Decoding perception and grammar: An auditory fMRI study

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Introduction

- Initial syntactic parsing difficulties have been associated with an early left anterior negativity (ELAN) at about 100 – 200 ms in the event-related potentials (Friederici et al., 1993).
- Recent MEG studies localized such early syntax-related neural modulations in sensory cortices (Dikker et al., 2009; Herrmann et al., 2009).
- In this context, the resemblance of early syntactic and auditory perceptual responses has been highlighted (Dikker et al., 2009).
- The spatial resolution of MEG, however, is limited and some effects might not be observable due to source orientation or cancelation effects.
- In the present study, the high spatial resolution of fMRI was used to shed light on the neural mechanisms underlying early syntactic processes in the auditory modality. The study aimed at elucidating on the role of auditory sensory cortices in these processes.

Methods

fMRI activation findings were related to early syntactic processes by presenting two-word utterances that elicited only an early, but no later (> 300 ms) syntax-effect in a previous EEG study (Hasting & Kotz, 2008). Stimuli were constructed in a 2 × 2 fashion by varying the grammaticality and the perceptual markedness of the utterances (Table 1). Participants conducted a grammaticality judgment task.

	Perceptual markedness	
Grammaticality	**unmarked**	**marked**
correct	e.g., "im Knie" *(in-the knee)*	e.g., "er kniet" *(he kneels)*
incorrect	e.g., "er Knie" *(he knee)*	e.g., "im kniet" *(in-the kneels)*

Table 1: Stimulus materials in a 2 x 2 design (Transcripts of the auditory utterances)

Imaging was conducted using a 3-T Siemens TRIO scanner (Erlangen, Germany). Echo-planar imaging scans were acquired in 30 axial slices, with a repetition time of 2 s and an in-plane resolution of 3 × 3 mm². The measured slice thickness was 2 mm plus an interslice gap of 1 mm.

For the data analysis, a conventional univariate subtraction analysis was applied as well as a multi-voxel pattern analysis (MVPA; Haynes & Rees, 2006). MVPA has been shown very sensitive to small activation changes, thus, providing a method potentially able to detect small syntax-related sensory effects which might be concealed in the conventional analysis.

Results

Perceptual-based processes: Two-word utterances which were perceptually overtly marked by the suffix "-t" led to stronger hemodynamic responses bilaterally within the auditory cortex (AC). Consistently, the MVPA also revealed left and right superior temporal gyrus (STG) and AC regions to be equally informative for separating the unmarked from the perceptually marked conditions (Figure 1 and 2).
Grammar-based processes: Stronger activations for syntactically incorrect than correct two-word utterances were found in the left middle superior temporal sulcus (STS) extending into the posterior STS, in the left inferior frontal gyrus (IFG, BA44), the left anterior STG as well as in the right STS/STG extending into anterior and posterior areas. The MVPA showed compatible results: Decoding accuracies were found to be significantly above chance level in the left-hemispheric inferior and superior IFG (BA44), anterior STG, STS and posterior middle temporal gyrus (MTG; Figure 1 and 2). Decoding accuracies were higher in left- than right-hemispheric regions ($F_{1,24}$ = 34.67, p < 0.001).

