Contribution of sympathetic vasoconstriction to the fMRI global signal during autonomic arousals

Pinar S Özbay, Catie Chang, Dante Picchioni, Hendrik Mandelkow, Miranda G Chappel-Farley, Peter van Gelderen, Jacco A de Zwart, and Jeff H Duyn

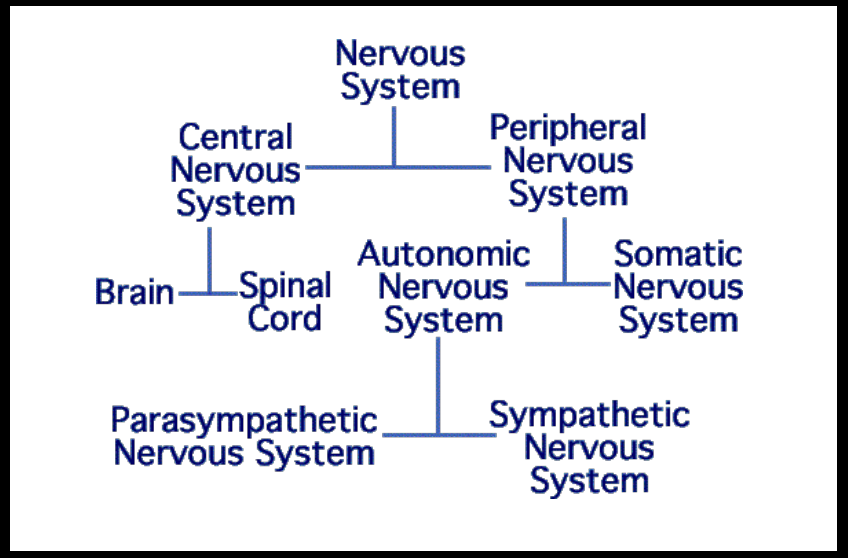
Advanced MRI Section, LFMI, NINDS, NIH

Declaration of Financial Interests or Relationships

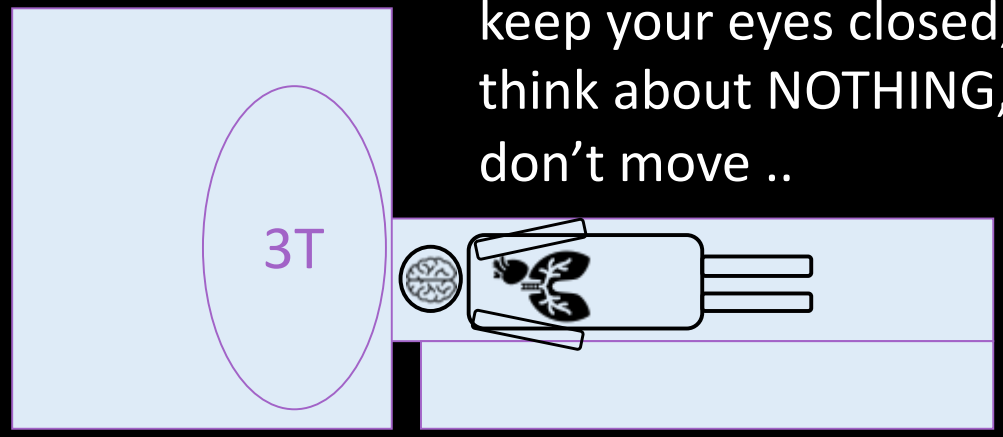
Speaker Name: Pinar S Özbay

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

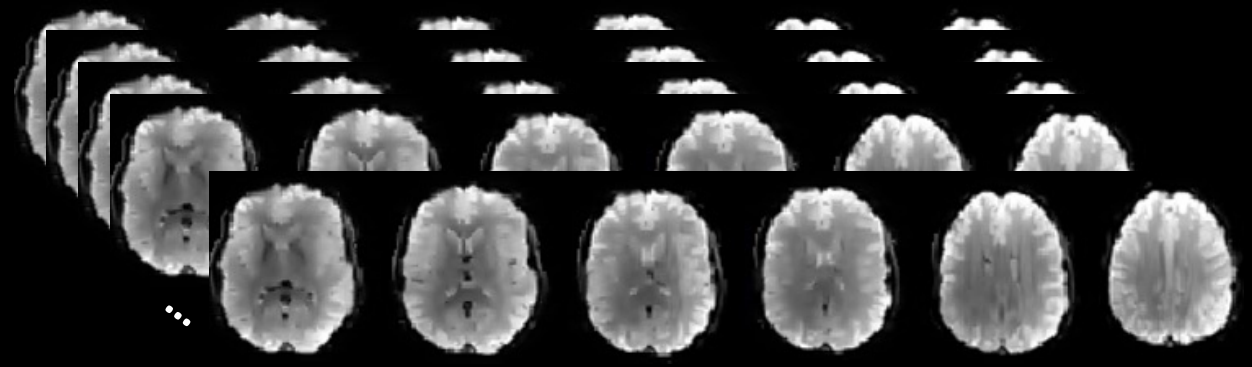
Effects of sympathetic activity contributing to the fMRI



