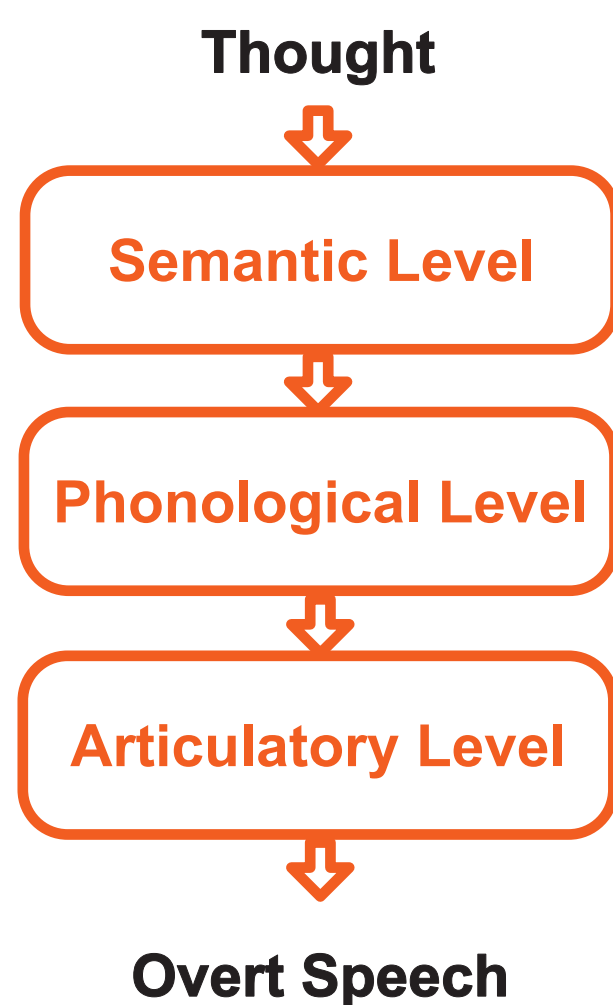




Introduction

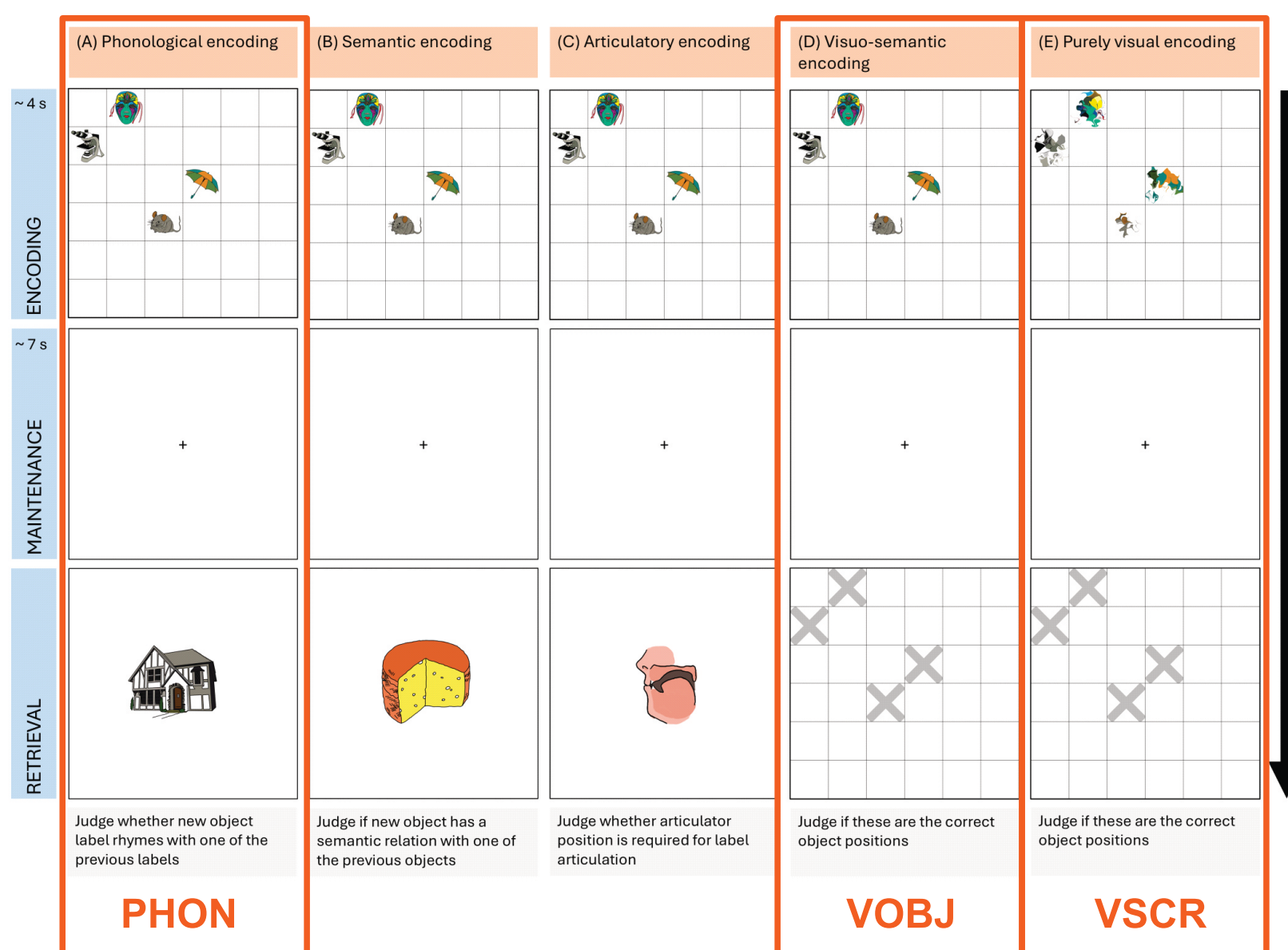
- **Modes of thinking** can differ between individuals - both in frequency and phenomenology [1].
- **Inner speech** can present as a full monologue or highly condensed at other times.
- **Levels of inner speech**: different linguistic processing stages are reached during an IS episode [2].



Aims of the LISP project:

- 1 Identify oscillatory dynamics underlying different levels of inner speech by
- 2 investigating task-related differences in neural processing of visual objects and by
- 3 exploring individual differences in habitual experience of inner speech (assessed by IRQ and VISQ-R) by 2) investigating task-related differences in neural processing of visual objects.

Materials & Methods



Conditions & Tasks:

- 3 conditions within-subject
- 40 trials per condition (blocked)
- pre-tests: digitspan & Corsi blocks
- questionnaires: IRQ [3], VISQ-R [4]

Participants:

- Healthy German-speaking adults (n = 35; 12 ♂)
- Mean age: 22.7 (SD = 3.7) years

EEG-Recording:

- 64-channel active electrode system (g.SCARABEO electrodes, g.GAMMACAP extended 10-20 layout)
- g.tec g.HIAMP amplifier system (sampling frequency 512 Hz)

EEG-Preprocessing:

- semi-automatic artefact rejection
- high-pass filtered at 0.3 Hz, low-pass filtered at 100 Hz
- removal of microsaccades using costrap algorithm [5]
- automatic ICA-based removal of eye and muscle artefacts (SASICA) [6]
- re-referencing to averaged mastoids
- bad channel interpolations
- cut epochs [-3 s, 11 s])
- notch filter to reduce line noise at 50 Hz

Time-Frequency-Analysis:

- Wavelet analysis (wavelet width = 12, 80 logarithmically spaced frequency bins between 5 Hz – 80 Hz)
- Baseline: [-1, -0.1] (inter-trial intervals)
- Selection of frequency bands based on condition-independent visual inspection and hypotheses

Statistics:

