A multimodal cortical network of sensory expectation violation revealed by fMRI

Miro Grundei*[1,2], Timo Torsten Schmidt*[1], Felix Blankenburg[1,2]

[1)] Neurocomputation and Neuroimaging Unit, Freie Universität Berlin, Berlin Germany

[2)] Berlin School of Mind and Brain, Humboldt Universität zu Berlin, Berlin Germany

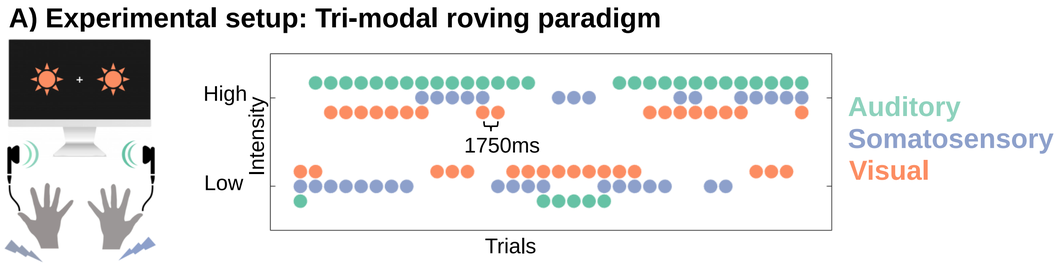
Motivation

- The brain is subjected to multi-modal sensory information in an environment governed by statistical dependencies.
- Mismatch responses (MMRs) have provided valuable insights into the brain's processing of statistical regularities and the generation of corresponding sensory predictions (Paavilainen, 2013; Yaron *et al.*, 2012; Bekinschtein *et al.*, 2009; Dehaene *et al.*, 2015; Heilbron & Chait, 2018).
- Although comparable early and late MMRs have been shown across audition, somatosensation and vision (e.g. Grundei *et al.*, 2022), very few studies allow direct comparisons between modalities, in particular using fMRI (Downar *et al.*, 2000).
- Here, we present an fMRI experiment investigating MMRs to probabilistic sequences in a novel tri-modal version of the roving stimulus paradigm which allows for manipulation of cross-modal predictability.

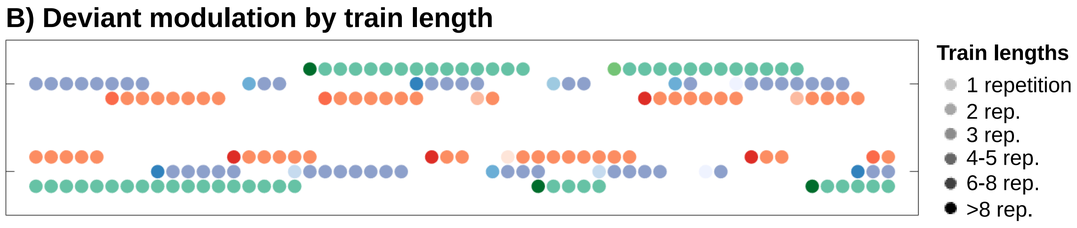
Experimental Design

- Participants (N=29) were simultaneously presented with sequences of low and high intensity stimuli in the auditory, somatosensory and visual modality in the fMRI scanner (6 runs, 400 trials each), depicted in figure 1A.

A) Experimental setup: Tri-modal roving paradigm



B) Deviant modulation by train length



C) Predictability of stimulus transitions by multi-modal configuration

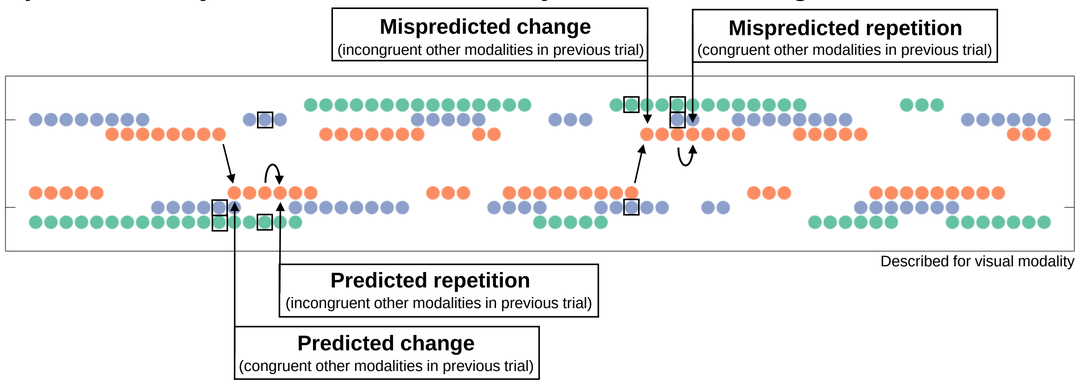


Figure 1: Eperimental design

- B) In each modality, sequences consisted of trains of repeating stimuli of different lengths. We were interested in the modulation of the deviant response as a function of the train lengths of prior standard repetitions, thus grouping deviants in 6 categories.
- C) Different types of sequences were sampled from a probabilistic model with first order Markov dependency between possible stimulus combinations.
  The overall change probability of stimuli was fixed at $p = 0.175$ while the change probability *conditional* on multi-modal configurations could vary according to different types of probability settings:
  These settings correspond to higher or lower (conditional) probability of a change/repetition in one modality given the other two modalities are congruent (both high / both low), or incongruent (one high / one low).

