Neural mechanisms of Cognitive Control:

Insights from simultaneous EEG/fMRI-recordings

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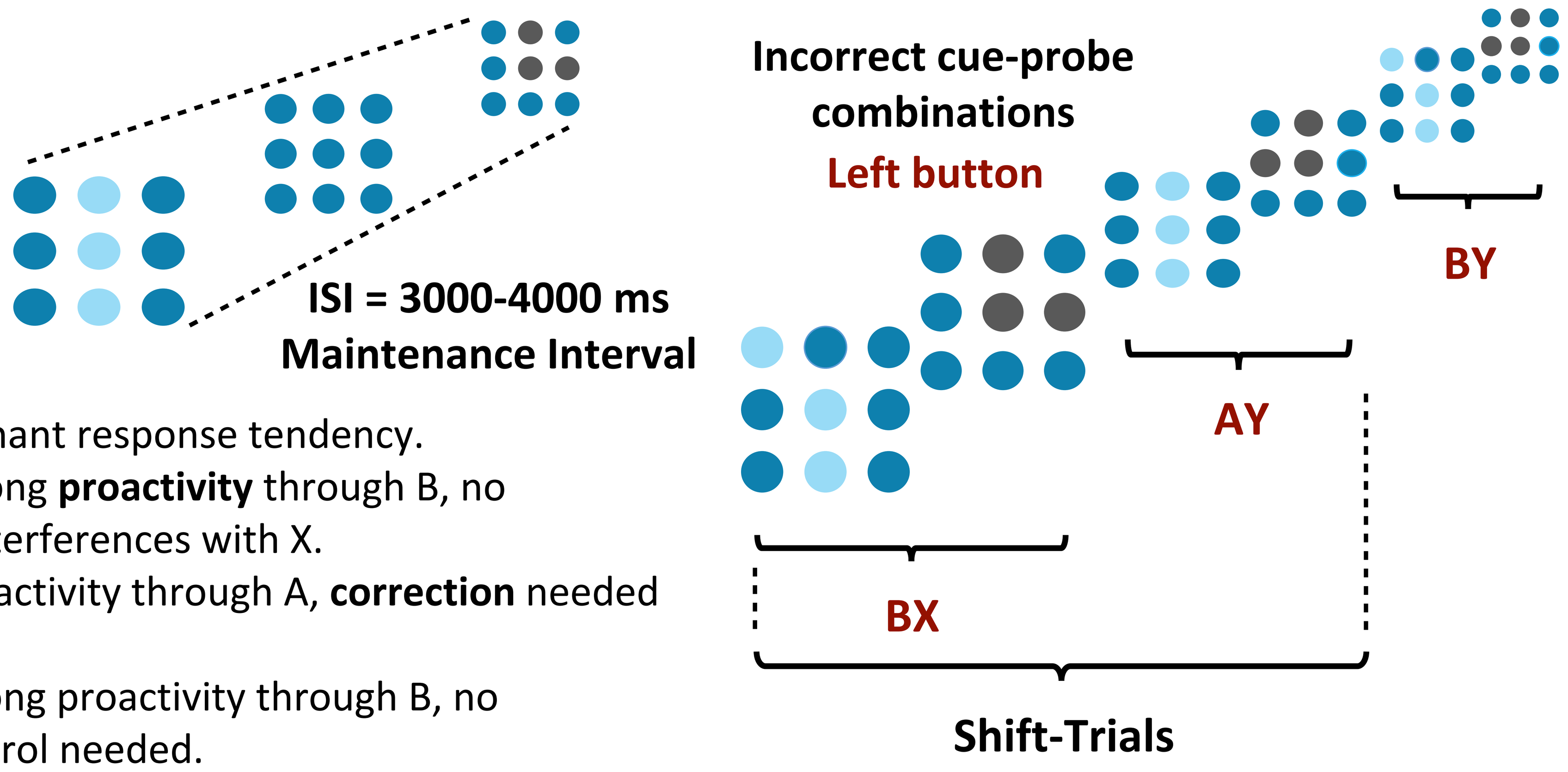
Theoretical Background

