Body Language: The Stomach Modulates Brain Activity at Rest and during Speech Processing

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Background

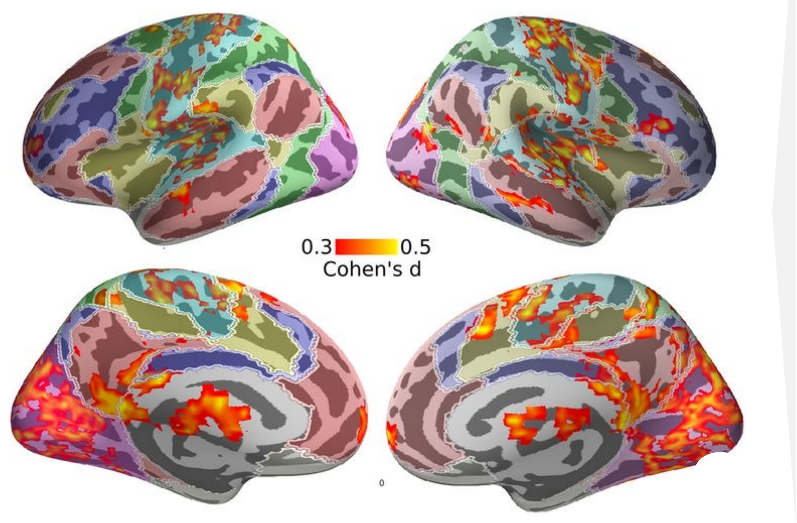

Figure 1. Gastric network layout. Effect sizes (Cohen's *d*) of gastric-BOLD coupling, regions significantly phase synchronized to the gastric rhythm marked in orange and overlaid on top of cortical parcellation in seven RSNs proposed by Yeo et al., 2011. Color codes: light blue = somatomotor, purple = visual, orange = default mode, yellow = salience, dark blue = control, green = attention, dark grey = limbic, light grey = subcortical RSNs respectively. **Figure from Rebollo et al. (2022).**

- visceral oscillations in the stomach (gastric rhythm) modulate temporal organisation of spontaneous brain activity at rest[1,2,3]
- *gastric resting state network* overlaps with traditional RSNs and encompasses not only areas integrating visceral information, but also unimodal sensory-motor regions[2]
- spectral scale of gastric-brain modulation mostly unknown[4]

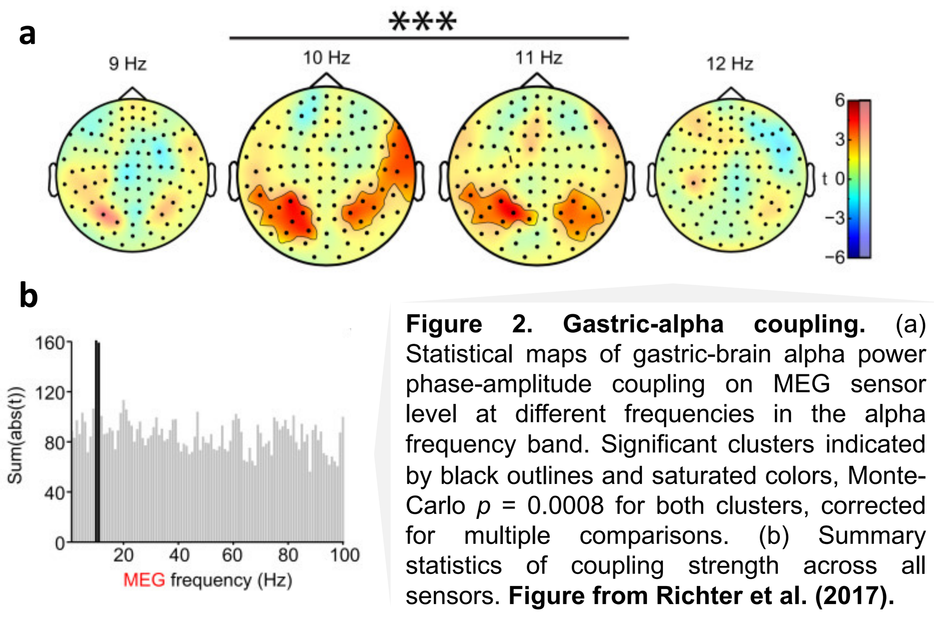

Figure 2. Gastric-alpha coupling. (a) Statistical maps of gastric-brain alpha power phase-amplitude coupling on MEG sensor level at different frequencies in the alpha frequency band. Significant clusters indicated by black outlines and saturated colors, Monte-Carlo $p = 0.0008$ for both clusters, corrected for multiple comparisons. (b) Summary statistics of coupling strength across all sensors. **Figure from Richter et al. (2017).**

