Cortical auditory distance representation based on direct-to-reverberant energy ratio

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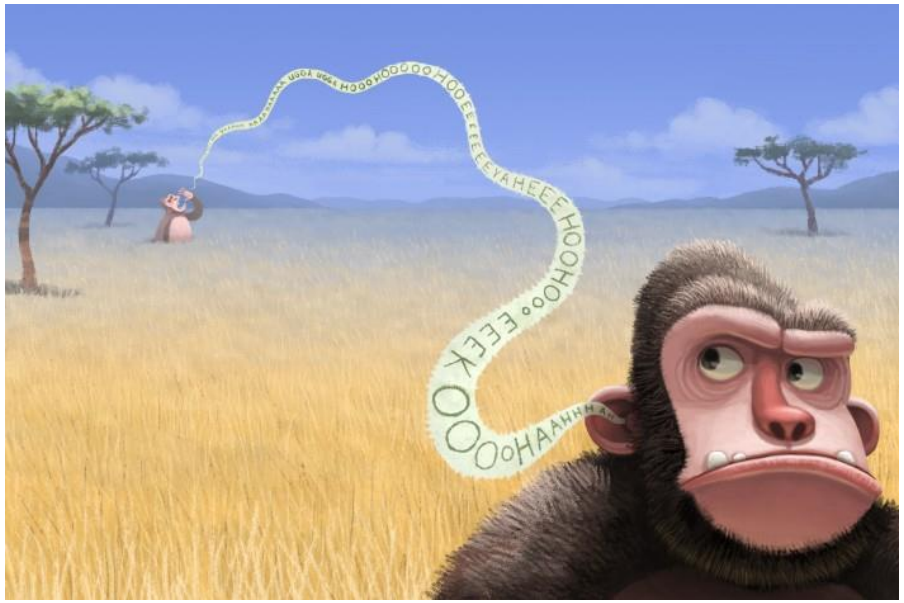
Introduction

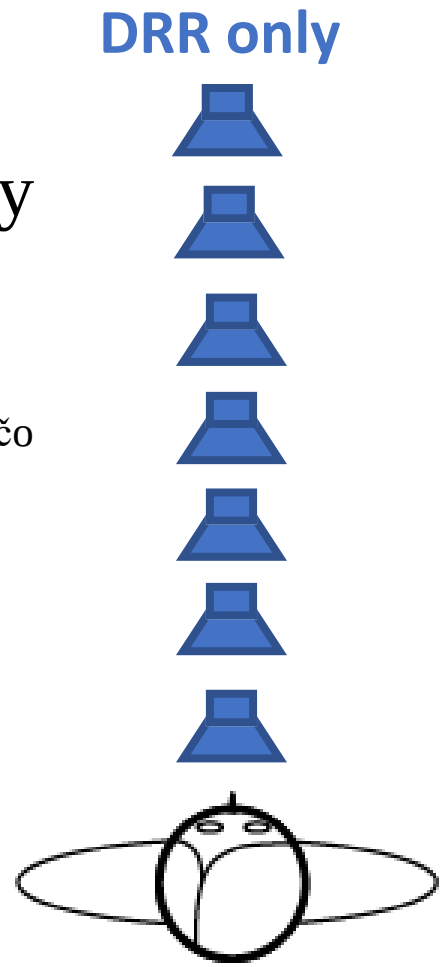
- Information about distance of objects that surround us in the environment is often important.

- The auditory modality is special in that it provides such information even for objects that are occluded or behind the listener (Brungart and Simpson, 2002b; Genzel et al., 2018; Kolarik et al., 2016; Maier et al., 2004; Neuhoff, 1998; Shinn-Cunningham et al., 2001; Zahorik et al., 2005).