The dynamic exertion of cognitive control in accordance to everyday demands is a key factor in executive functioning and goal directed behaviour. Both active maintenance and flexible updating of context information in working memory constitute efficient behavioural control. Therefore, two distinct modes of control can be identified: **proactive** (i.e. preparatory, context-driven) and **reactive control** (i.e. corrective, stimulus-driven) (1). Past research points to the dorsolateral prefrontal cortex (DLPFC) to be the core structure for both modes (4). While proactive control optimises behaviour in the long-term and should be less demanding in terms of prefrontal resources, it should involve more central and posterior parietal areas (i.e. motor preparation). In late behavioural correction, due to the uncertainty of a situation, the anterior cingulate cortex (ACC) should be activated (1). Similar differences in neural activity should be found in Event-Related Potentials (ERPs). In particular, late fronto-parietal positivity associated with working memory updating and maintenance (i.e. P3b, Late Positive Potentials) should relate to the processing of predictive context cues and increased efforts to integrate new information into behavioural plans.
These findings have been observed in the past but only isolated from one another. The aim of this study was the identification of **joint signal sources** separating modes of control and providing further evidence for dual mechanisms of cognitive control in multimodal data approach.

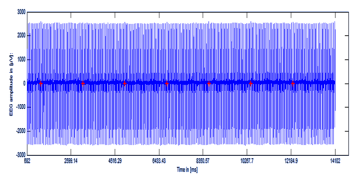
Paradigm



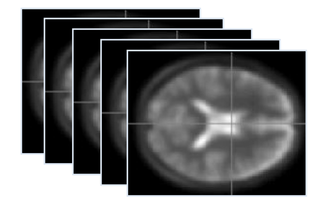
- **AX** – 65% = Dominant response tendency.
- **BX** – 11.6 % = Strong **proactivity** through B, no correction, but interferences with X.
- **AY** – 11.6 % = proactivity through A, **correction** needed because of Y.
- **BY** – 11.6 % = Strong proactivity through B, no correction or control needed.

Experimental Setup and Design

EEG Data (9 Subjects)
T timepoints
C electrodes
M trials
T*C by M matrix

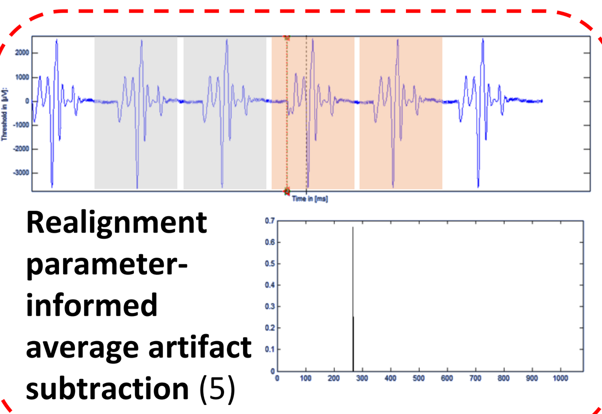


fMRI Data (9 Subjects)
T timepoints
X voxels
M trials
T*X by M matrix



Realignment

Realignment Parameters



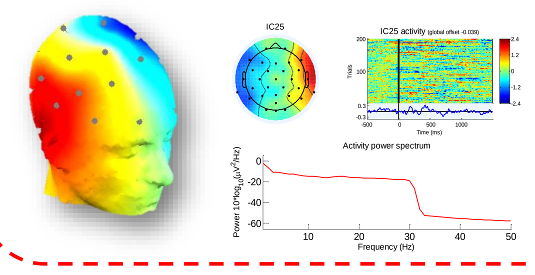
Realignment parameter-informed average artifact subtraction (5)

Hemodynamic lag, temporally unmatched

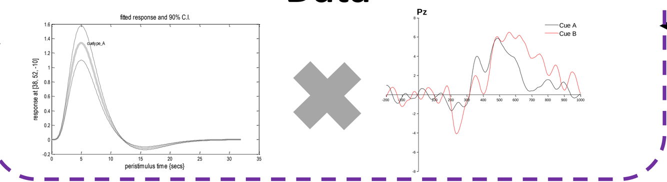
Hemodynamic Response Function

Alignment of temporal resolution with HRF

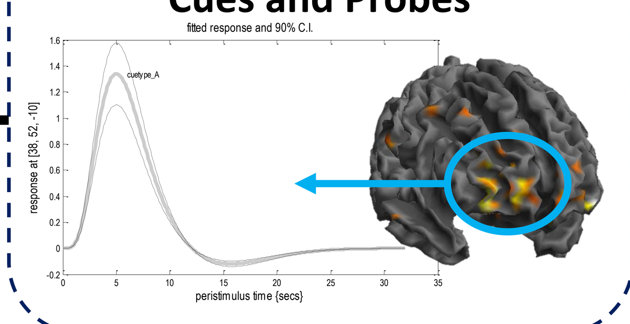
ICA correction of cardioballistic artifacts (3) and single subject ERPs