Aim

- replicate spatial layout of gastric network using MEG
- characterise full frequency spectrum of gastric-brain coupling
- gastric-brain coupling in a task context that involves unimodal sensory or motor regions?

Methods

- N = 26 healthy participants (14 ♀, 25.5 ± 2.8 y)
- concurrent 275 sensor MEG + EGG
- individual T1 for source reconstruction

Stimuli and Tasks

- 12-min resting state
- 2x 12-min passive listening tasks:
  - story segments (*speech* condition)
  - tone sequence derived from speech condition (*s2s* condition)

Regions of Interest

- passive listening condition analysis based on ROIs connected to speech/auditory processing
- IFG, STS, vmPFC, Insula, SMA, primary & secondary somatosensory cortices, auditory cortices

Fig. 3. Stimuli and Tasks. *Speech* condition: Participants were asked to passively listen to 4-min audiobook sequences in German. Part of example sentence shown, English translation in light grey. Syllable onsets marked. Dark blue waveform represents sentence sound wave. *S2s (speech2sound)* condition: participants were asked to passively listen to a sine tone sequence derived from speech condition. Tones correspond temporally to syllable onsets of speech condition. Light blue waveform represents tone sound wave.

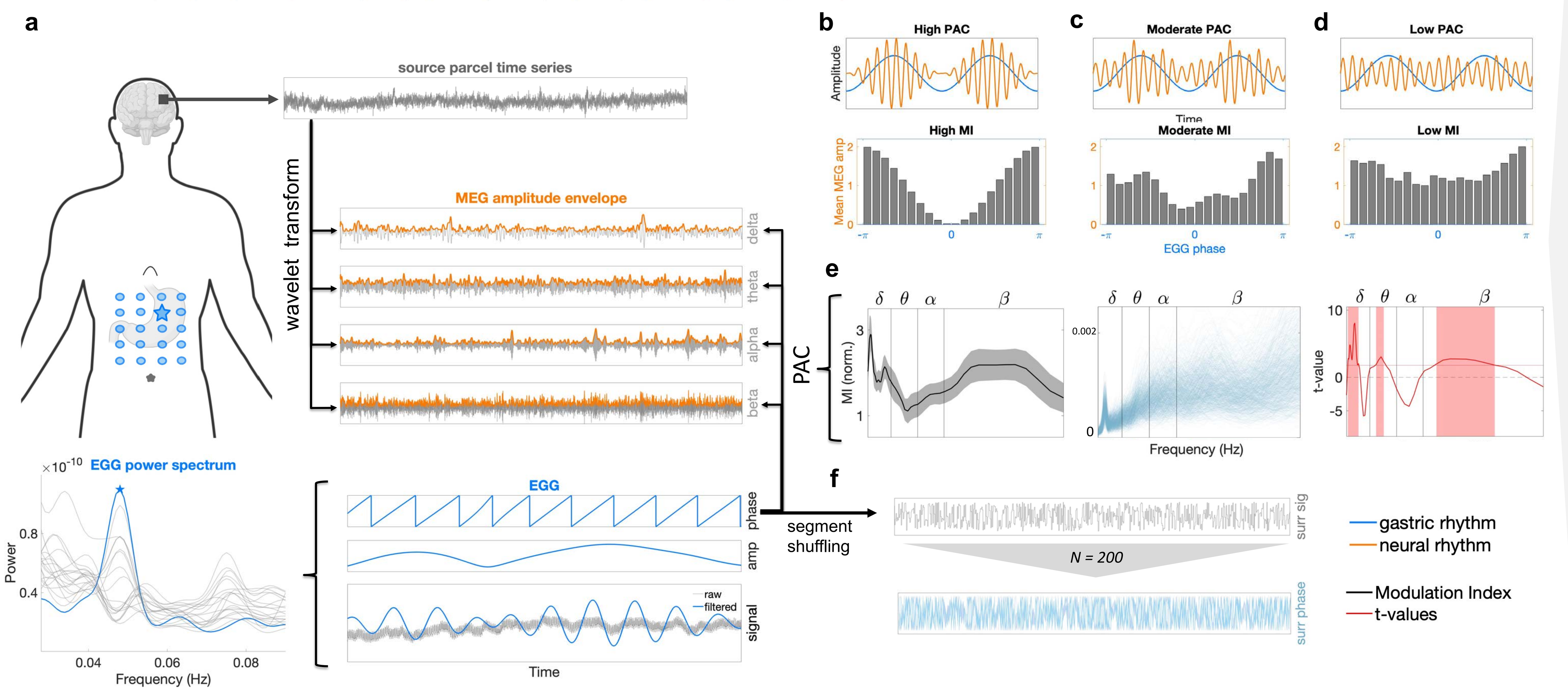

Figure 4. EGG & MEG data processing and PAC analyses. (a) Data acquisition and processing. Gastric rhythm recorded with a 4 x 5 high-density EGG electrode array layout. Fast Fourier Transform applied to compute EGG power spectrum and select EGG electrode