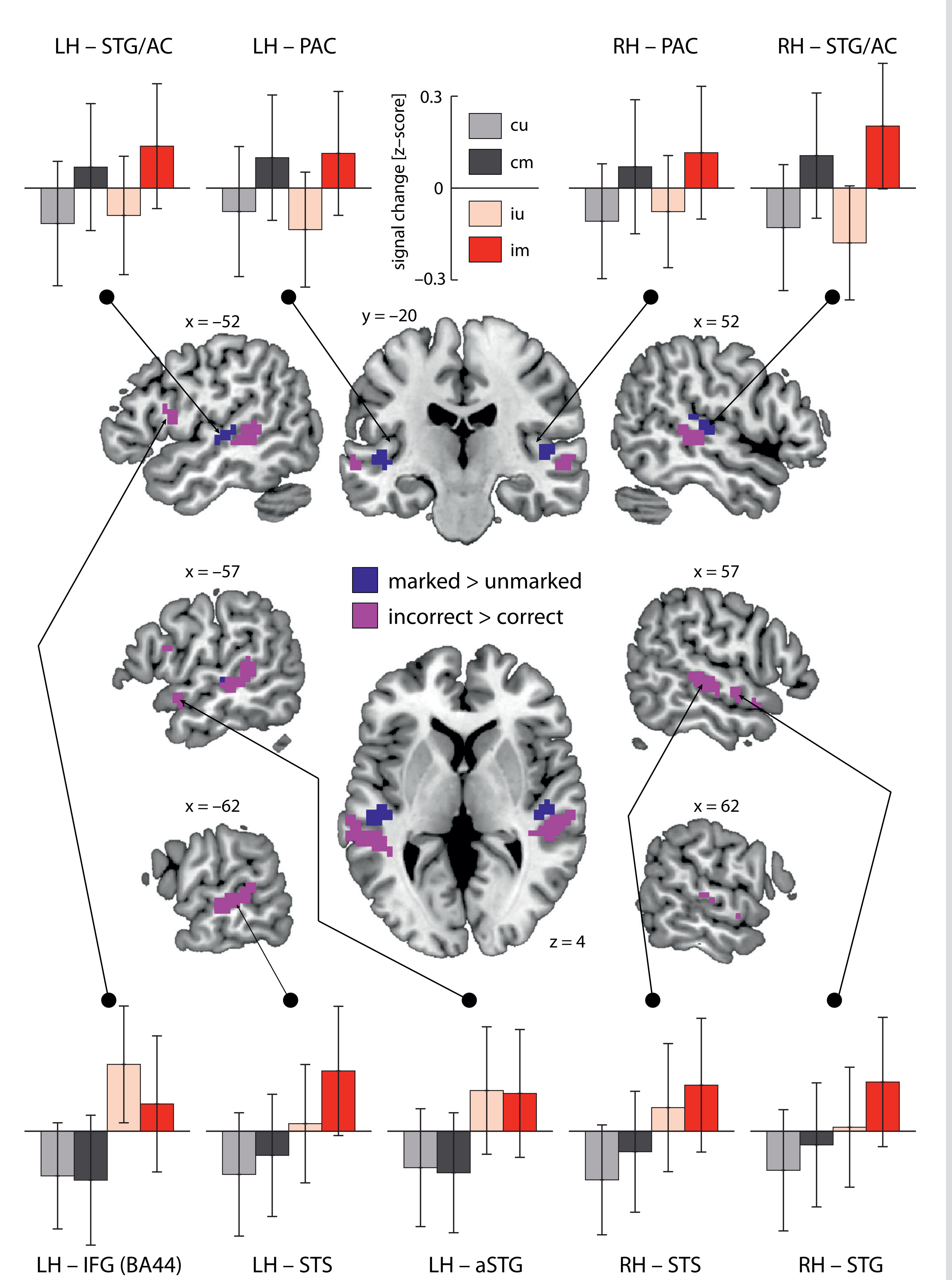

Figure 1: Group activation maps for the univariate contrasts. Center: syntactically incorrect > correct (magenta), perceptually marked > unmarked (blue), z-maps thresholded at p ≤ 0.0001 and a cluster extent of k ≥ 8 voxels. Top and Bottom: z-normalized percent signal change for each ROI and condition (cu – correct unmarked, cm – correct marked, iu – incorrect unmarked, im – incorrect marked). The error bars reflect the standard error of the mean.