Convolution of single subject EEG Data

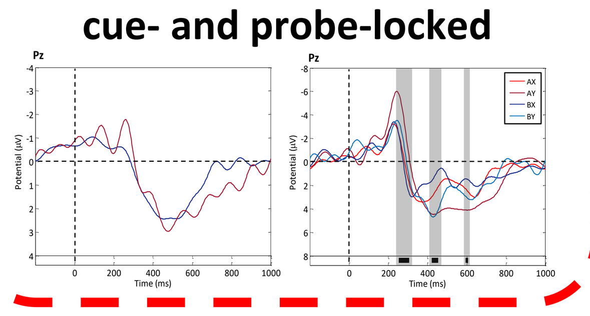


First Level Contrasts Cues and Probes



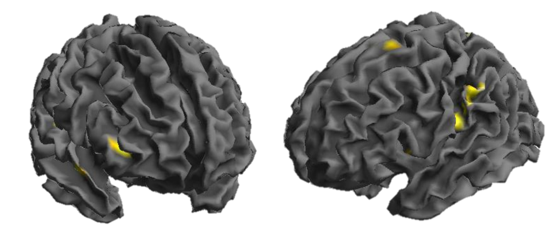
Joint Data Space
[T*C + T*X] by M
for sample N of both data modalities

Grand Averages cue- and probe-locked

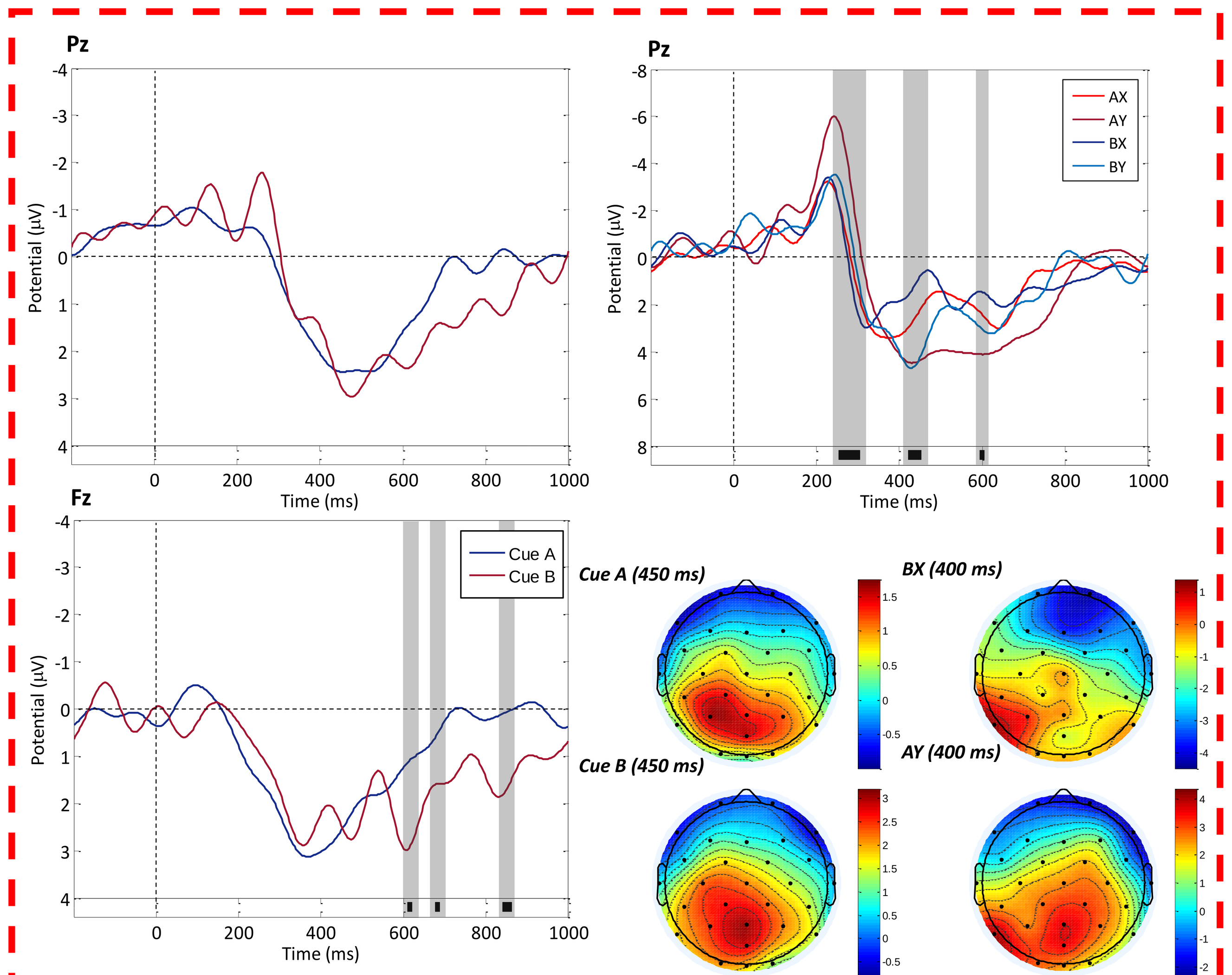


Joint Independent Component Analysis (jICA): Extraction of shared component weights matrix with complementary components [2]

Second Level Contrasts cues and probes

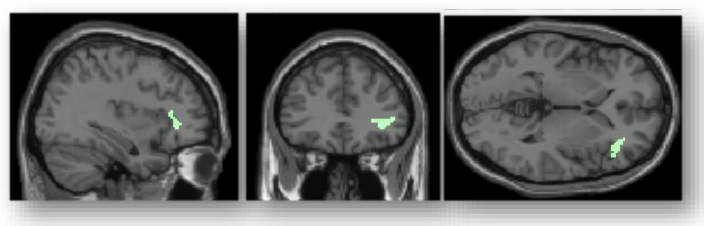


Results

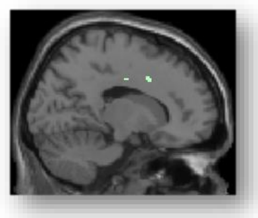


Differences with p-values < .05 marked grey

Contrast **A>B,** p < .05 (FWE-corr.)

