

Statistical Analysis of Neuroeconomic Data

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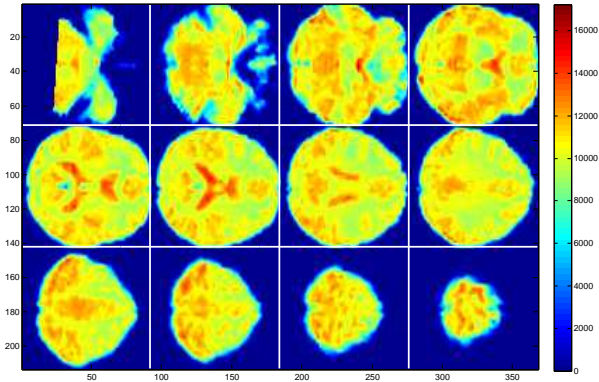


Motivation

- Which part of our brain is activated during *risky decisions* ?
- Can statistical analysis help to detect this area?



Different brain visualization



Motivation

- search for neuro-physiological analogue to the specification of risk type
- massive data set from experiments
 - ▶ statistical analysis necessary
 - ▶ dimension reduction keeping the data structure
 - ▶ **time** consideration (DSFM)



Outline

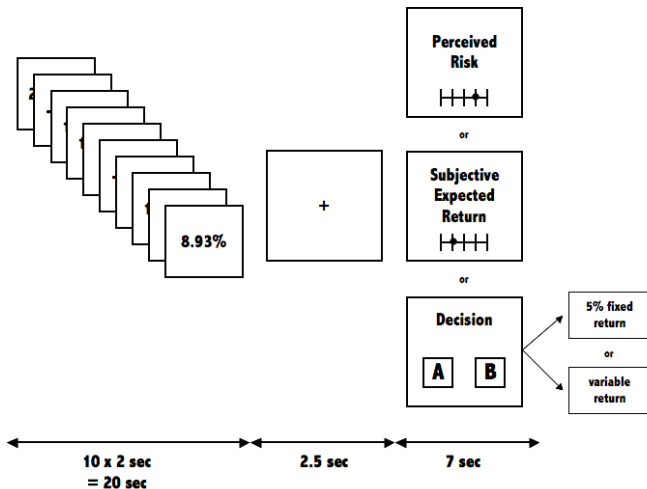
1. Motivation ✓
2. Experiment
3. Statistical Model
4. Results
5. Future Perspectives



Experiment participants

- ▣ 20 volunteers (age 18-35 years)
- ▣ 11 females, 9 males
- ▣ native German speakers, right-handed (according to the Edinburgh Handedness Inventory)
- ▣ no history of neurological or psychiatric diseases
- ▣ flat payment (10 EUR) \pm outcome resulting from the participant's decision
- ▣ 2 participants excluded due to extensive head motion and modeling problems





Risk Perception and Investment Decision (RPID)



RPID task in each trial

1. presentation of a return stream (rs)
 - ▶ ten returns from an investment (each for 2 sec)
 - ▶ each rs independent of the others
 - ▶ 9 different combinations of means (6%, 9%, 12%) and standard deviations (1%, 5%, 9%)



RPID task

2. decision *or* subjective judgment task (chosen randomly)
- ▶ choice between an investment with 5% fixed return (safe investment) and the investment represented by the r_s (risky investment)
 - ▶ subjective expected return judge with range: -5% – 15%
 - ▶ perceived risk judge on scale: 0 (no risk) – 100 (maximum risk)

Altogether: 81 trials (3 tasks 27 times) in 57 mins.



fMRI Acquisition

- fMRI = functional Magnetic Resonance Imaging
- noninvasive technique of recording brain's signals
- BOLD (blood oxygenation level dependent)-sensitive imaging
- 1.5 T Magnetom Sonata MRI system (Siemens)
- 26 axial slices of 4mm thickness



Data Set

Series of 3-dim images

- each scan transformed on the resolution $2 \times 2 \times 2mm^3$
- 91 slices
- observed every 2.5 seconds
- data set: series of 1360 images with $91 \times 109 \times 91$ voxels

High-dimensional, high frequency data.



Dynamic Semiparametric Factor Model (DSFM)

$$Y_{t,j} = m_0(X_{t,j}) + \sum_{l=1}^L Z_{t,l} m_l(X_{t,j}) + \varepsilon_{t,j}, \quad 1 \leq j \leq J.$$

$$X_{t,j} = (X_{t,1}, \dots, X_{t,J})^\top$$

observable covariates defined on \mathbb{R}^d

$$Y_{t,j} = (Y_{t,1}, \dots, Y_{t,J})^\top$$

observable random vector

$$Z_{t,j} = (Z_{t,1}, \dots, Z_{t,L})^\top$$

unobservable L -dimensional process

$$(m_0, \dots, m_L)$$

unknown real-valued functions defined on a subset of \mathbb{R}^d

$$\varepsilon_{t,j} \sim (0, \sigma_{t,j}^2)$$

errors with $\sigma_{t,j}^2 < \infty$



Fitting fMRI Data

- cut off parts of images without brain scan
- reduction of the original data by taking every second slice in each direction
- voxel's index (i_1, i_2, i_3) as covariate $X_{t,j}$
- BOLD signal as $Y_{t,j}$
- then $J_t = 36 \times 46 \times 46$ and $T = 1360$



Estimation of DSFM

- choose $K = 7 \times 8 \times 8 = 448$ parabolic tensor B-splines to estimate \hat{m}
- set $L = 3$

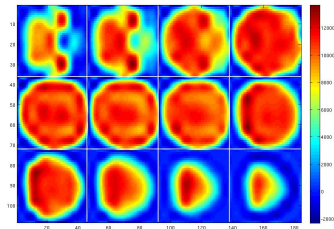
$$1 - RV(L) = \frac{\sum_t^T \sum_j^{J_t} \{Y_{t,j} - \hat{m}_0(X_{t,j}) - \sum_{l=1}^L \hat{Z}_{t,l} \hat{m}_l(X_{t,j})\}^2}{\sum_t^T \sum_j^{J_t} (Y_{t,j} - \bar{Y})^2}$$