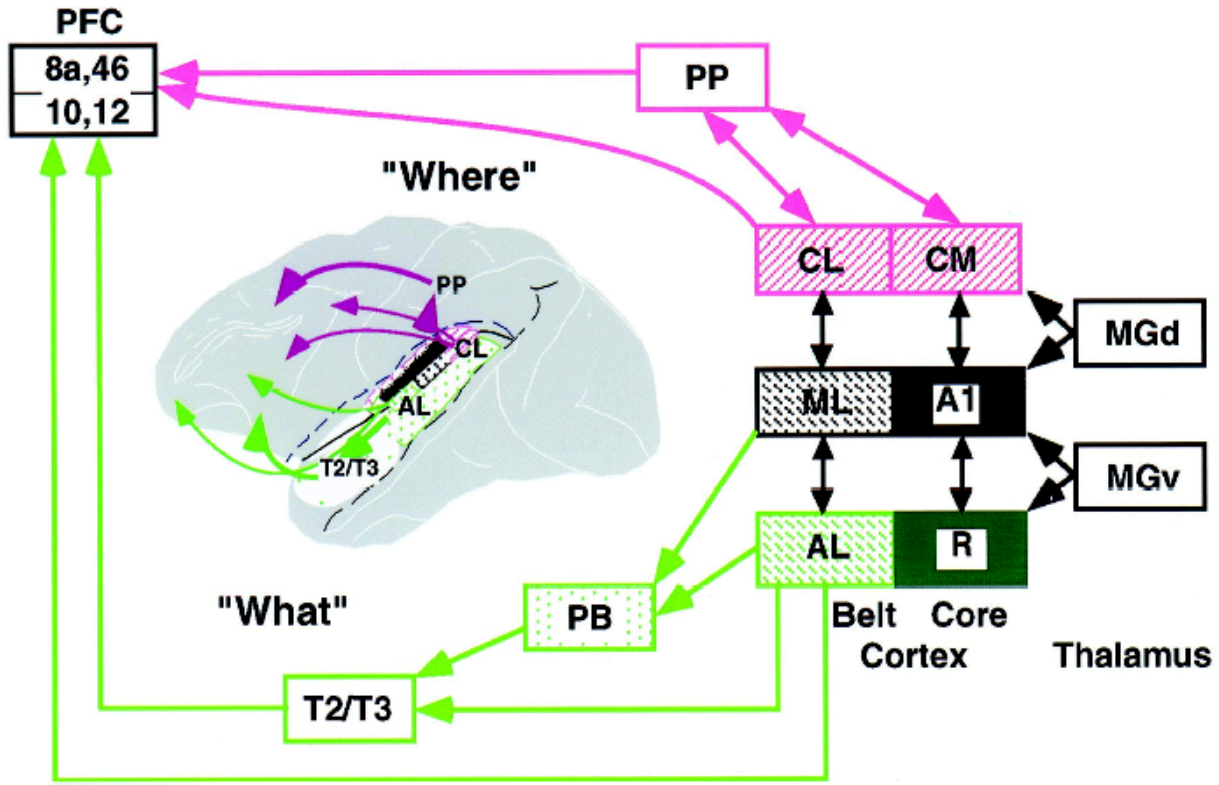
Distance perception: Main cues

- Multiple cues (for a review, see Zahorik et al., 2005)
- Intensity cue – often dominant but requires familiarity (Warren, 1999)
- Main intensity-independent cues are **ILD and DRR** (Kopčo et al., 2012)



Neural correlates of distance perception

- An abundance of human neuroimaging evidence exists of their broader anatomical subdivisions and functional pathways.



Rauschecker, 1998a; Rauscheckre and Tian 2000, 2001;

Neural correlates of distance perception

- An abundance of human neuroimaging evidence exists of their broader anatomical subdivisions and functional pathways.

Where pathway

- Posterior non-primary AC (planum temporale (PT) and posterior superior temporal gyrus (STG))
- Strongly activated by horizontal sound direction changes. (Ahveninen et al., 2006; Rauschecker, 1995, 1997, 1998; Brunetti et al., 2005; Deouell et al., 2007; Tata and Ward, 2005)

What pathway

- Anterior non-primary AC areas (anterolateral Heschl's gyrus, anterior superior temporal gyrus, and posterior planum polare)
- Strongly related to the sound-source identity. (Griffiths and Warren, 2002)

Neural correlates of distance perception

- However, neuronal representations of distance have been studied much less intensively.
- Our previous fMRI study (Kopco et al., 2012) provided evidence of neuron populations sensitive to intensity-independent auditory distance cues in these spatially-sensitive AC areas as well.