Human subjects

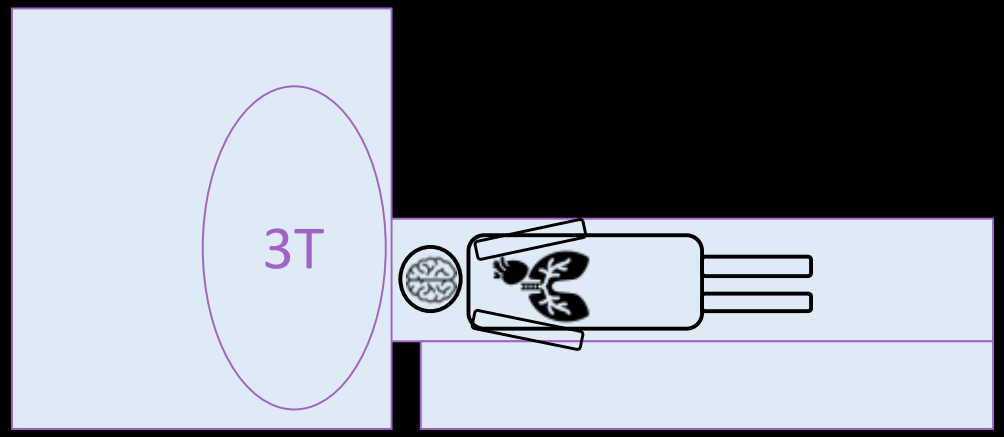


Instructions
e.g.
keep focus on the (little-central) dot,
keep your eyes closed, but don't fall asleep,
think about NOTHING,
don't move ..



Effects of sympathetic activity contributing to the fMRI

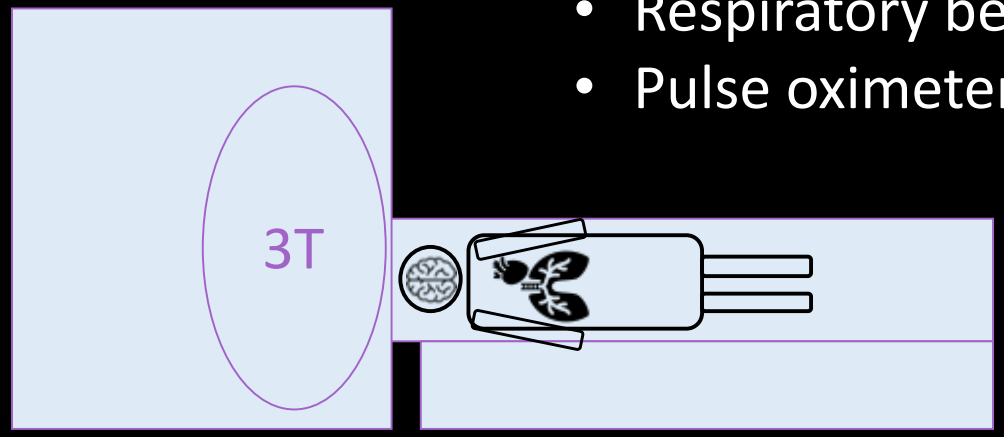
Human subjects



- Substance of abuse ✖
  - Alcohol, caffeine, nicotine ..
- Psychology
  - Hormonal changes ✖
  - Anti-depressants
- Motion ✖
- Mental state
  - Awake
  - Drowsy
  - Sleeping
  - Focus
  - Relaxed
  - Alert
  - Stress
  - Emotional ..
- Systemic physiology
  - Cardiac and respiratory cycle

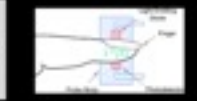
Measures of physiology

Human subjects



- Respiratory bellows
- Pulse oximeter (finger-tip photoplethysmogram (PPG) signal)

Main use of the PPG signal in fMRI



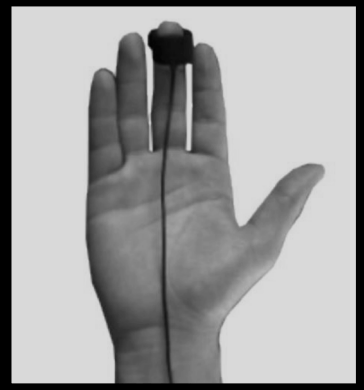
A photoplethysmogram (PPG) is an optically obtained plethysmogram that can be used to detect blood volume changes from the fingertip.