No.of factors	$L = 1$	$L = 2$	$L = 3$
$1 - RV(L)$	0.9144	0.9146	0.9237

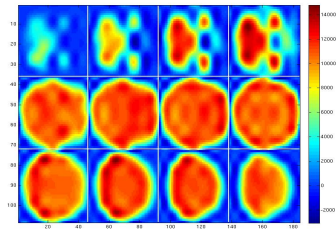


Factor loading \hat{m}_0

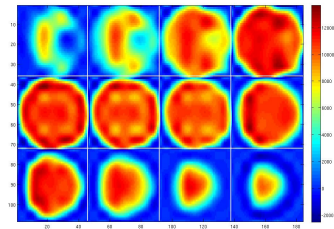
Proband 9



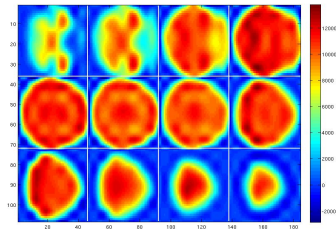
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Proband 11

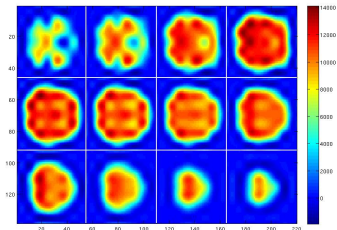


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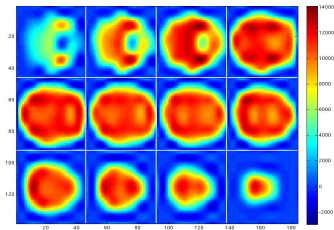


Factor loading \hat{m}_0

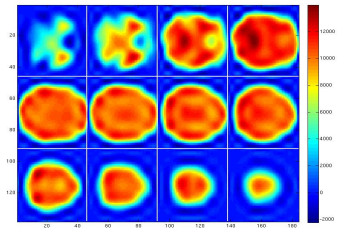
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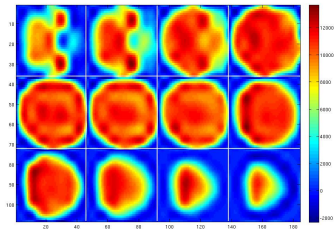
Proband 2



Proband 3

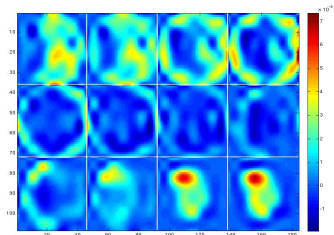


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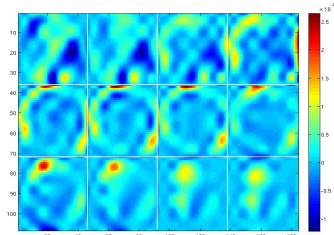


\hat{m}_1

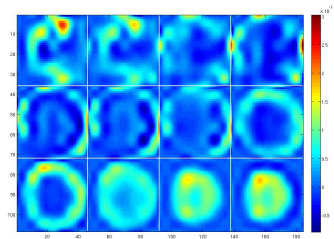
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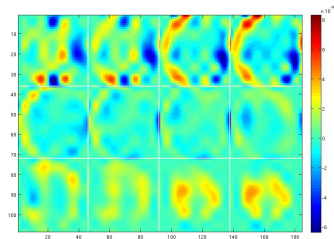
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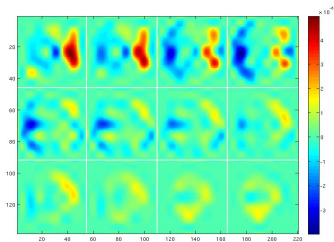


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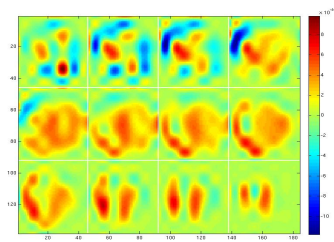


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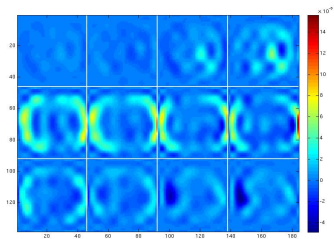
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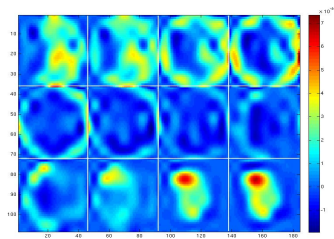
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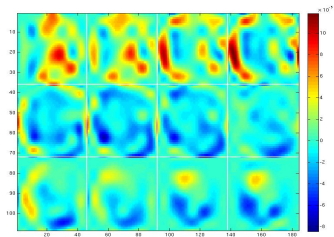


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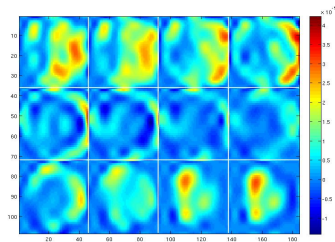


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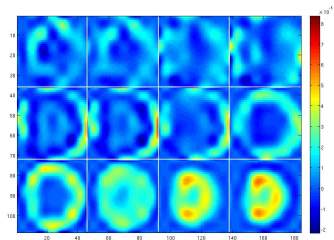
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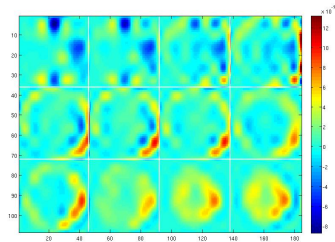
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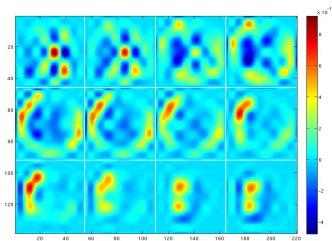


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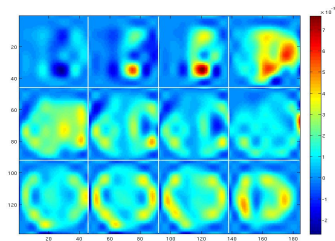


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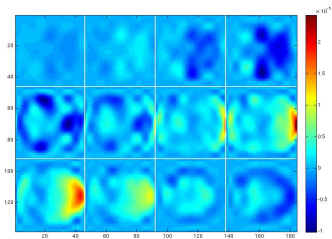
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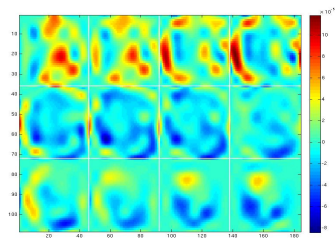
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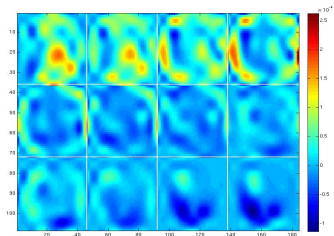