ILD + DRR

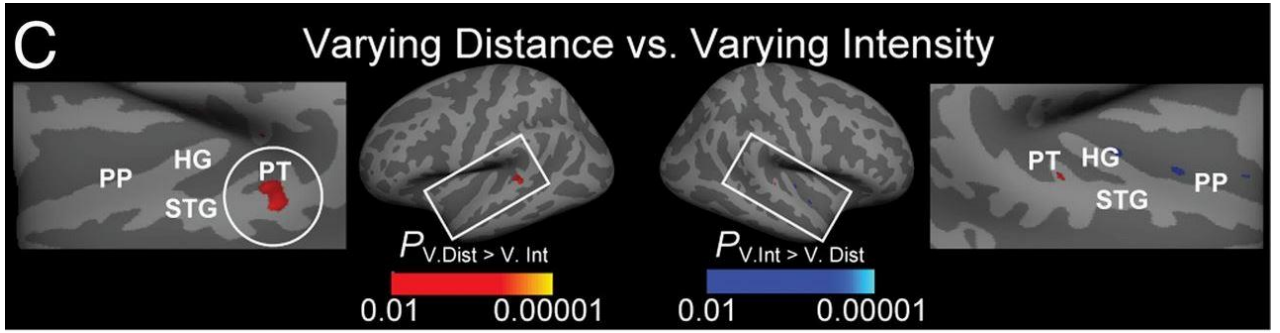
Neural correlates of distance perception

Kopco et al. (2012) results:

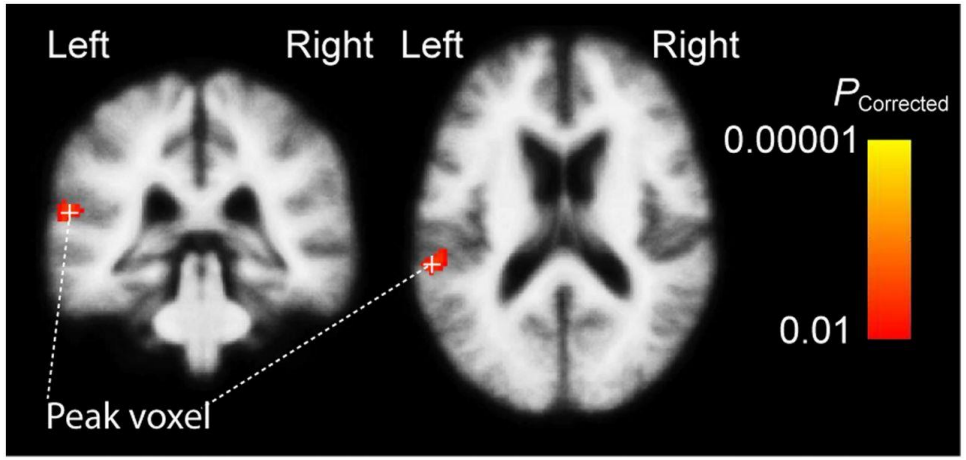
The distance-encoding area identified as a difference between varying-distance vs. varying intensity.

Activations:
Area in **planum temporale** (PT) and **superior temporal gyrus** (STG) contralateral to stimuli.

Surface-based:



Volume-based:



Kopco et al. (2012)

