Comparing multimodal data fusion approaches for simultaneous EEG-fMRI recordings

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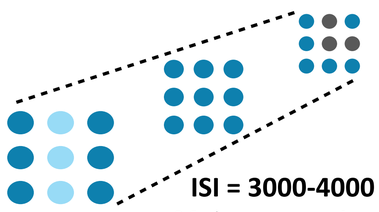
Theoretical Background

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). Concerning Event-Related Potentials (ERPs), 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 mostly isolated from one another. The aim of this study was the application of multimodal data fusion approaches to identify **joint and distinct signal sources** characterizing the different modes of control. These approaches vary in how much information they utilise, whether they are performed on the subject or trial level, which specific measures of fMRI or EEG are entered and in the physiological or statistical assumptions they make. In specific, the capabilities of **blind** and **semi-blind** source separation methods (i.e. joint and parallel Independent Component Analysis) for joint analyses are tested here.

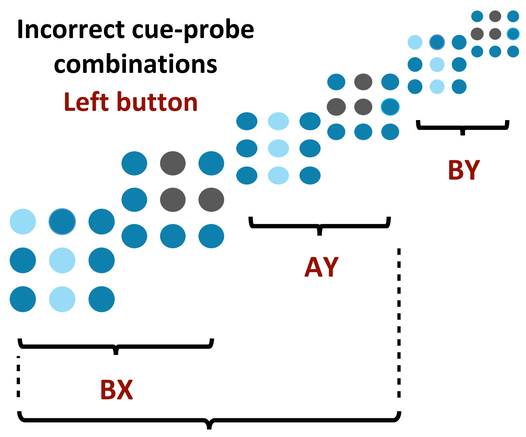
Paradigm

Right button
Correct cue-probe combination AX



ISI = 3000-4000 ms
Maintenance Interval

Incorrect cue-probe combinations
Left button

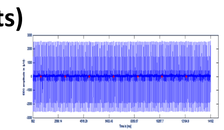


Shift-Trials

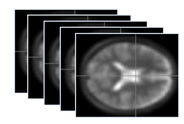
- **AX** – 65% = Dominant response tendency.
- **BX** – 11.6 % = Strong **proactivity** through B, no correction, but interferences with X.
- **AY** – 11.6 % = proactivity through A, **correction** needed because of Y.
- **BY** – 11.6 % = Strong proactivity through B, no correction or control needed.

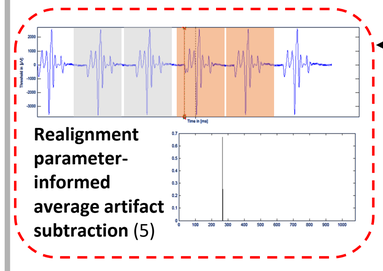
Experimental Setup and Design

EEG Data (13 Subjects)
T timepoints
C electrodes
M trials
T*C by M matrix



fMRI Data (13 Subjects)
T timepoints
X voxels
M trials
T*X by M matrix





Realignment parameter-informed average artifact subtraction (5)

Realignment Parameters

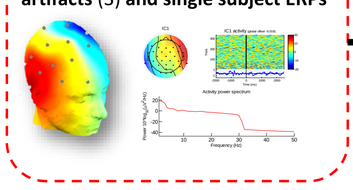
Realignment

Hemodynamic lag, temporally unmatched

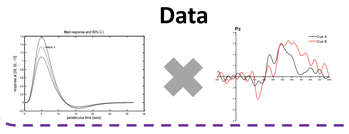
Hemodynamic Response Function

Alignment of temporal resolution with HRF

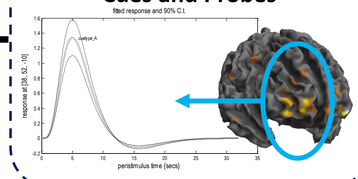
ICA correction of cardioballistic artifacts (3) **and single subject ERPs**



Convolution of single subject EEG Data

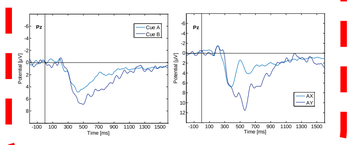


First Level Contrasts Cues and Probes



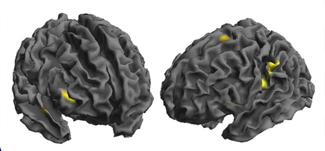
Joint Data Space
[T*C + T*X] by M
for sample N of both data modalities