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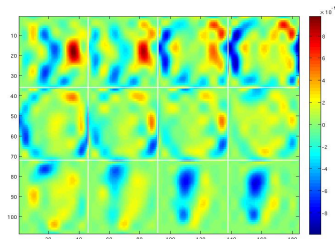


\hat{m}_3

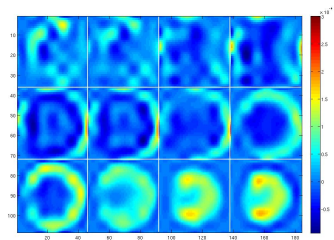
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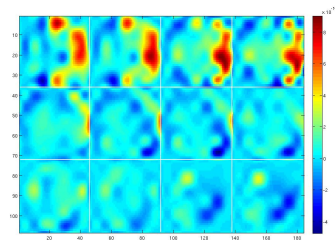
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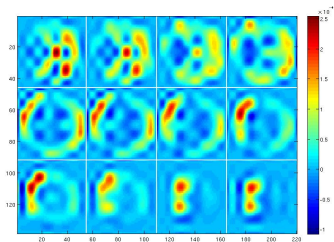


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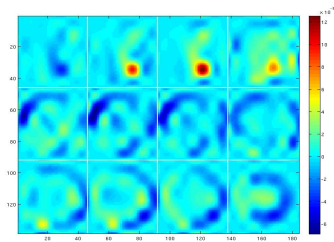


\hat{m}_3

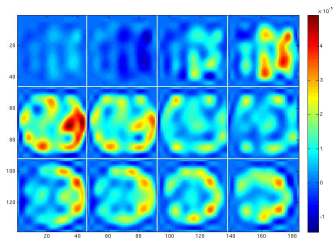
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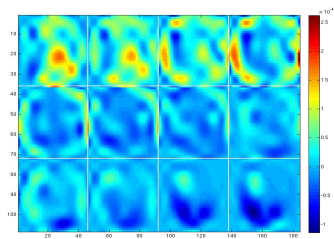
Proband 2



Proband 3



Proband 9



Estimates of Factor loadings \hat{m}_1

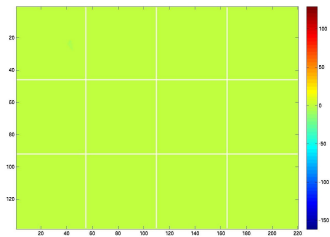
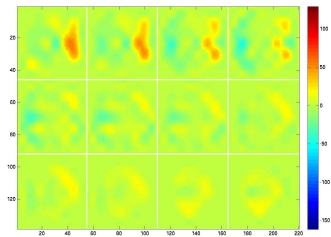
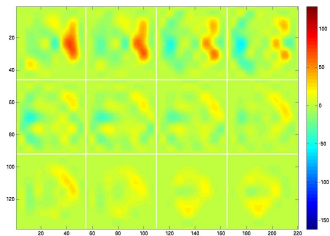
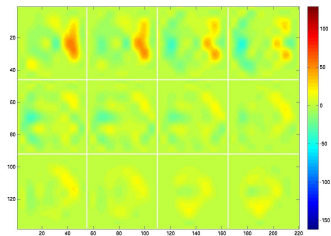
Factor loadings multiplied by \hat{Z}_i in 4 different time points.
Starting point in the time of decision task.

- ▣ proband 1
- ▣ proband 9
- ▣ proband 11
- ▣ proband 12



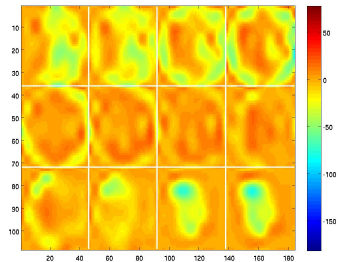
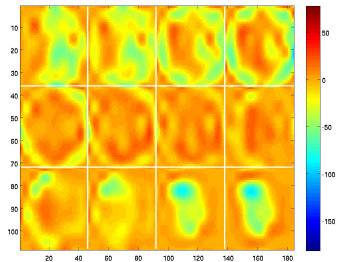
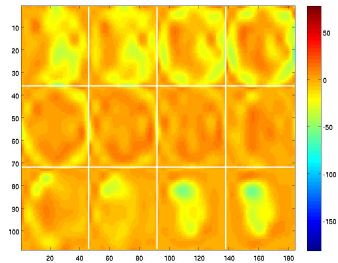
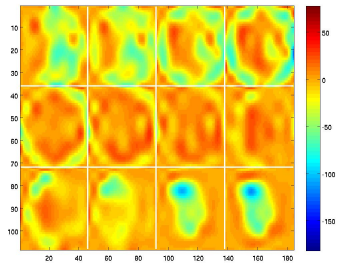
\hat{m}_1

Proband 1



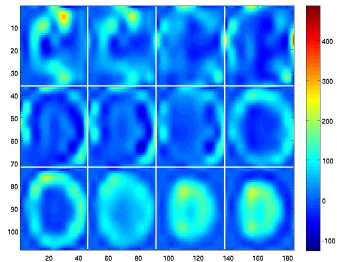
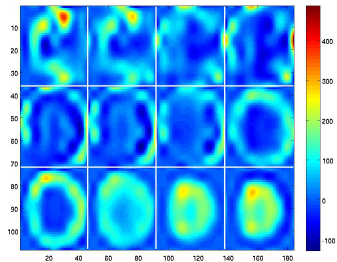
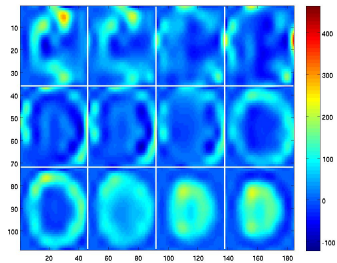
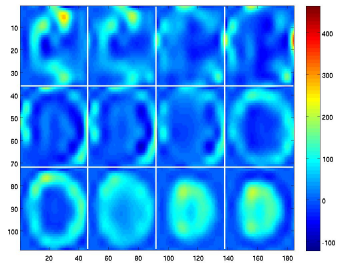
\hat{m}_1