Neural correlates of distance perception

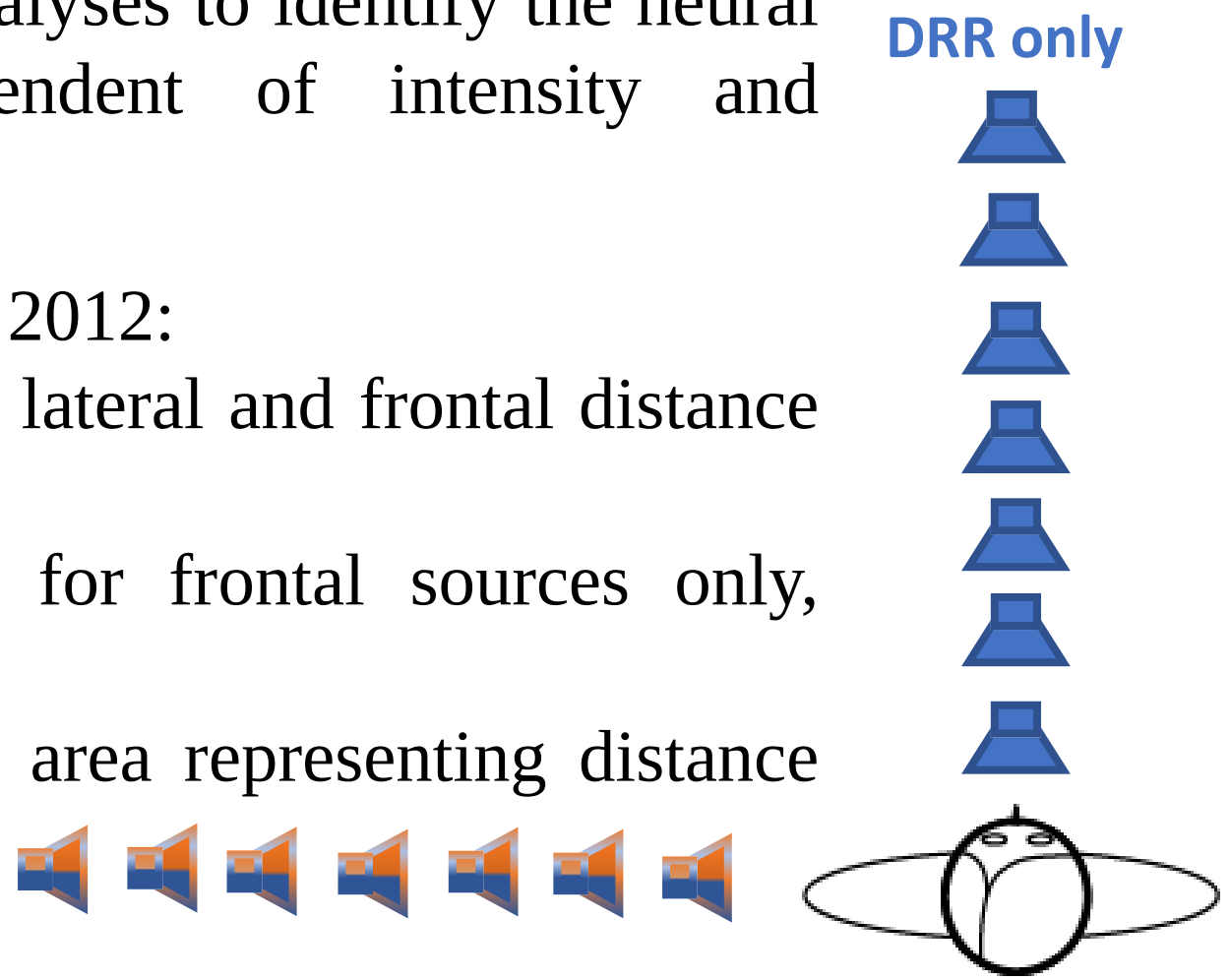
- Here distance varied along the interaural axis. For these sources, two intensity-independent cues are available, interaural level difference (ILD) and direct-to-reverberant energy ratio (DRR).
- It is thus possible that the findings are an epiphenomenon of activations of direction-encoding neurons that are sensitive to ILD. (Imig et al., 1990; Johnson and Hautus, 2010; Lehmann et al., 2007; Tardif et al., 2006; Zimmer et al., 2006)
- Further studies are, therefore, needed to verify the existence of auditory cortex distance representations that do not involve cues shared with directional hearing.