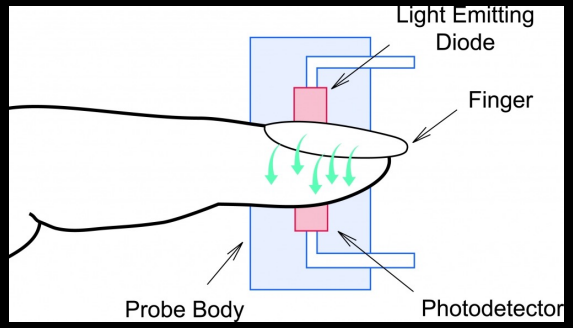
A PPG is often obtained by using a pulse oximeter which illuminates the skin and measures changes in light absorption.

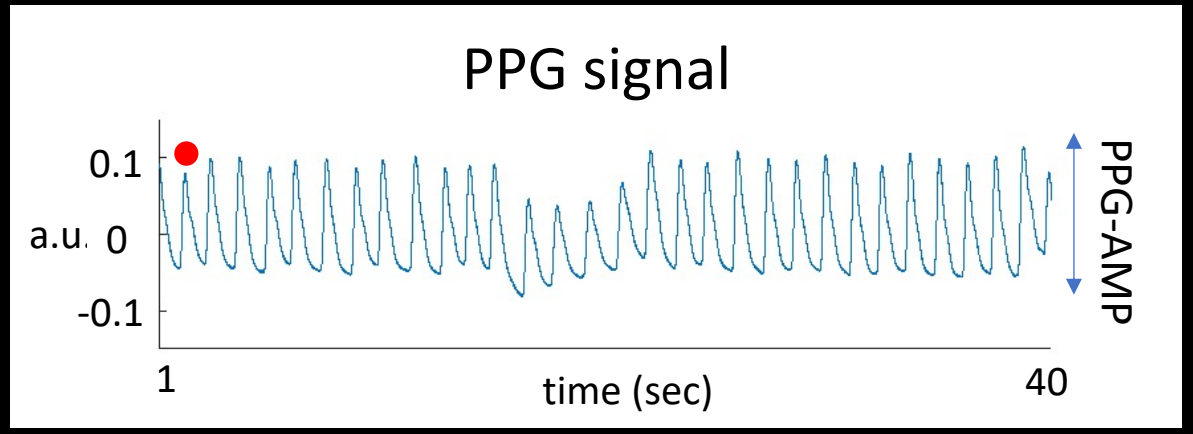
> Heart rate variation (beats-per-minute)

Changes in the PPG amplitude (PPG-AMP)
> Fluctuations in finger-skin sympathetic tone
> Peripheral vasodilation / vasoconstriction

Main use of the PPG signal in fMRI







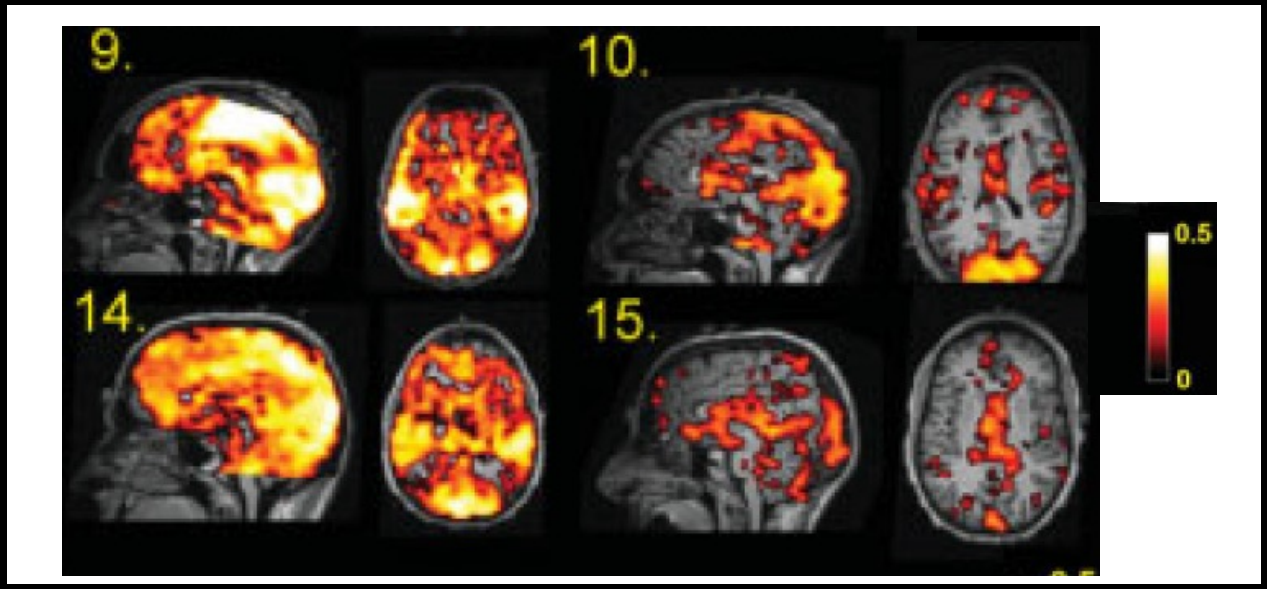
A photoplethysmogram (PPG) is an optically obtained plethysmogram that can be used to detect blood volume changes from the fingertip.