Grand Averages cue- and probe-locked

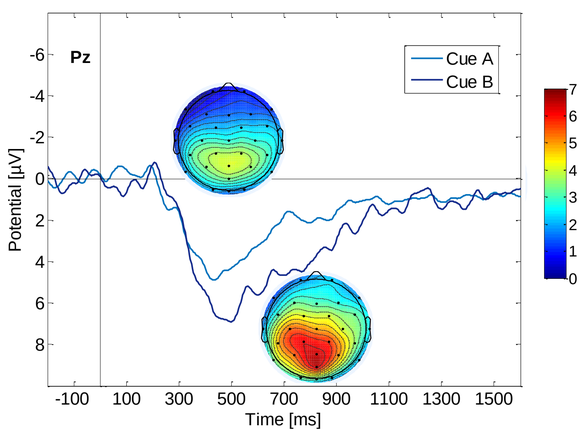


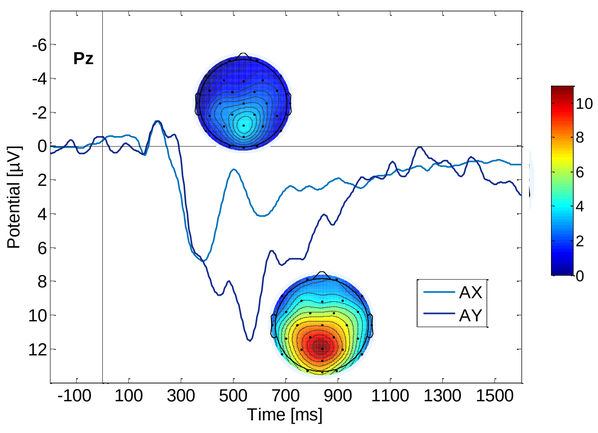
Joint and Parallel Independent Component Analysis (jICA and pICA): Extraction of shared component weights matrix with complementary components (2)

Second Level Contrasts cues and probes

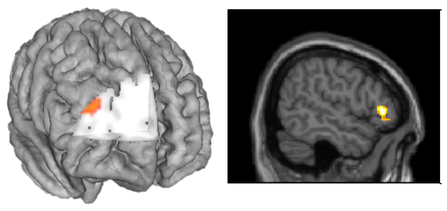


Results

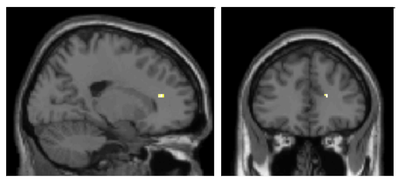




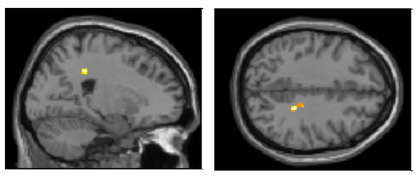
ROI analysis, Contrast **A>B,** p < .05 (FWE-corr.)

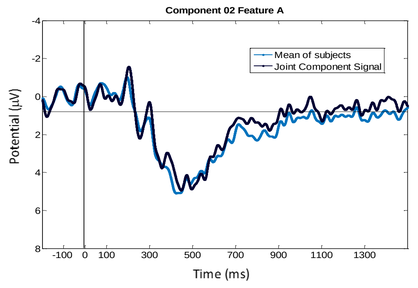


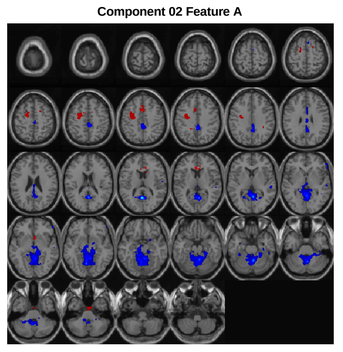
ROI analysis, Contrast **AY>AX,** p < .05 (FWE-corr.)

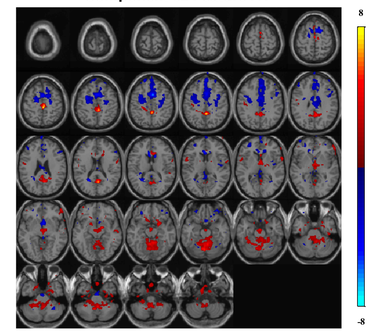


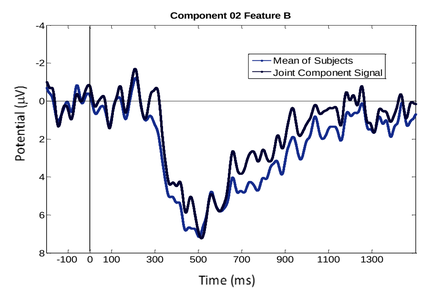
ROI analysis, Contrast **BX>BY**, p < .05 (FWE-corr.)