Current study: Frontal source

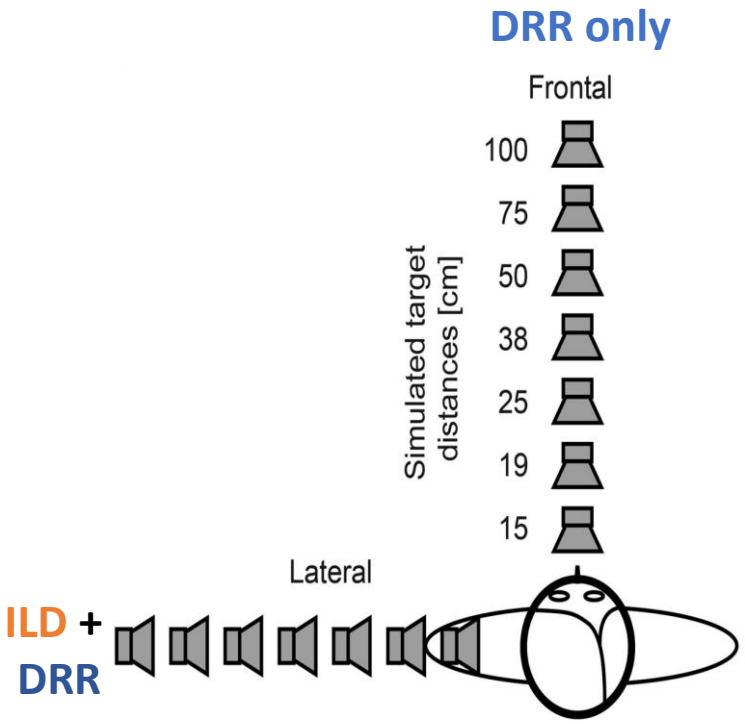
In this study we combined behavioral experiments, fMRI measurements, and computational analyses to identify the neural representation of distance independent of intensity and directional cues.

Using methods similar to Kopco et al 2012:

1. Compare behavioral sensitivity to lateral and frontal distance variation.
2. Examine distance representation for frontal sources only, containing **DRR**.
3. Is the identified cortical distance area representing distance percept or cues?

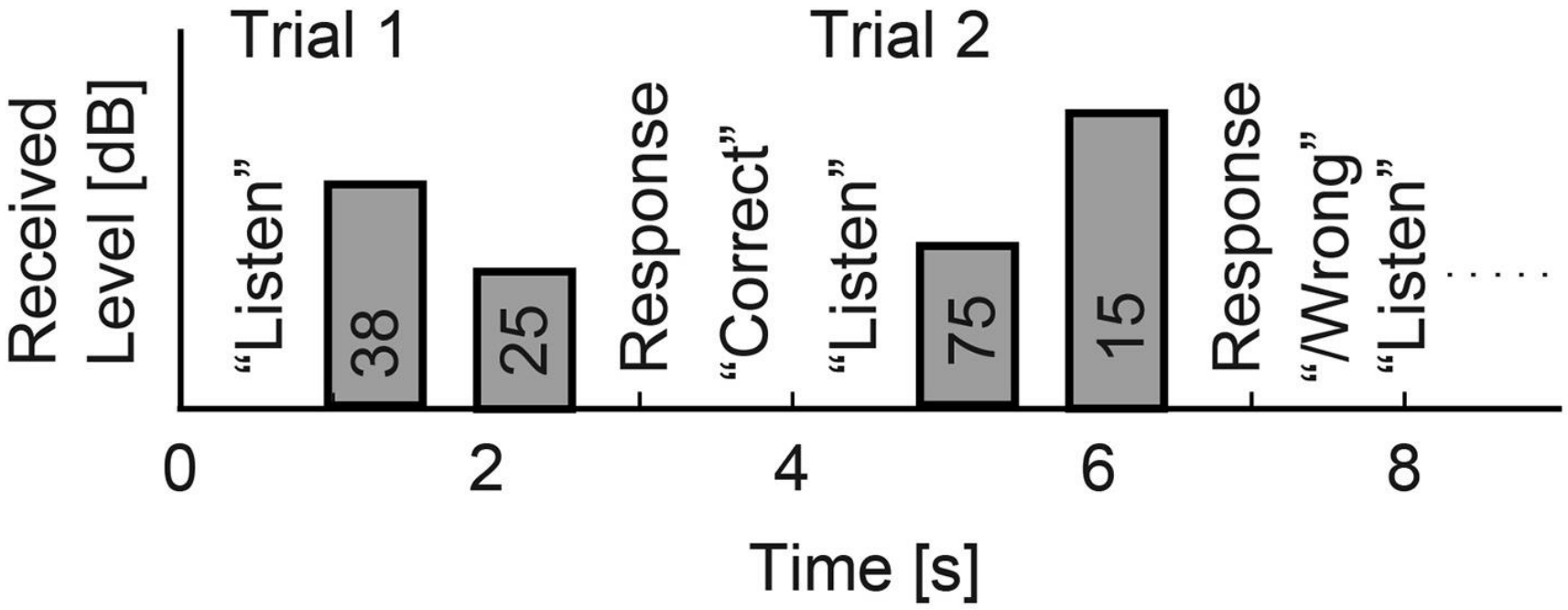


Methods: Behavioral experiment



- Virtual reverberant environment
- Nonidividualized BRIRs recorded in a small classroom (Shinn-Cunningham et al., 2005)
- Stimulus direction: frontal and lateral
- Intensity cue elimination: overall level normalization + 6-dB rove
- Stimuli: 2 300-ms noise bursts presented sequentially