with peak power in the normogastric range (0.35 – 0.65 Hz). EGG phase and amplitude time series extracted via Hilbert transform after filtering raw peak electrode signal. Brain activity recorded with MEG, source reconstructed via beamformer approach and aggregated in a recent parcellation of the cerebral cortex. MEG amplitude envelope time series extracted for 60 frequencies between 0.5 and 30 Hz, here depicted spectrally aggregated for frequency bands and one exemplary parcel. (b) (c), (d) Upper panel shows simulated gastric and neural rhythms depicting high, moderate and low PAC respectively. Lower panel contains corresponding distributions of mean neural rhythm amplitudes across 20 phase bins of gastric rhythm; reflecting high, moderate and low MI values according to the level of PAC. (e) PAC strength for one exemplary cortex parcel quantified with MI computed based on EGG phase and MEG amplitude envelope time series for each of the 60 frequencies. Left panel denotes average MI across participants, standard error shaded. Middle panel shows N = 200 surrogate MI spectrafor an exemplary subject used for signifcance testing in resting state. Right panel depicts t-values across frequencies. Frequency ranges with significant coupling marked in red, significance according to t-values (tested against surrogate distribution or between conditions). (f) Single surrogate EGG signal in upper panel created by segment shuffling. Lower panel shows null distribution of N=200 surrogate phase traces. PAC = Phase-Amplitude Coupling, MI = Modulation Index.