Proband 9



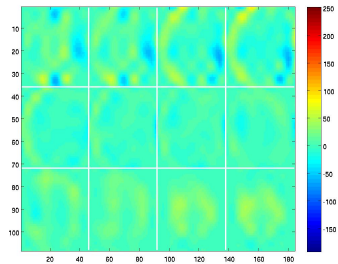
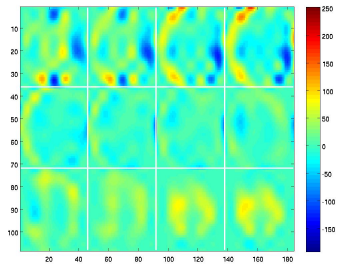
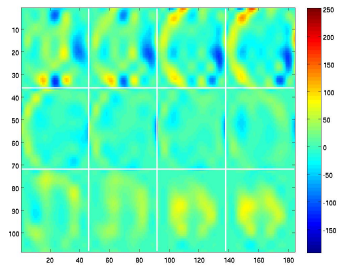
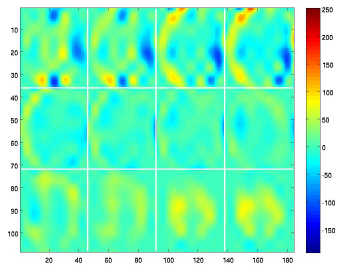
\hat{m}_1

Proband 11



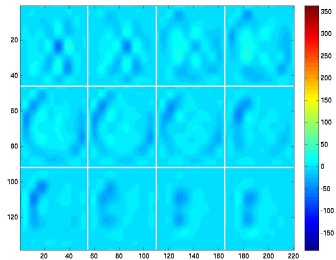
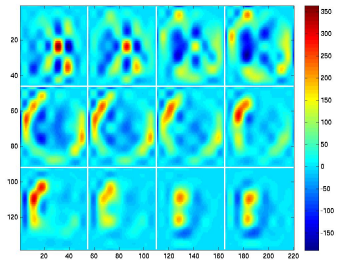
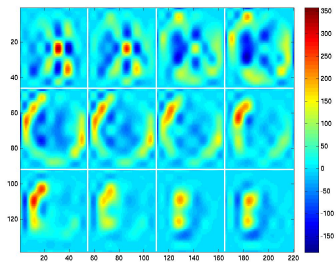
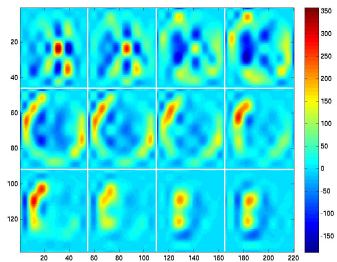
\hat{m}_1

Proband 12



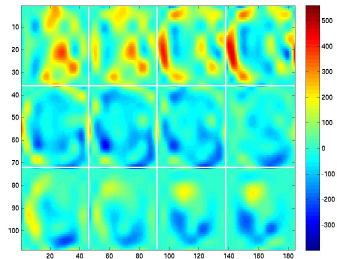
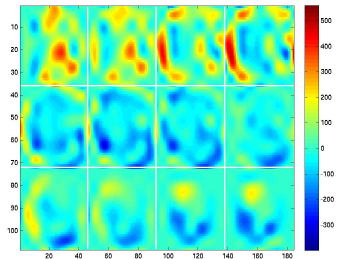
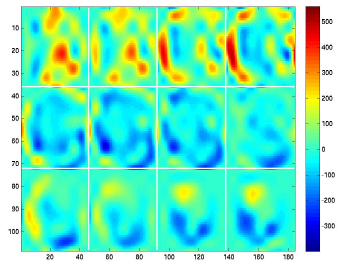
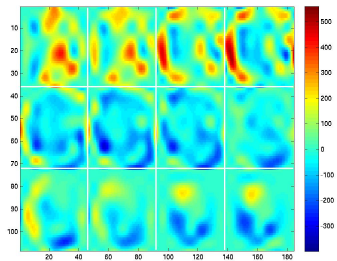
\hat{m}_2

Proband 1



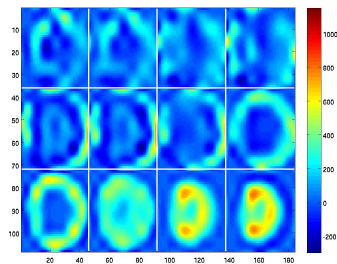
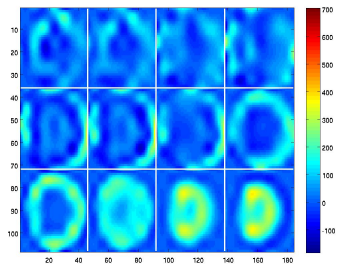
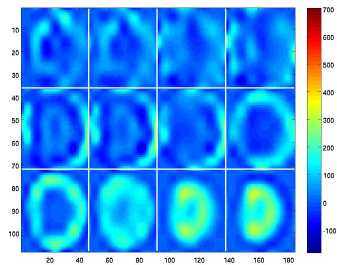
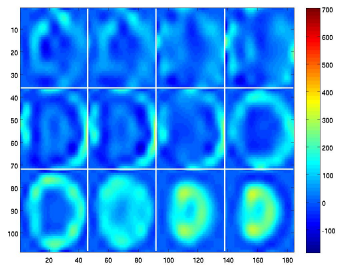
\hat{m}_2