Methods

- GLM analyses were used to inspect mismatch responses (contrasting Deviant>Standard stimuli), deviant modulation by train lengths (linear contrast across deviants with increasing numbers of prior standards) & cross-modal predictability (contrasting Mispredicted>Predicted transitions).
- PPI analyses were used to inspect connectivity modulations from seed regions in the sensory cortices (identified by the MMR contrast) to the remaining voxels of the brain related to MMR effects (Deviant>Standard contrast).
- All conjunction analyses correspond to conjunction against the global null hypothesis (Friston *et al.*, 1999, 2005).

Conclusion

- Overall, our findings shed light on mismatch responses to multi-modal probabilistic inputs in a shared cortical network of expectation violation:
- We replicate and extend the initial findings by Downar *et al.* (2000).
- Connectivity modulations are found in the extended mismatch network from sensory regions to shared network hubs during expectation violation.
- Deviant responses within the network increase as a function of standard repetition, suggesting comparable computation across the senses.
- IPS was identified to signal cross-modal expectation violation and might keep track of (global) multi-modal sequence regularities, in line with recent indications for a role of IPS during abstraction of sequences patterns (Planton & Dehaene, 2021) and P3 responses to global regularity violations (e.g. Bekinschtein *et al.*, 2009)

Results

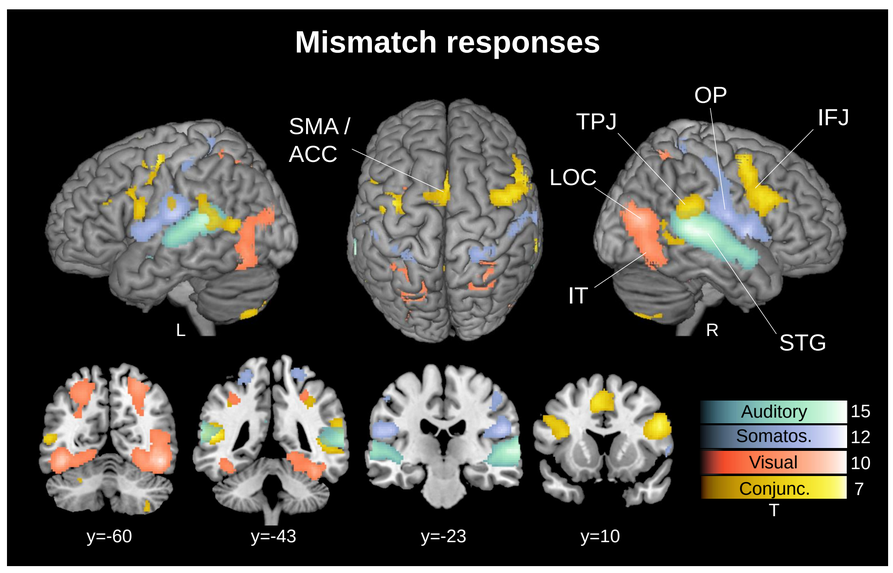


Figure 2: Contrasted Deviant>Standard trials

- Modality specific activation most pronounced in higher order sensory regions such as STG, SII, IT & LOC
- Modality general activation in temporo-parietal and inferior frontal regions (TPJ, IFJ), most pronounced on the right hemisphere