Preliminary Results

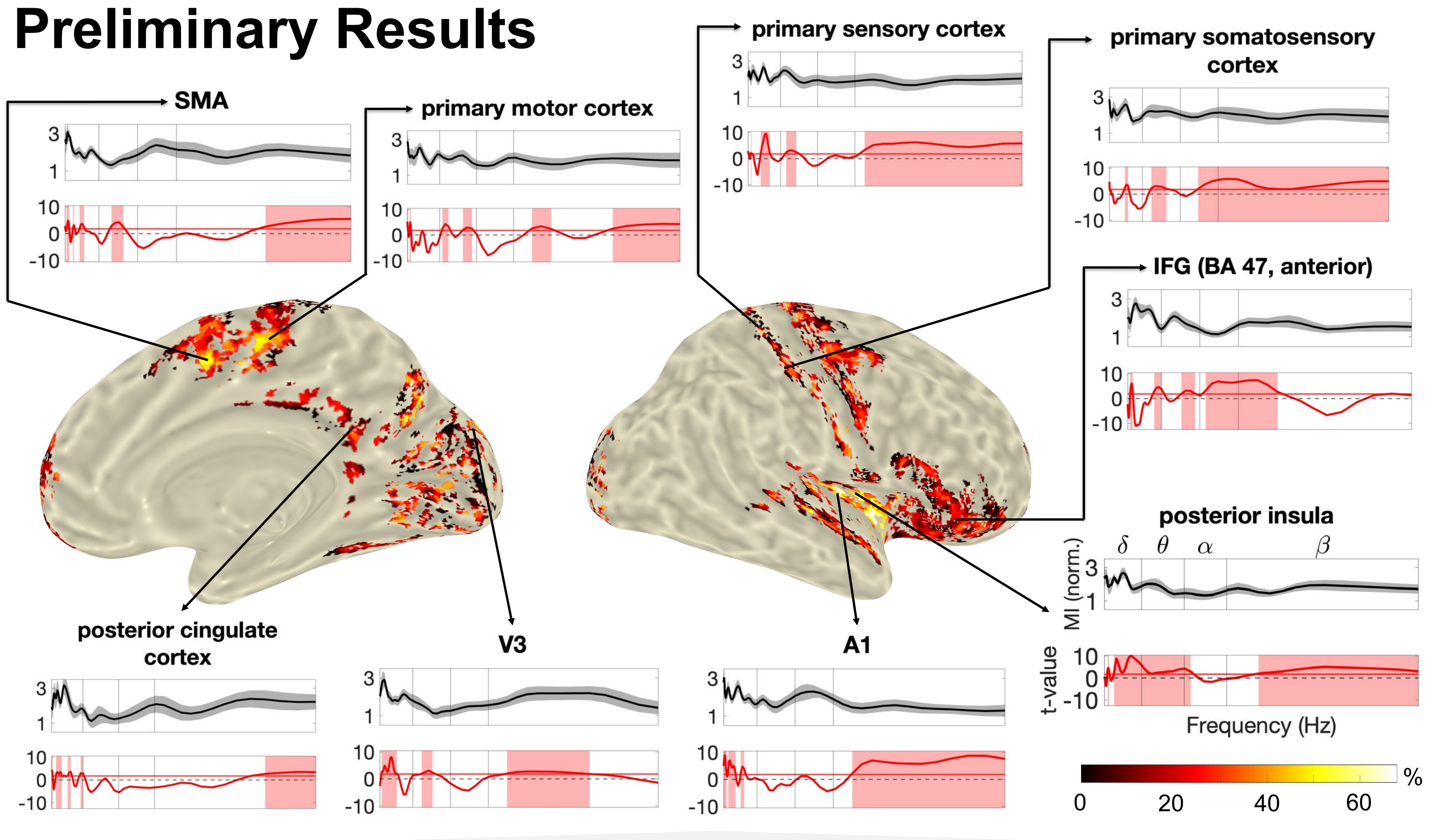

Figure 5. Gastric-brain coupling at rest. Significantly coupled bilateral brain regions plotted exemplary on inflated right hemisphere surface. Heatmap indicates percentage of significantly coupled frequencies. T-value spectra across frequencies for bilaterally averaged MI spectra in selected regions. Standard error of averaged MI spectra shaded in grey. Frequency ranges with significant coupling marked in red, significance according to critical value of $t(26)= 1.706$, tested against surrogate distribution. Critical value marked by red horizontal line. SMA = supplementary motor area, IFG = inferior frontal gyrus, BA = Brodmann Area.