Proband 9



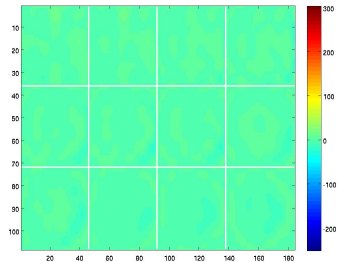
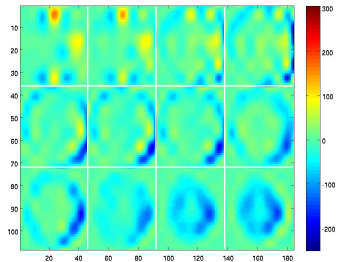
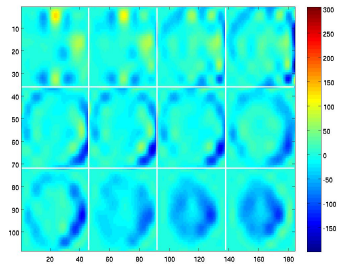
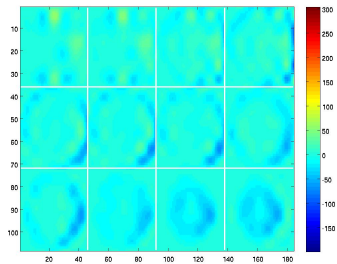
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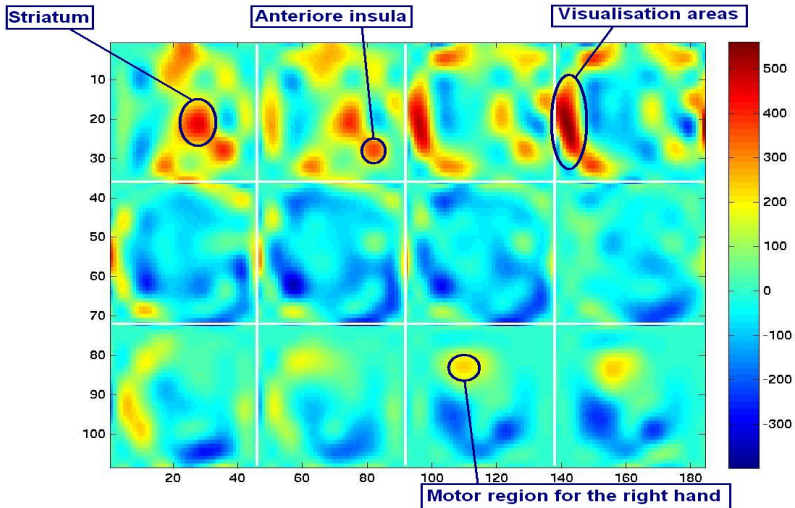
Proband 11



\hat{m}_2

Proband 12

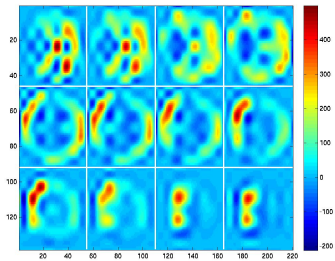
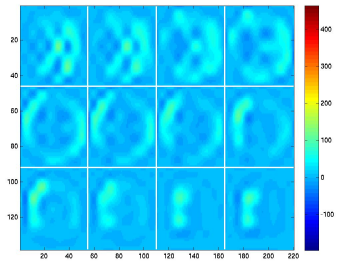
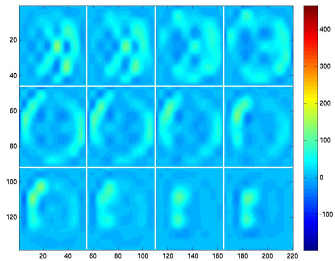
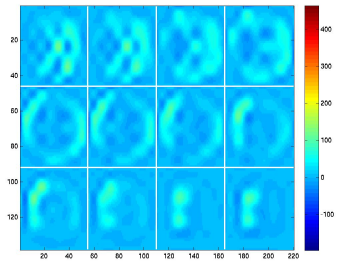




Estimated basis function \hat{m}_2 .

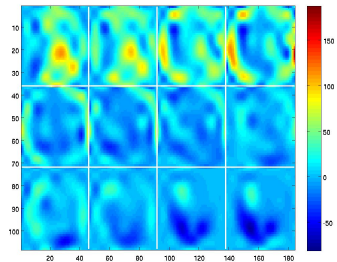
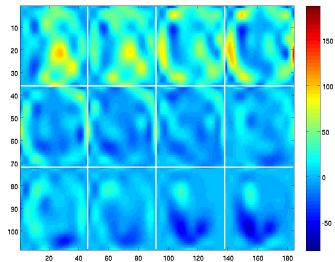
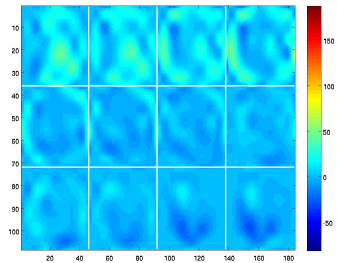
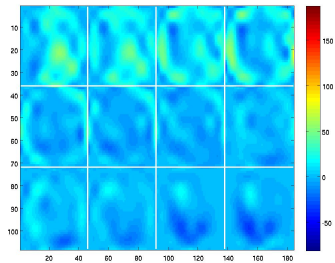
\hat{m}_3

Proband 1



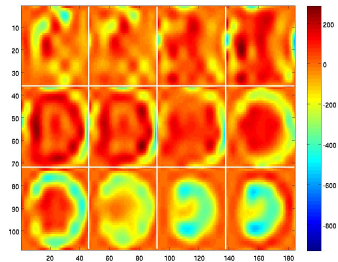
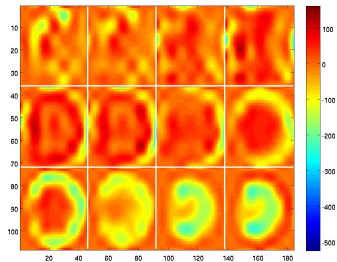
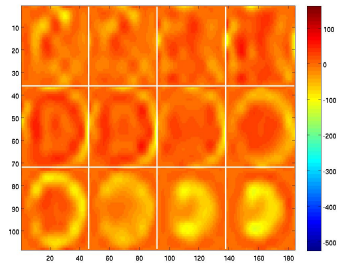
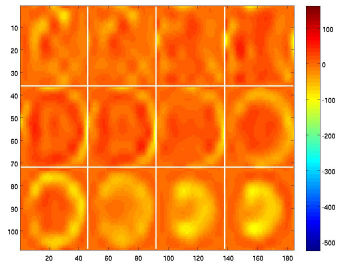
\hat{m}_3