- Cluster-based permutation tests (cluster-alpha = 0.05) for PHON vs. VOBJ and VOBJ vs. VSCR for encoding and maintenance time windows in frequency bands pre-defined by hypotheses and condition-independent visual inspection.
- Linear mixed model (per region of interest and frequency band), FDR correction:

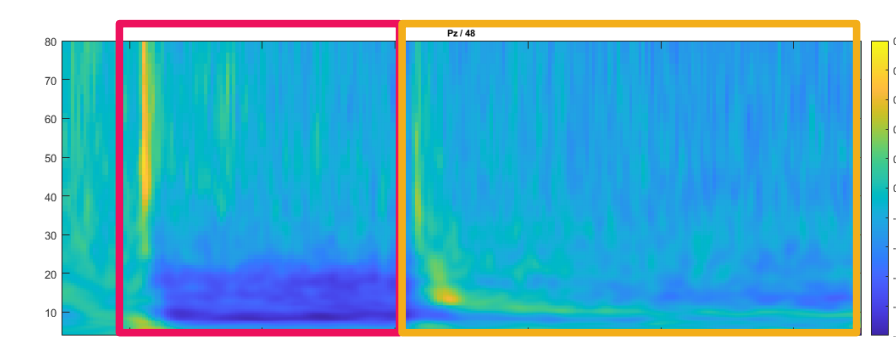
$$Power \sim Condition + IRQ_{IV} + IRQ_{VI} + max_{corsi} + max_{digitspan} + Condition * IRQ_{IV} + Condition * IRQ_{VI} + Condition * max_{corsi} + Condition * max_{digitspan} + (1 | participant)$$

Results from Experiment 1

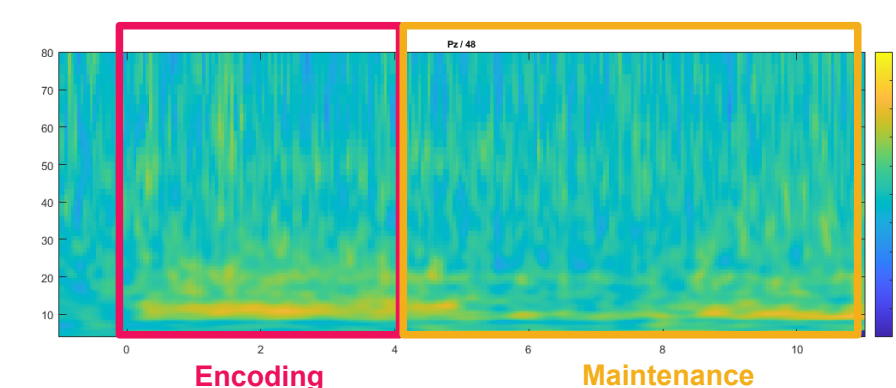
1 Alpha & beta distinguish verbal and visual processing

