encoding the horizontal sound location.

Auditory Cue-elicited late ERPs (ACOP)



Contra - ipsi hemispheric difference *re*. cue location (in head-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 polarity depends on cue location in head-centered frame.

ACOP in eye-centered reference frame

Head-centered (left FP):

-25° -12.5° 0° 12.5° 25°

Peripheral Central

Cue/Target FP Cue/Target

Head-centered (right FP):

-25° -12.5° 0° 12.5° 25°

Central Peripheral

Cue/Target FP Cue/Target

Eye-centered (both FPs):

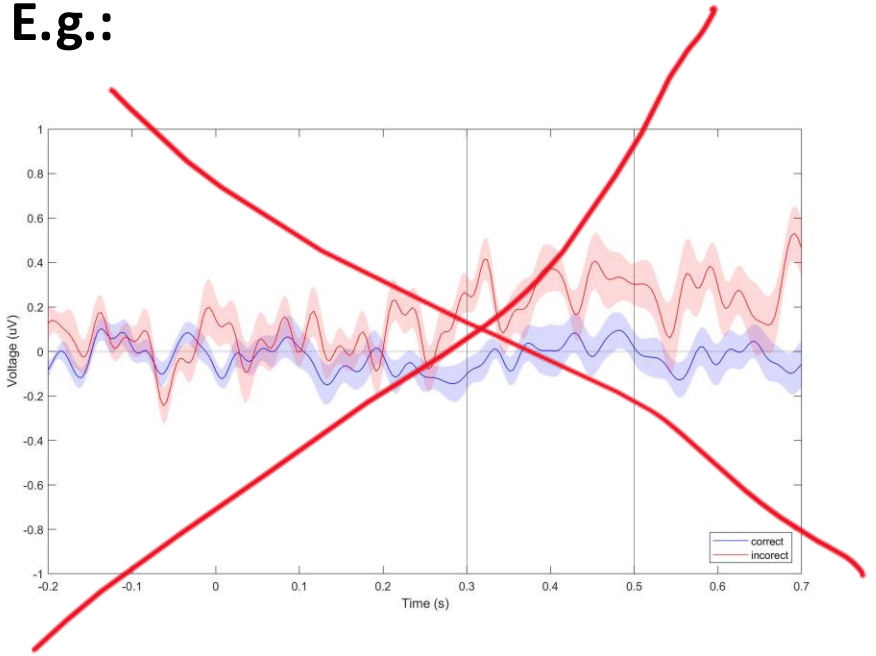
-25° -12.5° 0° 12.5° 25°

Left Right

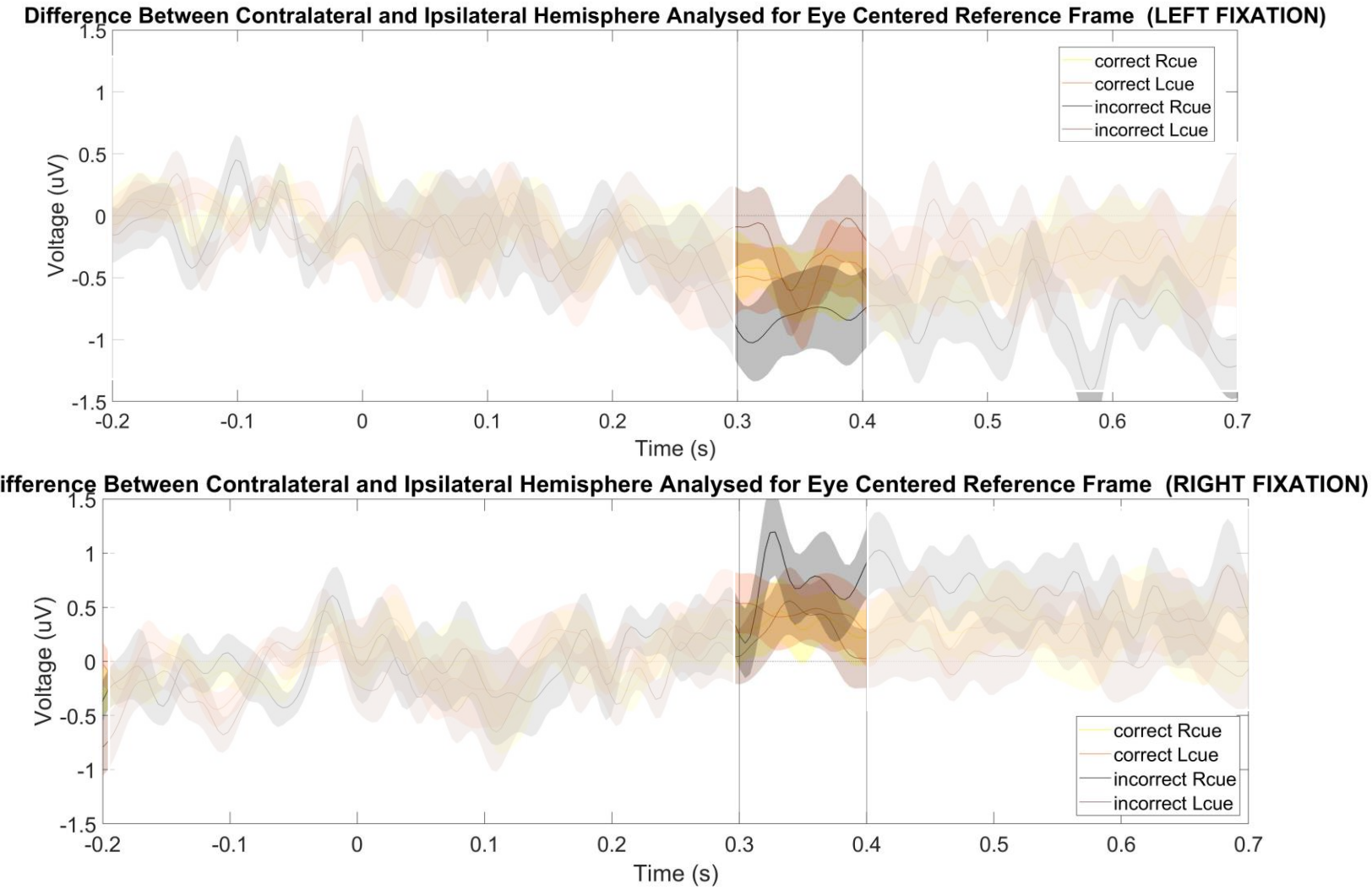
Cue/Target FP Cue/Target

Transforming representation to eye-centered reference frame might simplify results.

E.g.:



ACOP in eye-centered reference frame



Same data, eye-centered reference frame:

ACOP observed:

- for both central and peripheral cues (= left & right cue re. fixation), interacting with fixation and correctness.

ACOP not consistent in eye-centered RF. Moreover, dependence on correctness different than in Feng et al. (2004)

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 (flanker effect?).
These effects correlate with **P2-N2 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 reflected in **late target-evoked N2-P3** ERP components over occipital electrodes.

ACOP in response to **cue predicts accuracy** of subsequent **target discrimination, independent** of cue **validity. Reference frame** possibly **mixed**.

Future studies: use a different cue to reduce the distractive effect of invalid auditory cue.