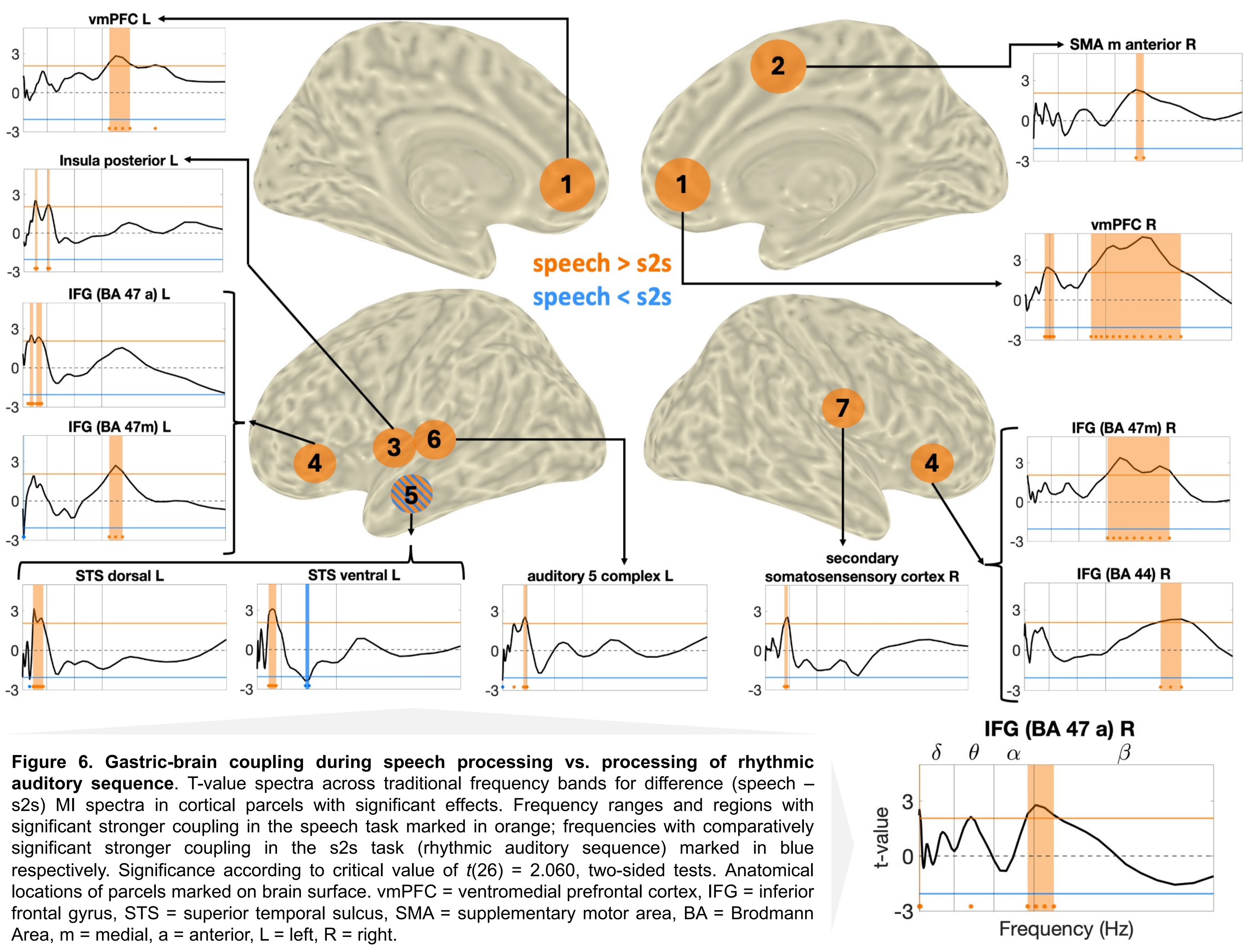

Figure 6. Gastric-brain coupling during speech processing vs. processing of rhythmic auditory sequence. T-value spectra across traditional frequency bands for difference (speech – s2s) MI spectra in cortical parcels with significant effects. Frequency ranges and regions with significant stronger coupling in the speech task marked in orange; frequencies with comparatively significant stronger coupling in the s2s task (rhythmic auditory sequence) marked in blue respectively. Significance according to critical value of $t(26) = 2.060$, two-sided tests. Anatomical locations of parcels marked on brain surface. vmPFC = ventromedial prefrontal cortex, IFG = inferior frontal gyrus, STS = superior temporal sulcus, SMA = supplementary motor area, BA = Brodmann Area, m = medial, a = anterior, L = left, R = right.

Discussion

- gastric-brain modulation across all traditional frequency bands in a widespread network of cortical regions
- modulation patterns are not uniform across brain areas and frequencies
- task context: stronger coupling effects during more complex cognitive processing
- possible functional roles of gastric-brain coupling: [cf. 2,5]
  - homeostatic/allostatic regulation
  - time scale for coordination of body maps & maps of external space
  - predictive coding: optimal alignment of neural activity for sensory processing
  - scaffold for large-brain organisation
- future directions:
  - evoked potentials across gastric phase
  - externally generated (e.g. auditory) vs. internally generated ERPs (e.g. HEP)

References

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