Methods: Behavioral experiment

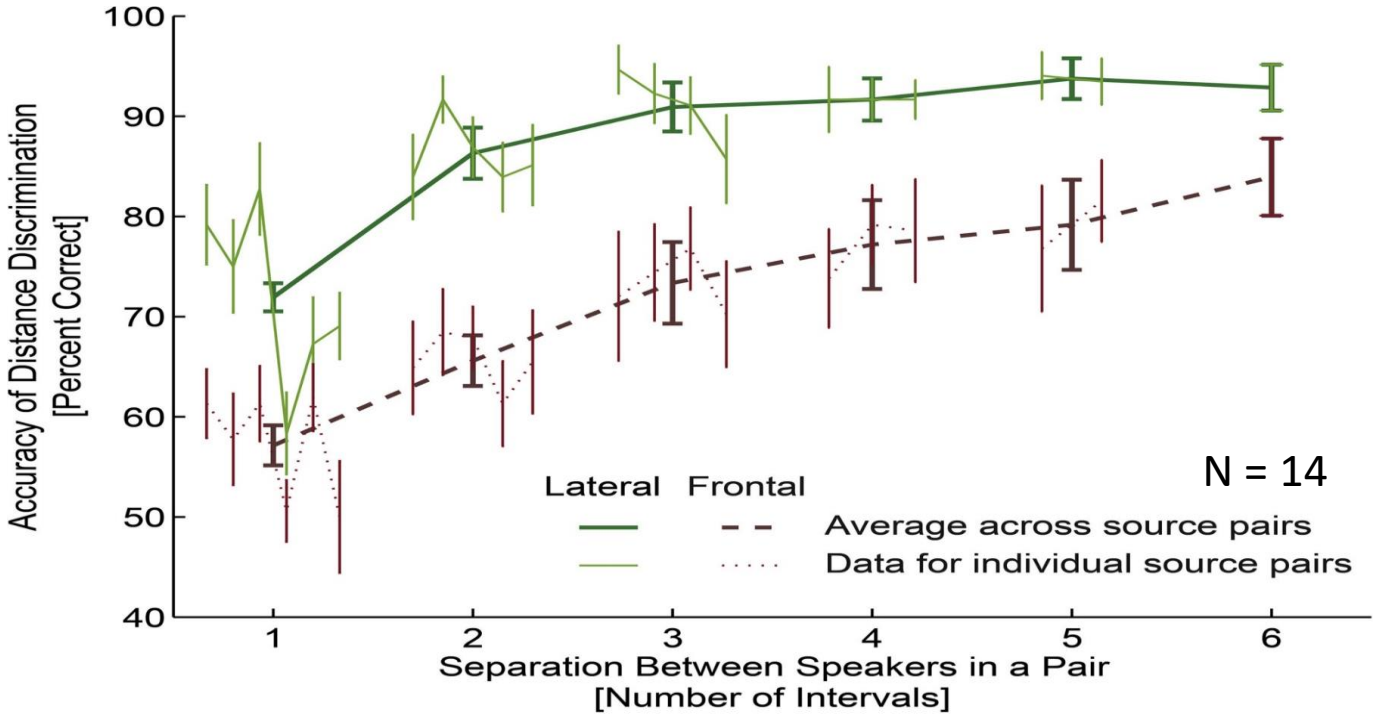


Task:

Which of the sounds is closer to the listener?

*Subjects were instructed to ignore the intensity cue.