Proband 9



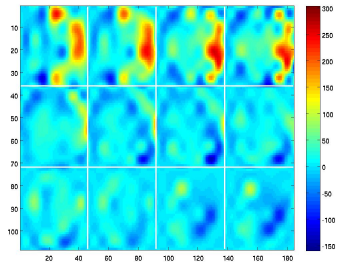
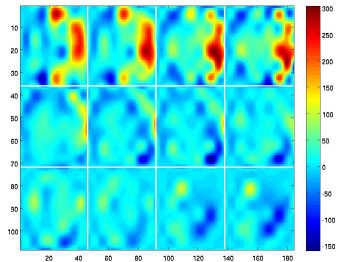
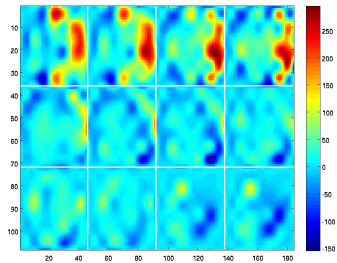
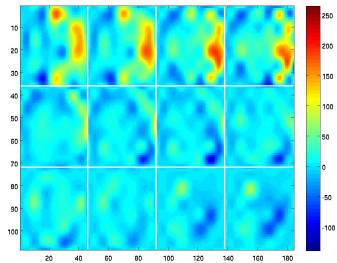
\hat{m}_3

Proband 11

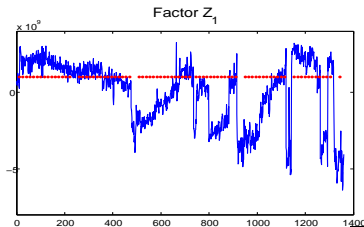
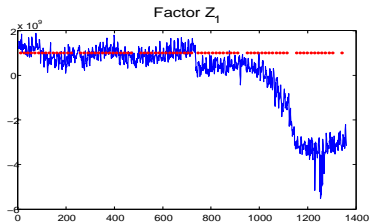
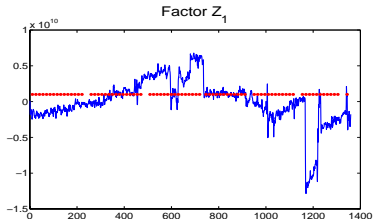
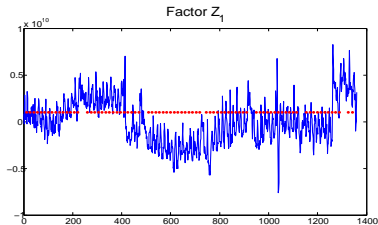


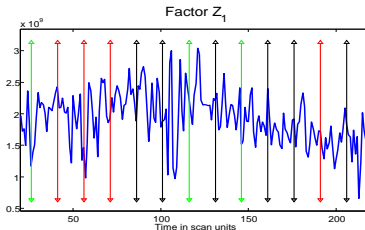
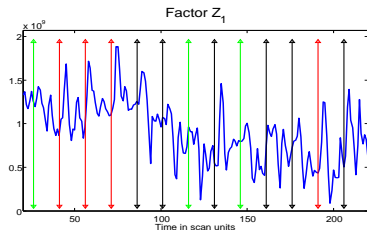
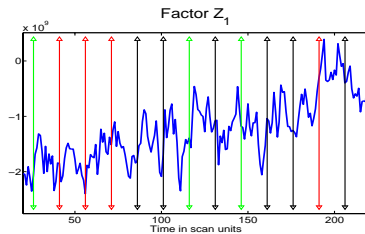
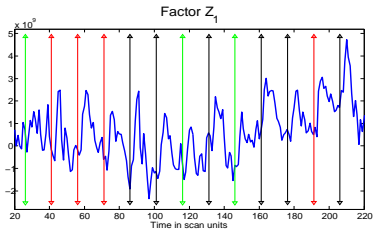
\hat{m}_3

Proband 12



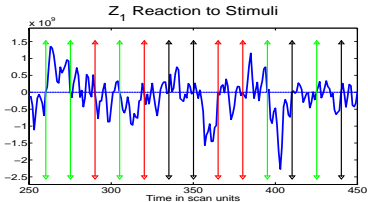
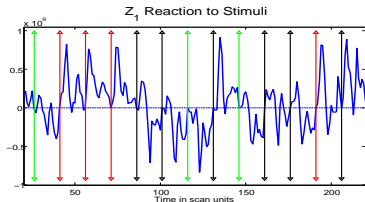
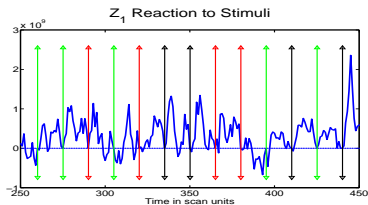
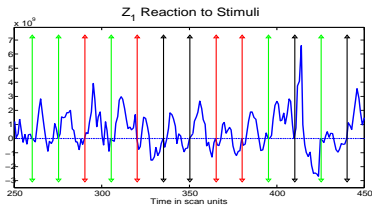
Factor \hat{Z}_1





Lines correspond to the time points of judgement tasks
decision, return, risk.

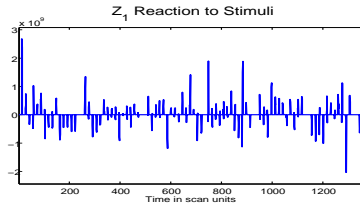
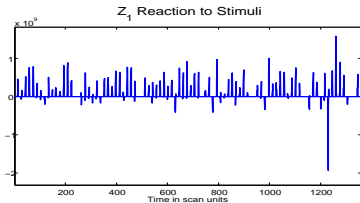
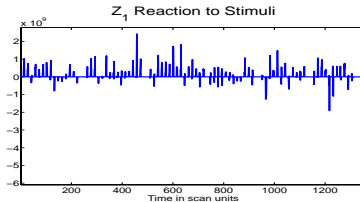
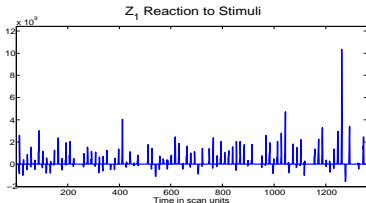


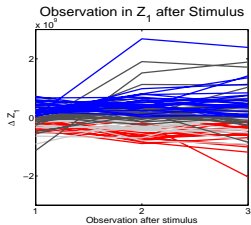
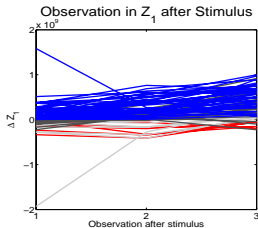
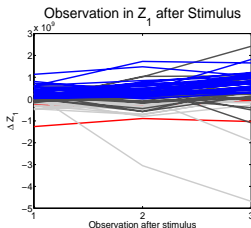
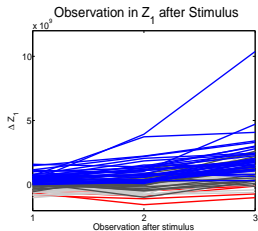


Lines correspond to the time points of judgement tasks
decision, return, risk.