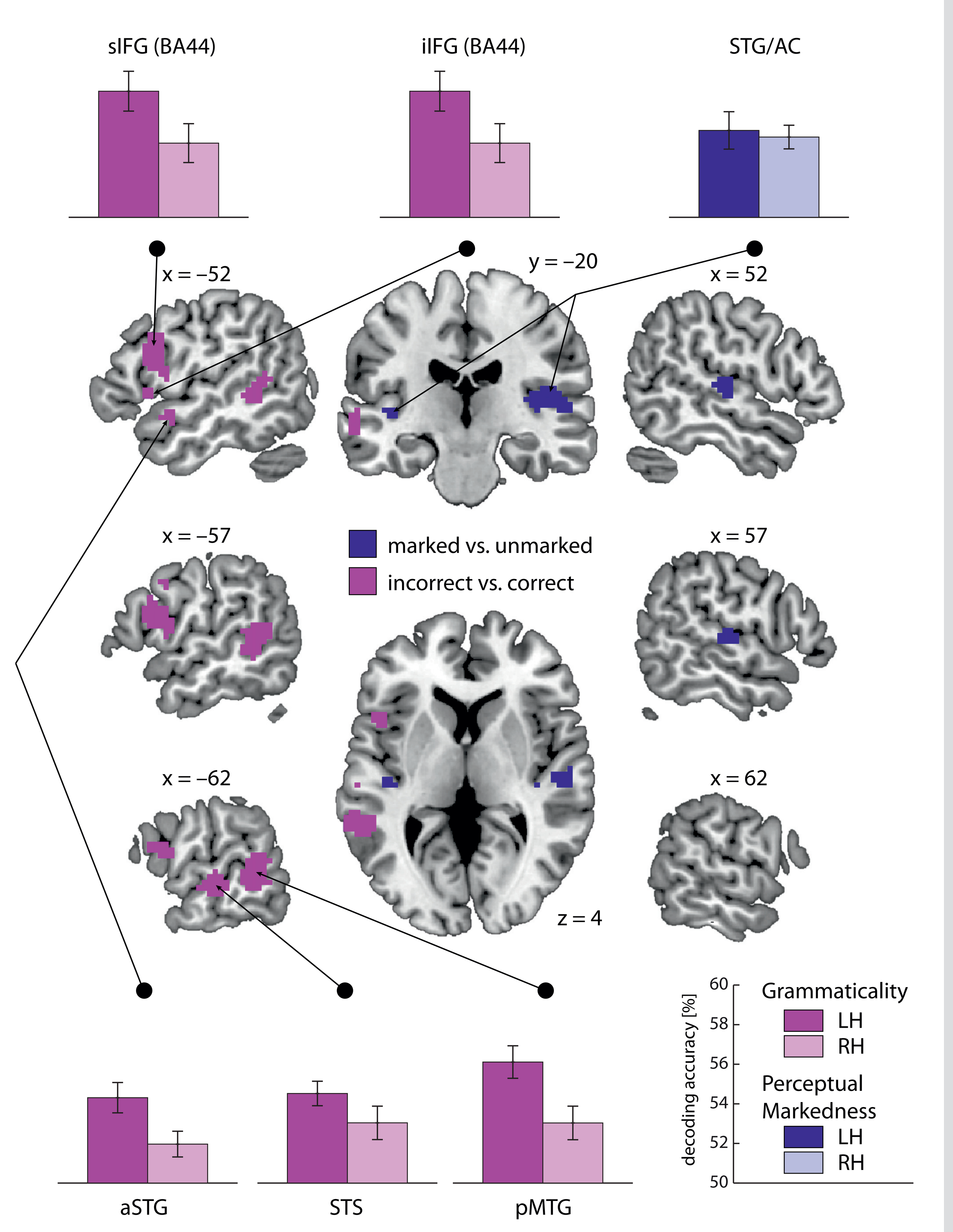

Figure 2: Group decoding accuracy maps for the multivariate classifications. Center: syntactically incorrect vs. correct (magenta), perceptually marked vs. unmarked (blue), z-maps thresholded at p ≤ 0.0001 and a cluster extent of k ≥ 8 voxels. Top and Bottom: decoding accuracies for the left hemispheric regions and their homologue regions in the right hemisphere. The error bars reflect the standard error of the mean.

Discussion

- Auditory cortex activation patterns were only observed for the perceptually overtly marked vs. unmarked conditions, consistent with previous studies showing primary AC and (para)belt areas strongly responsive to more basic acoustic features of the auditory signal.
- No syntax-related activation patterns were observed in these regions, speaking against syntax-inflicted sensory cortex modulations.
- Instead, neural imprints of grammar were found in a wide network of higher-level cortical areas showing a lateralization of higher decoding accuracies to the left hemisphere in the syntax-related MVPA.
- This is in agreement with previous studies manipulating the grammaticality in sentence processing paradigms (e.g., Friederici et al., 2003).
- Thus, the current data provide clear evidence for a distinction between regions involved in pure perceptual processes and regions involved in initial syntactic processes.

References

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