PHON - VOBJ

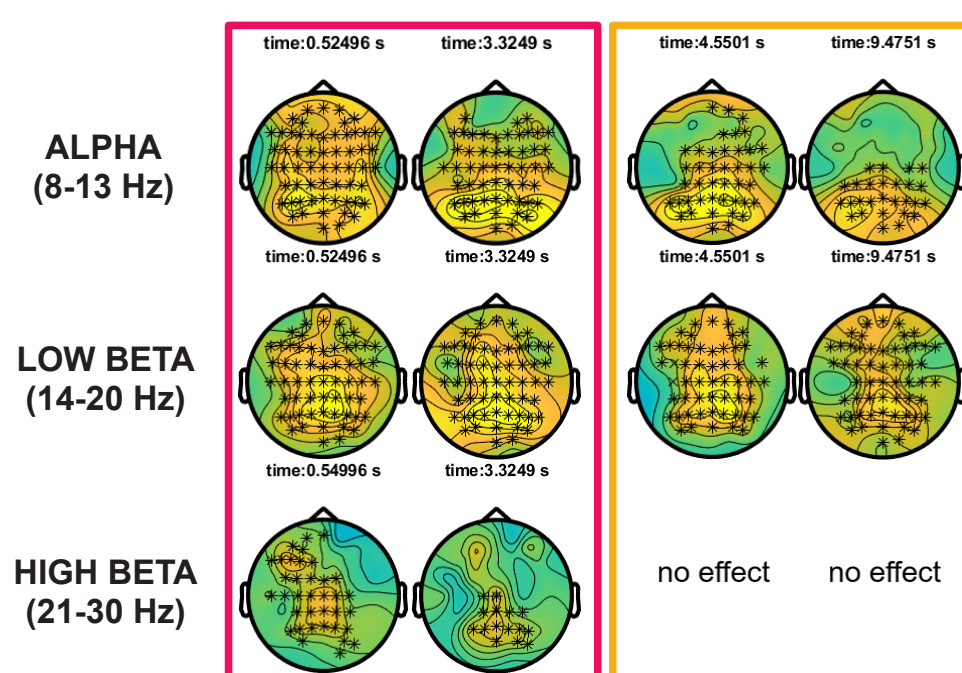
a) Time series for PHON



b) Raw effect of PHON-VOBJ

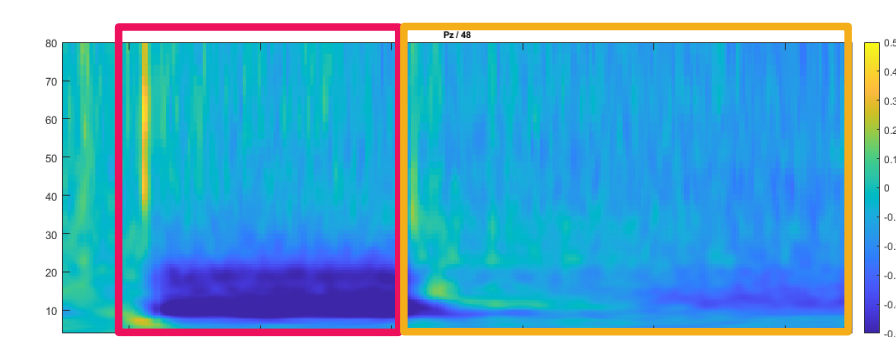


c) Clusters of PHON-VOBJ

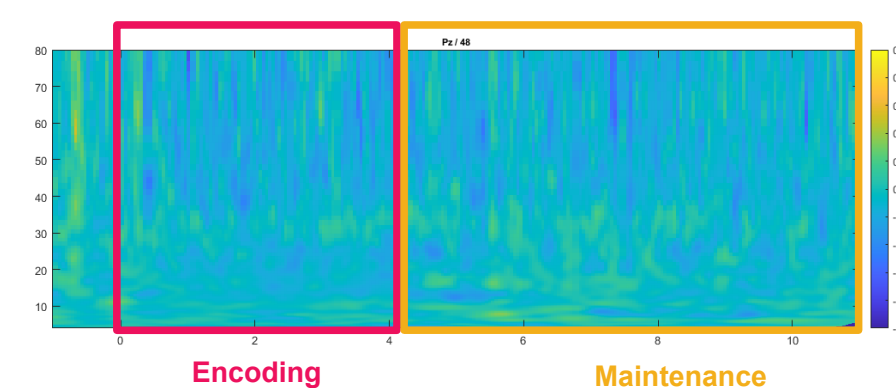


VOBJ - VSCR

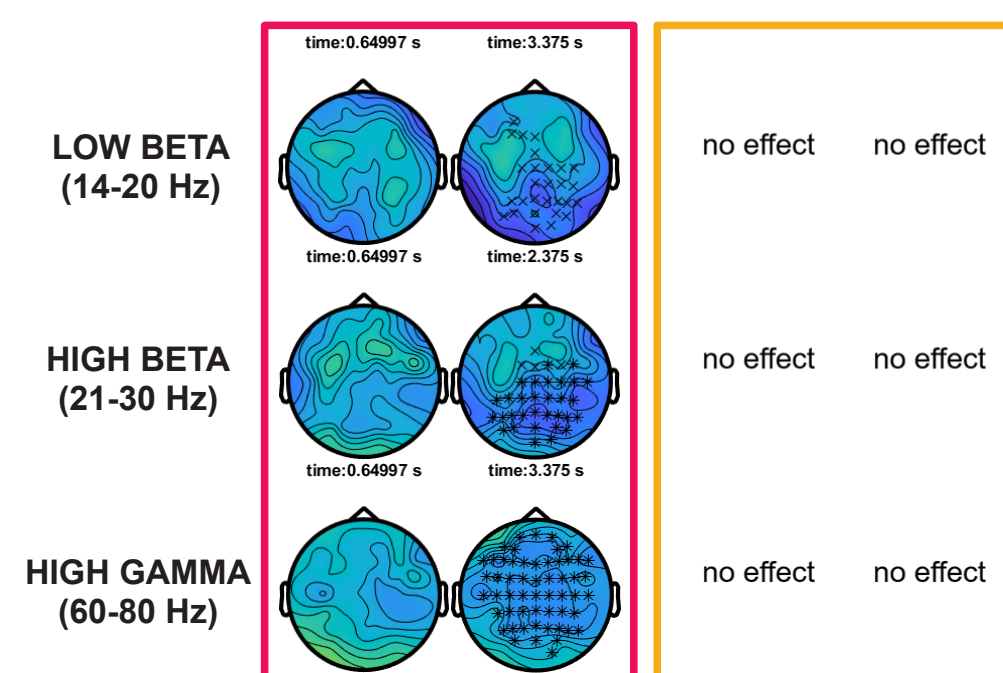
a) Time series for VOBJ



b) Raw effect of VOBJ-VSCR

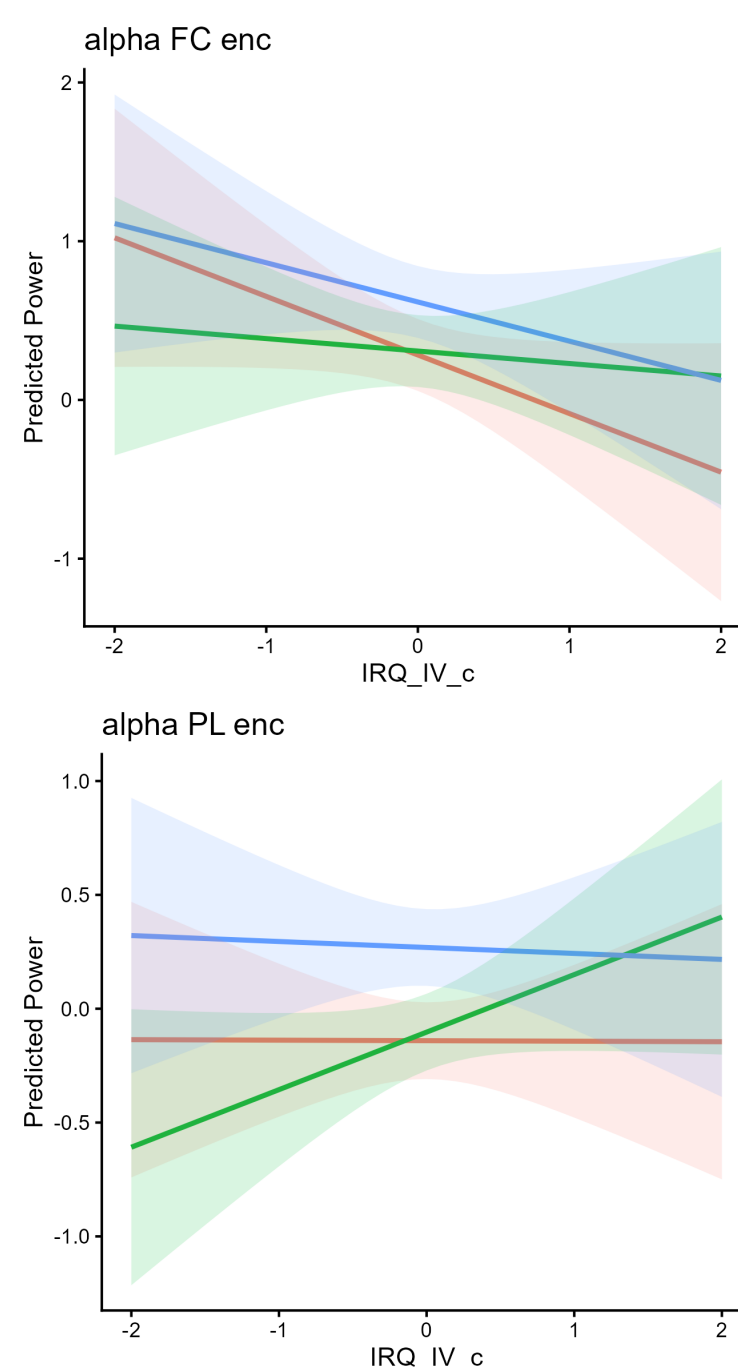


c) Clusters of VOBJ-VSCR

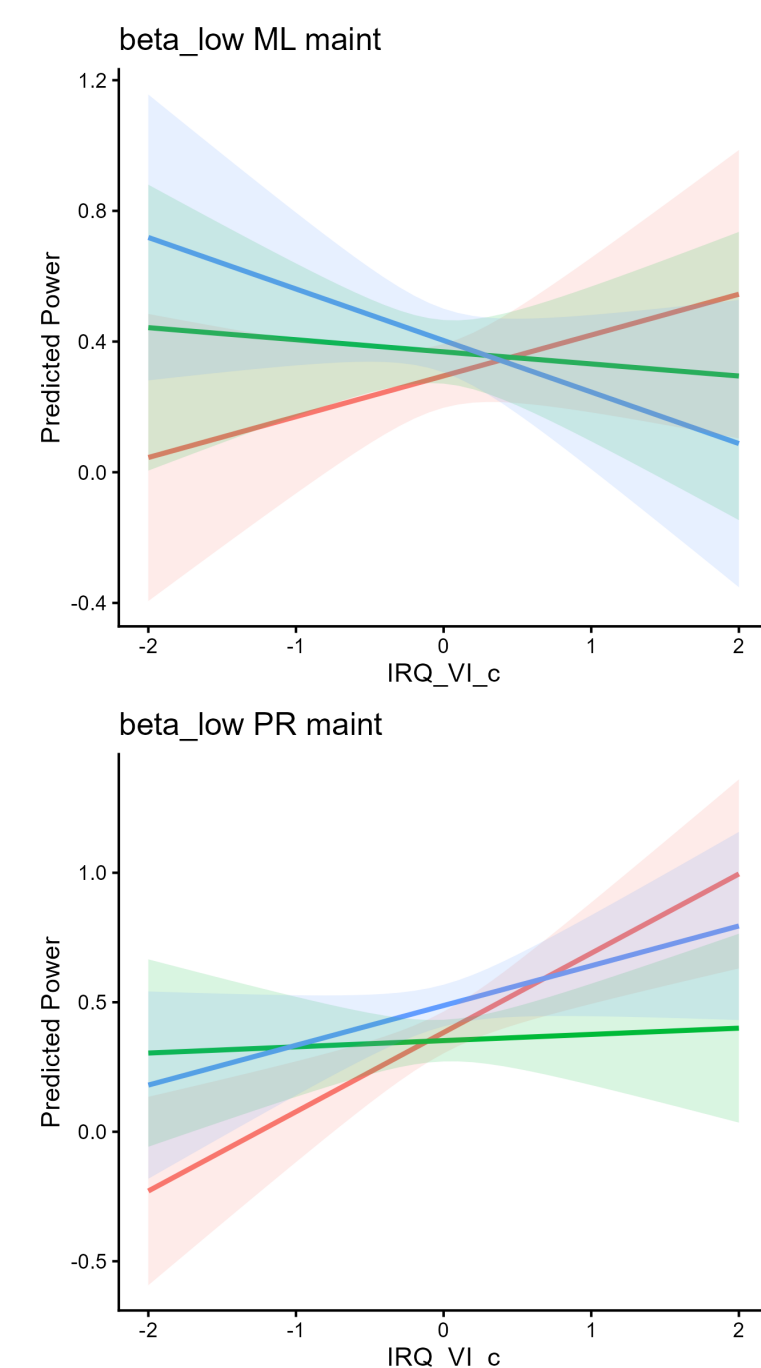


2 IRQ scores modulate power differences

Internal verbalization scores (IRQ-IV) predict condition specific differences in the **alpha band**.



Visual imagery scores (IRQ-VI) predict condition specific differences in the **lower beta band**.



Discussion

- **Visual and verbal working memory differ only in alpha and beta power**, particularly over posterior regions.