Reaction to stimuli

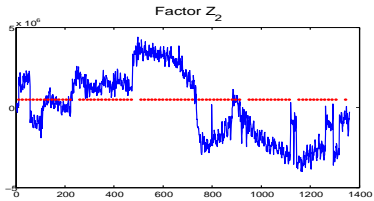
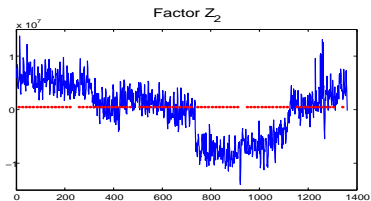
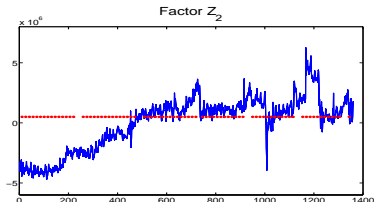
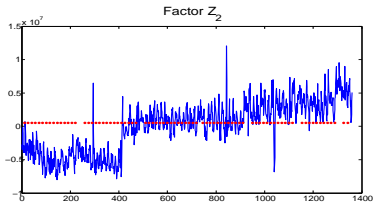


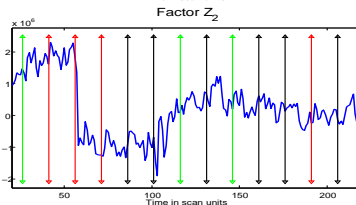
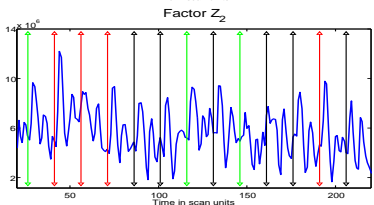
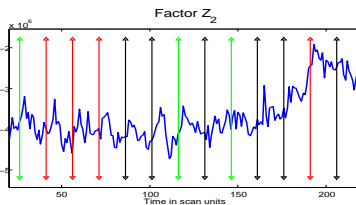
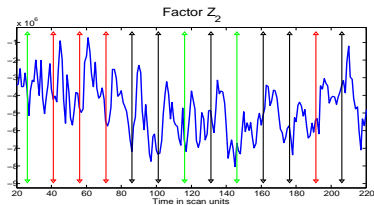


Blue lines: all 3 points > 0 , light gray lines: 2 points > 0 ,
gray lines: 1 point > 0 , red lines: all 3 points ≤ 0 .



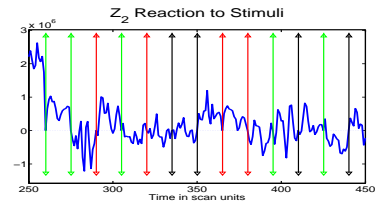
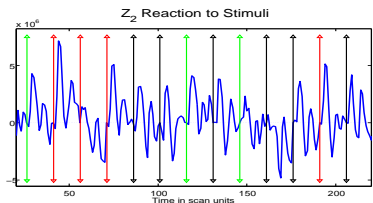
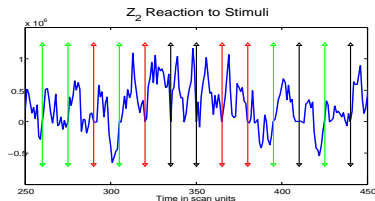
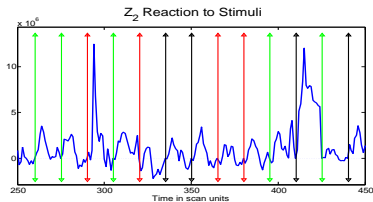
Factor \hat{Z}_2





Lines correspond to the time points of judgement tasks
decision, return, risk.

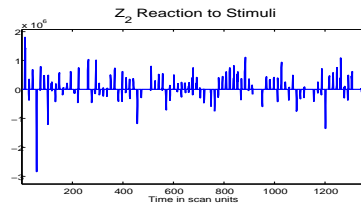
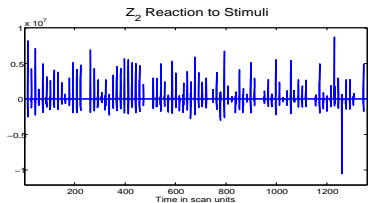
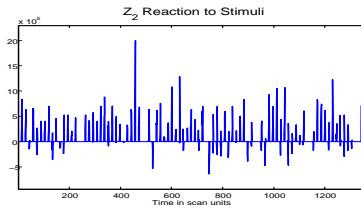
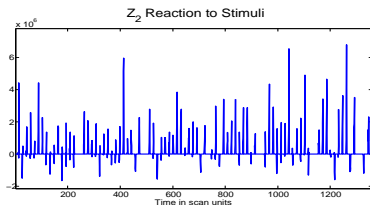


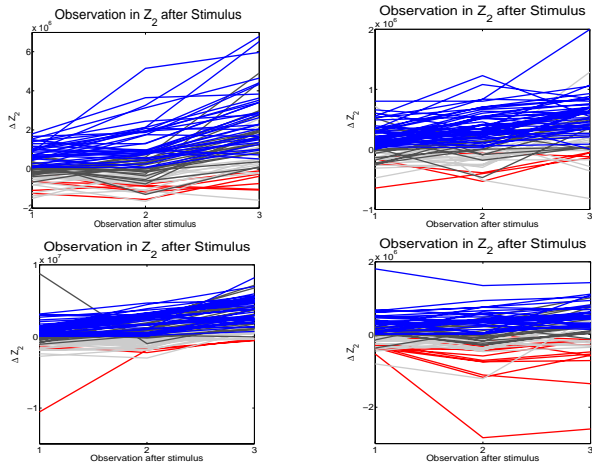


Lines correspond to the time points of judgement tasks
decision, return, risk.