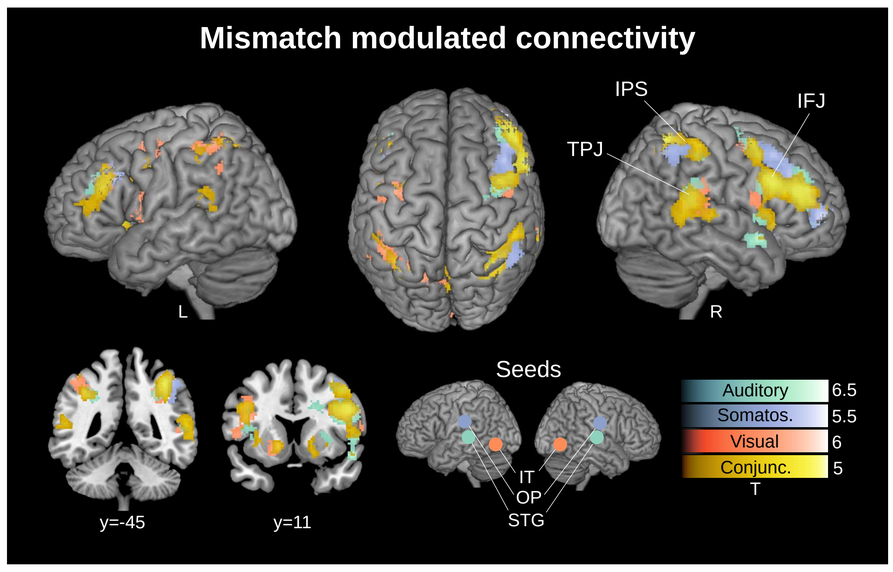


Figure 3: PPI connectivity

- PPI analyses show increased connectivity during mismatch processing from seed regions in sensory seed regions to modality general hubs of the network (TPJ, IPS, IFJ)
- Left and right seed regions project primarily to the right hemisphere

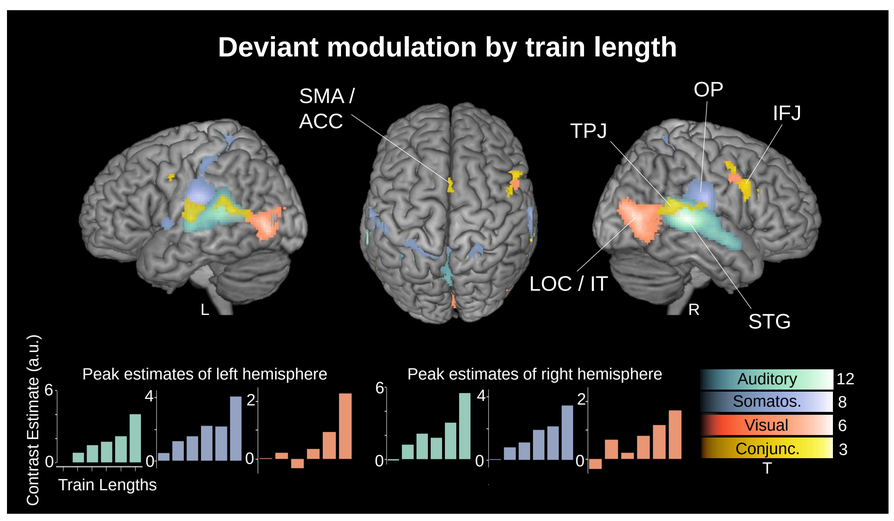


Figure 4: Linear contrast over 6 binned levels of train lengths (1, 2, 3, 4-5, 6-8, >8 repetitions of standards)

- Deviant responses increase as a function of the number of prior standard repetitions

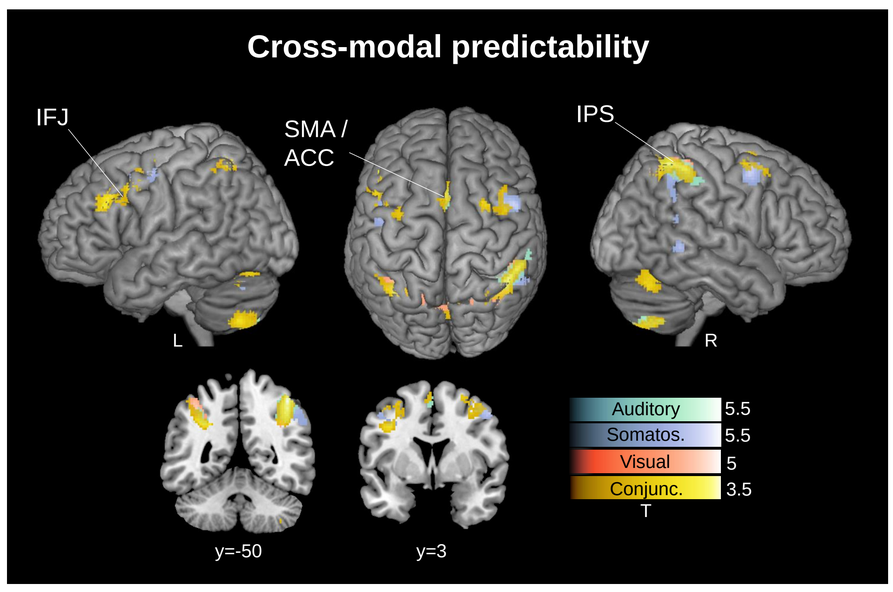


Figure 5: Contrasted Mispredicted>Predicted trials

- Cross-modal expectation violation is accompanied by increased activity around the IPS & left IFJ

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