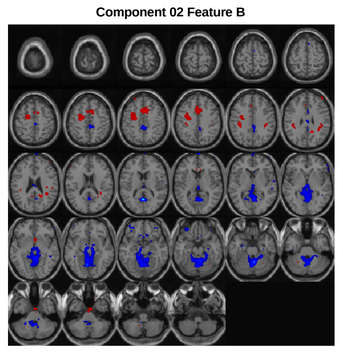


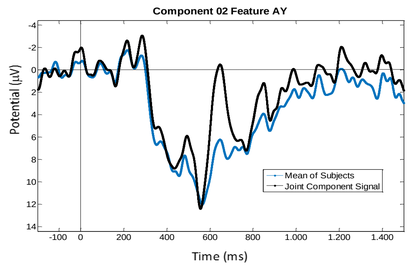


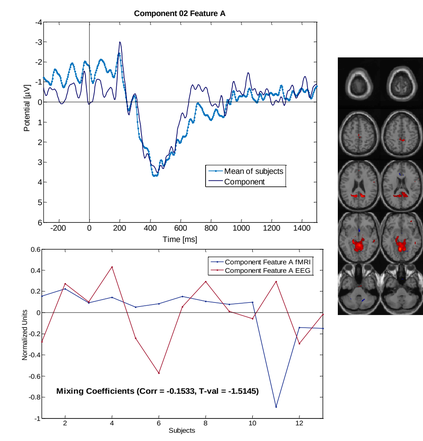


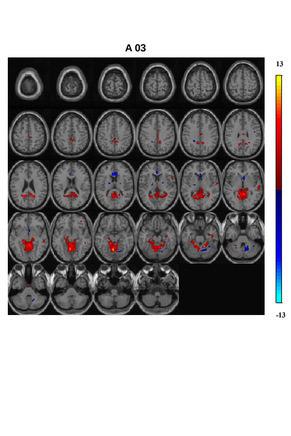


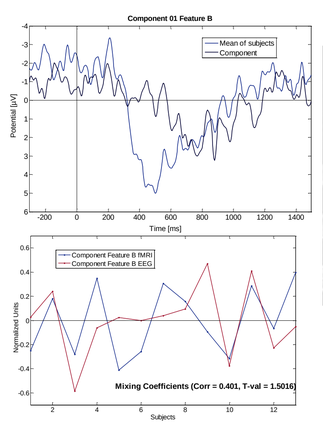


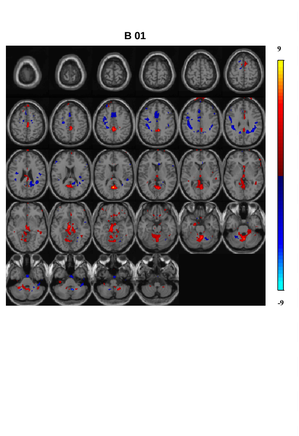












Selected joint components for EEG and fMRI data (cue- and probe-locked), marked voxels exceed z-value thershhold of 1.96.

Conclusions

- Further evidence for fonto-parietal structures (i.e. DLPFC, rigth middle and inferior frontal gyrus) underlying cognitive control functioning in working memory: 1) More prefrontal and less posterior parietal activity for ambiguous as opposed to predictive cues 2) Higher, sustained positivity (P3b, LPPs) for reactive control correcting behaviour and predictive cues (i.e. goal maintenance) as opposed to early behavioural optimisation and ambigguous cues
- Multimodal Data Integration (i.e. jICA) as a way of examining shared information between features in a joint data space.
- Otherwise lost information in means, 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.
- Joint and Parallel ICA as tools for multimodal data fusion is limited by:
  - Assumption of exclusively linear assosciations
  - Decomposition is constrained to identical (or correlated) modulation of data sources across subjects
  - Implemented as second level analysis, usage of higher order statistics

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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(3) Iannotti, G. R., Pittau, F., Michel, C. M., Vulliemoz, S., & Grouiller, F. (2015). Pulse artifact detection in simultaneous EEG–fMRI recording based on EEG map topography. *Brain topography*, *28*(1), 21-32.
(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.