Reaction to stimuli

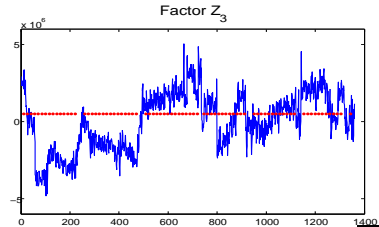
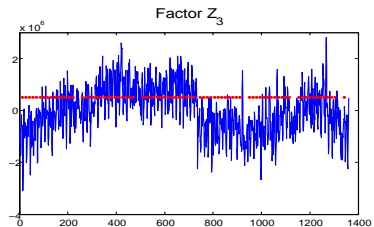
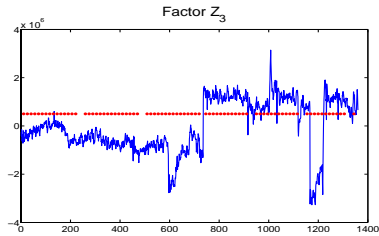
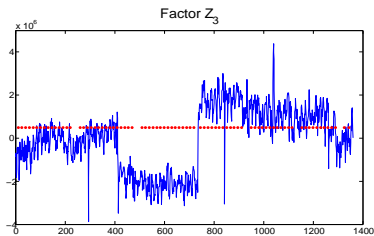


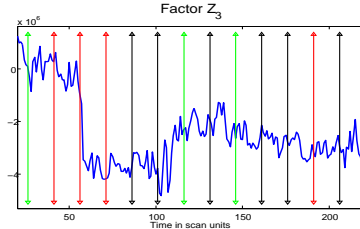
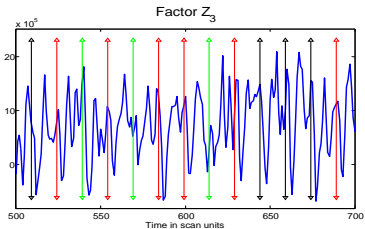
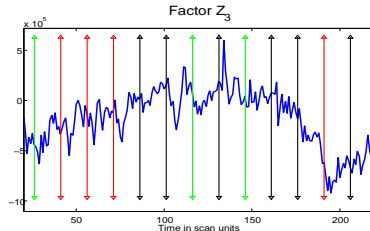
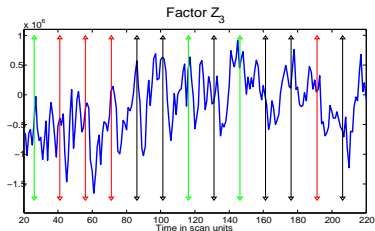


Blue lines: all 3 points > 0 , light gray lines: 2 points > 0 ,
gray lines: 1 point > 0 , red lines: all 3 points ≤ 0 .



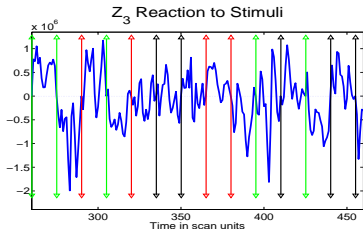
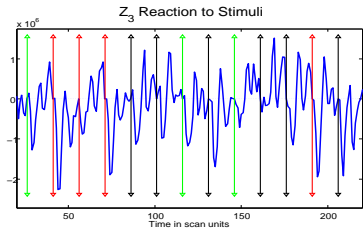
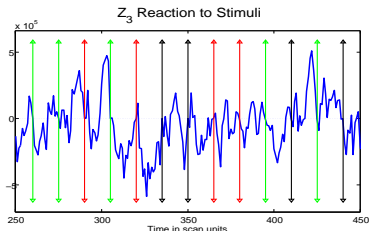
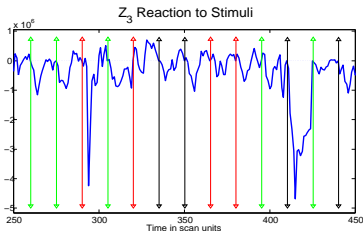
Factor \hat{Z}_3





Lines correspond to the time points of judgement tasks
decision, return, risk.

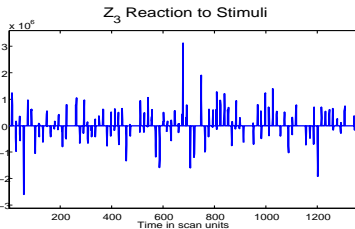
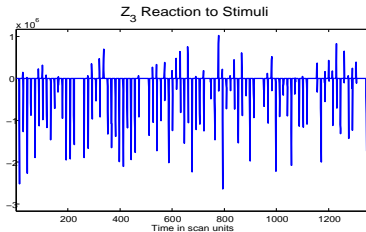
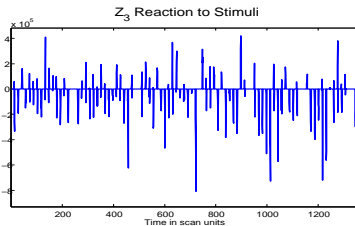
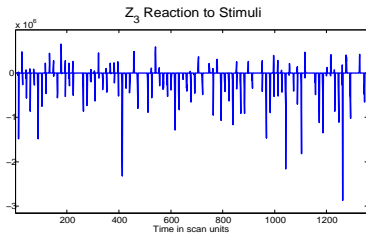


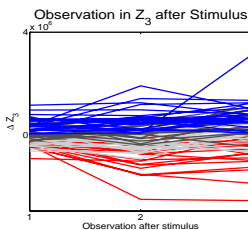
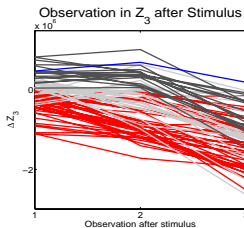
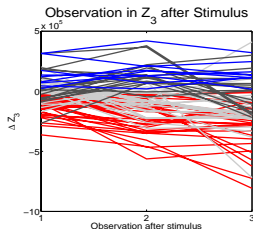
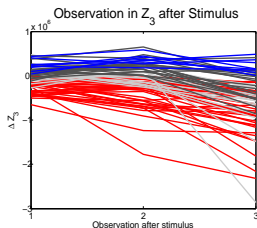


Lines correspond to the time points of judgement tasks
decision, return, risk.



Reaction to stimuli





Blue lines: all 3 points > 0 , light gray lines: 2 points > 0 ,
gray lines: 1 point > 0 , red lines: all 3 points ≤ 0 .



Conclusion

- basis functions (especially \hat{m}_2) identify activated areas, neurological reasonable
- estimated factors show differences for proband with different risk attitude



Future Perspectives

- Are there any differences in the reactions to the different types of stimuli?
- Could we separate risk-averse/risk-seeking participants according to \hat{Z}_i