- Theta is typically more prominent in verbal WM tasks and increasing with task difficulty [7]. **Theta did not show differences here.**

- Beta and gamma power differences between VOBJ and VSCR likely reflect implicit naming or object binding.

- **Internal verbalization appears to affect the nameable object vs. scrambled images contrast**, possibly reflecting the assigning of labels to the shapes.

- Memory span also modulated condition-specific power differences in alpha and both higher and lower beta, as well as behavioral outcomes.

References

- [1] Heavey, C. L., & Hurlburt, R. T. (2008). The phenomena of inner experience. *Consciousness and Cognition*, 17(3), 798–810. <https://doi.org/10.1016/j.concog.2007.12.006>
- [2] Grandchamp, R., Rapin, L., Perrone-Bertolotti, M., Pichat, C., Haldin, C., Cousin, E., Lachaux, J.-P., Dohen, M., Perrier, P., Garnier, M., Baci, M., & Loevenbruck, H. (2019). The ConDialInt Model: Condensation, Dialogality, and Intentionality Dimensions of Inner Speech Within a Hierarchical Predictive Control Framework. *Frontiers in Psychology*, 10, 2019. <https://doi.org/10.3389/fpsyg.2019.02019>
- [3] Roebuck, H., & Lupyan, G. (2020). The Internal Representations Questionnaire: Measuring modes of thinking. *Behavior Research Methods*, 52(5), 2063–2070. <https://doi.org/10.3758/s13428-020-01354-y>
- [4] Alderson-Day, B., Miltrenga, K., Wilkinson, S., McCarthy-Jones, S., & Fernyhough, C. (2018). The varieties of inner speech questionnaire – Revised (VISQ-R): Replicating and refining links between inner speech and psychopathology. *Consciousness and Cognition*, 65, 48–58. <https://doi.org/10.1016/j.concog.2018.07.001>
- [5] Hassler, U., Trujillo Barreto, N., & Gruber, T. (2011). Induced gamma band responses in human EEG after the control of miniature saccadic artifacts. *NeuroImage*, 57(4), 1411–1421. <https://doi.org/10.1016/j.neuroimage.2011.05.062>
- [6] Chaumon, M., Bishop, D. V. M., & Busch, N. A. (2015). A practical guide to the selection of independent components of the electroencephalogram for artifact correction. *Journal of Neuroscience Methods*, 250, 47–63. <https://doi.org/10.1016/j.jneumeth.2015.02.025>
- [7] Pavlov, Y. G., & Kotchoubey, B. (2022). Oscillatory brain activity and maintenance of verbal and visual working memory: A systematic review. *Psychophysiology*, 59(5), e13735. <https://doi.org/10.1111/psyp.13735>