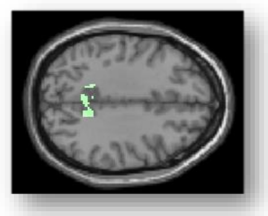


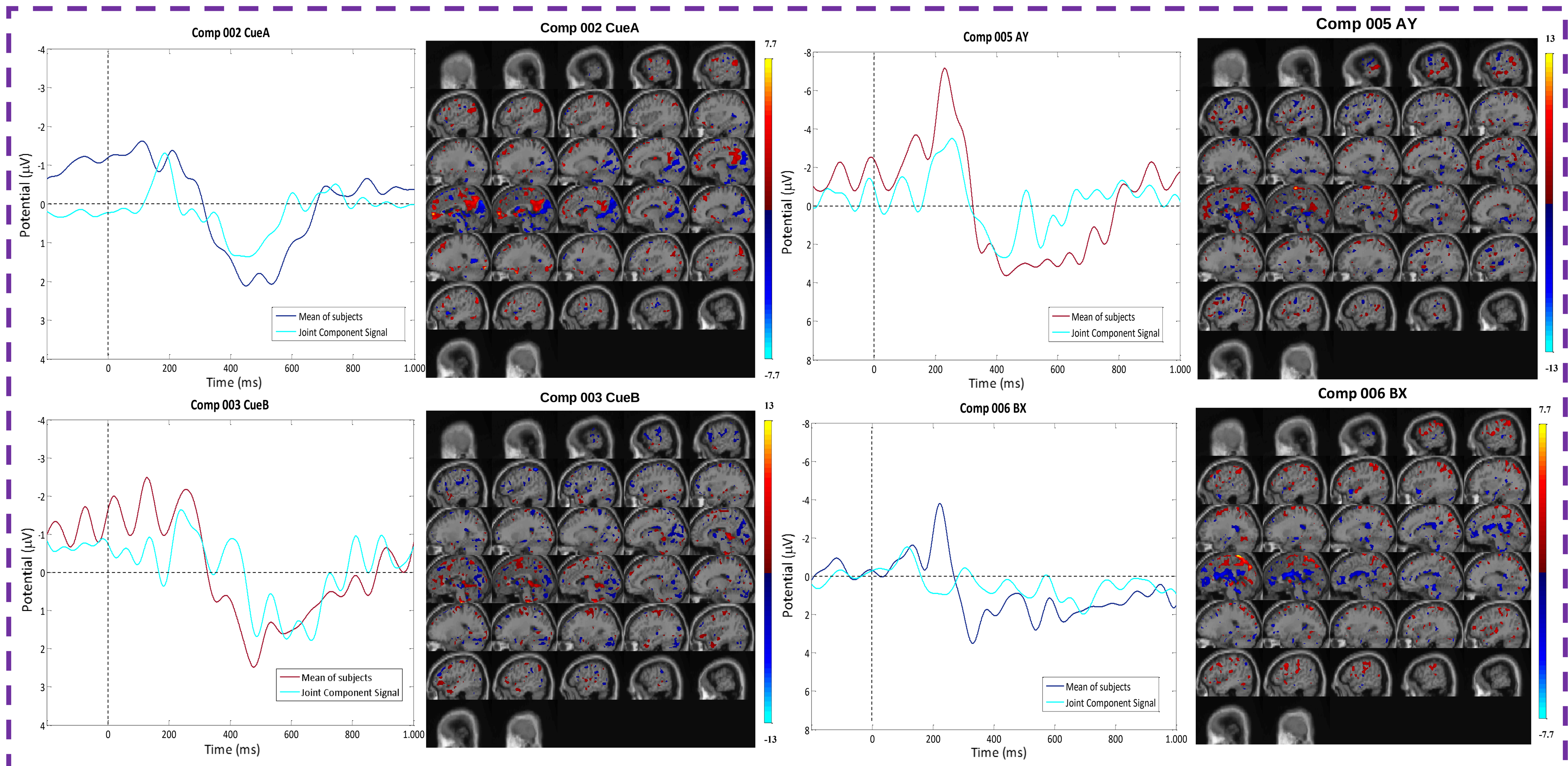
Contrast **AY>AX,** p < .05 (FWE-corr.)



Contrast **AY>BX,** p < .05 (FWE-corr.)

Contrast **BX>AY,** p < .05 (FWE-corr.)





Selected joint components for EEG and fMRI data (cue- and probe-locked), marked voxels exceed z-value thershhold of 1.5

Conclusions

- Further evidence for fonto-parietal structures (i.e. DLPFC, central parietal cortex) underlying cognitive control functioning in working memory: 1) More prefrontal and less posterior parietal activity for ambiguous as opposed to predictive cues 2) Higher late positive potentials (P3b, LPPs) for reactive control correcting behaviour as opposed to early behavioural optimisation (i.e. goal maintenance).
- In addition, cingulate cortex and putamen underlie late positivity associated with reactive control of working memory.
- Multimodal Data Integration (i.e. jICA) as a way of examining shared information between features in a joint data space.
- Otherwise lost information in isolated contrasts or grand averages can be extracted.
  - Means to observe simultaneous variation in data signals when investigating temporal and spatial dynamics of cognitive control functioning.

Literature

(1) Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in cognitive sciences, 16*(2), 106-113.
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(4) Lopez-Garcia, P., Lesh, T. A., Salo, T., Barch, D. M., MacDonald III, A. W., Gold, J. M., ... & Carter, C. S. (2016). The neural circuitry supporting goal maintenance during cognitive control: a comparison of expectancy AX-CPT and dot probe expectancy paradigms. *Cognitive, Affective, & Behavioral Neuroscience*, *16*(1), 164-175.
(5) Moosmann, M., Schönfelder, V. H., Specht, K., Scheeringa, R., Nordby, H., & Hugdahl, K. (2009). Realignment parameter-informed artefact correction for simultaneous EEG–fMRI recordings. *Neuroimage*, *45*(4), 1144-1150.