Results: Behavioral experiments



Grouping of Speaker Pairs by Separation Intervals

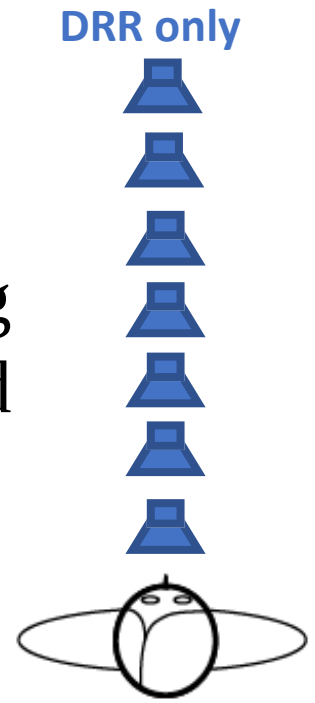
Intervals	1	2	3	4	5	6
Speaker Pairs [cm]	15 - 19	15 - 25	15 - 38	15 - 50	15 - 75	15 - 100
	19 - 25	19 - 38	19 - 50	19 - 75	19 - 100	
	25 - 38	25 - 50	25 - 75	25 - 100		
	38 - 50	38 - 75	38 - 100			
	50 - 75	50 - 100				
	75 - 100					

Results verify that intensity-independent distance perception is possible for the frontal sources in reverberation, and that performance for frontal sources is worse than for lateral sources for which both ILD and DRR cues are available.

Methods: Behavior during imaging

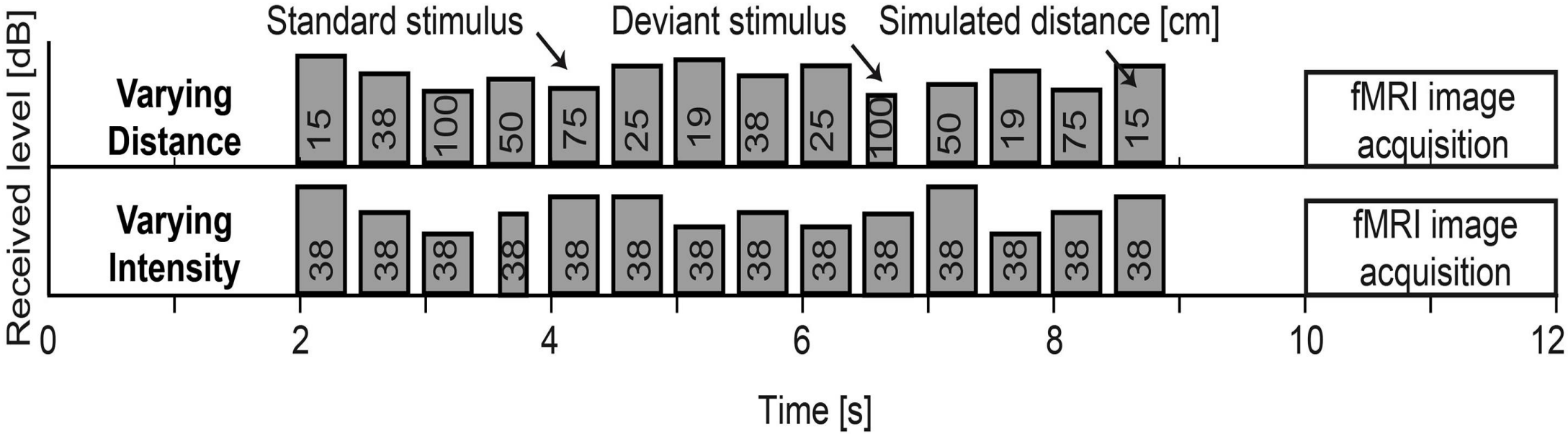
Methods similar to Kopco et al. (2012) :

- Sparse-sampling adaptation fMRI.
- The subjects participated in one session.
- Trials with two types of stimuli, varying in distance or varying in intensity, were randomly interleaved. Each stimulus consisted of a sequence of 14 noise bursts with SOA of 500 ms.



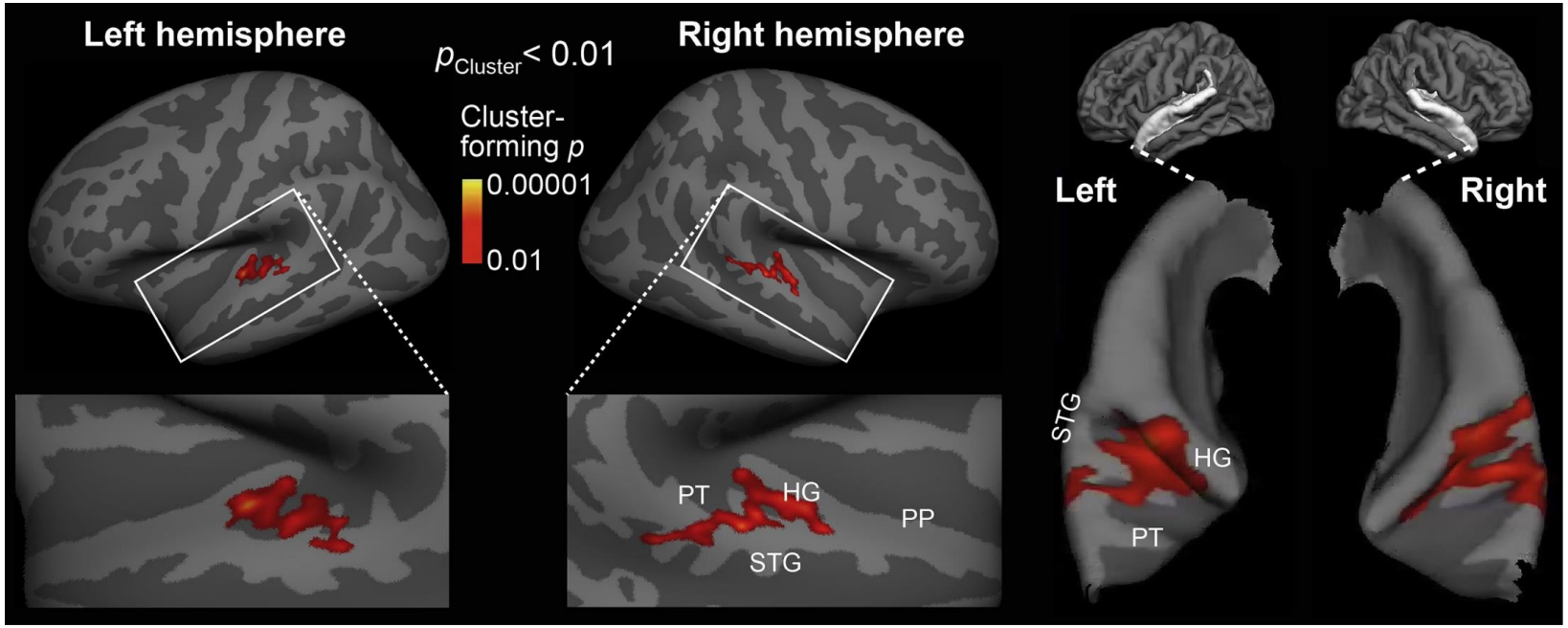
Methods: Structure of imaging trial

- In 50% of the sequences, one randomly chosen burst out of the 14 bursts was replaced by a 150-ms deviant.
- The listener's task during the fMRI session was to detect these short-duration deviants.



Results: Imaging experiments

- The distance-encoding area identified as a difference between varying-distance vs. varying intensity.
- Area in **planum temporale** (PT) and **superior temporal gyrus** (STG).
- Activation is bilateral.



N = 9

Discussion

Current study

- Posterior non-primary Acs
- Auditory distance
- Intensity-independent
- Frontal source (No ILD)

Ahveninen et al., 2014; Griffiths and Warren, 2002; Rauschecker, 2015

- Posterior non-primary Acs
- Sound direction changes, auditory motion stimuli

Kopco et al., 2012

- Posterior non-primary Acs
- Auditory distance
- Intensity-independent
- Lateral source (ILD)

Auditory distance area identified in the previous and current studies **encodes source distance independent of its direction** (or directional cues), even if the distance and direction representations are overlapping.

What next ??

- Is the identified cortical distance area representing distance percept or cues?

Congruent

ILD +

DRR

Incongruent

- Is the identified cortical distance area showing overlapping activations to individual cues and percept?

Summary

- Posterior auditory cortices (AC) are sensitive to frontally presented distance cues.
- These effects are independent of intensity- and direction-related binaural cues.
- fMRI activations to frontal distance cues are found in the right and left AC.
- The frontal reverberation-related auditory distance cues are behaviorally relevant.

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