A PPG is often obtained by using a pulse oximeter which illuminates the skin and measures changes in light absorption.

> Heart rate variation (beats-per-minute)

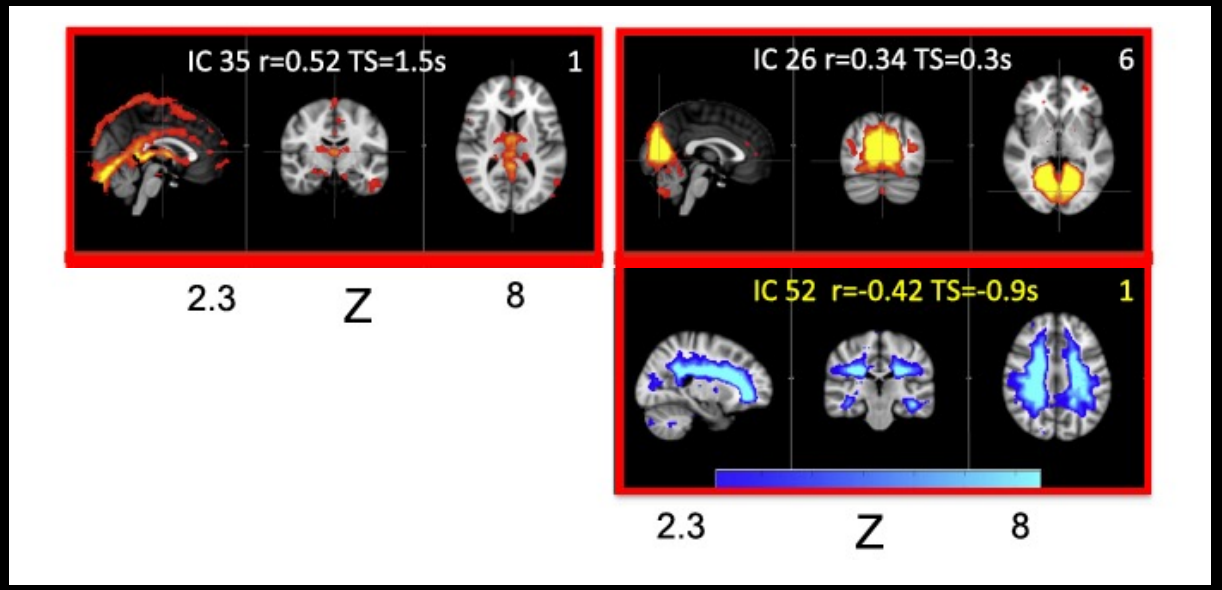
Changes in the PPG amplitude (PPG-AMP)
> Fluctuations in finger-skin sympathetic tone
> Peripheral vasodilation / vasoconstriction

fMRI studies used finger-skin vascular tone



(relax with eyes closed, 30 mins)

Houdt et al. 2016

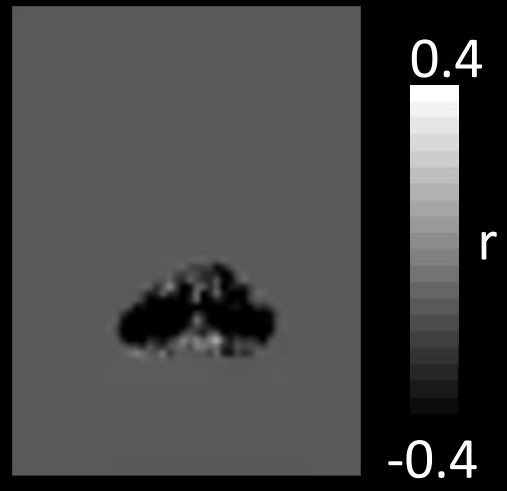


(lie quietly in the scanner and view a grey screen with a fixation point in the center, 10 mins)

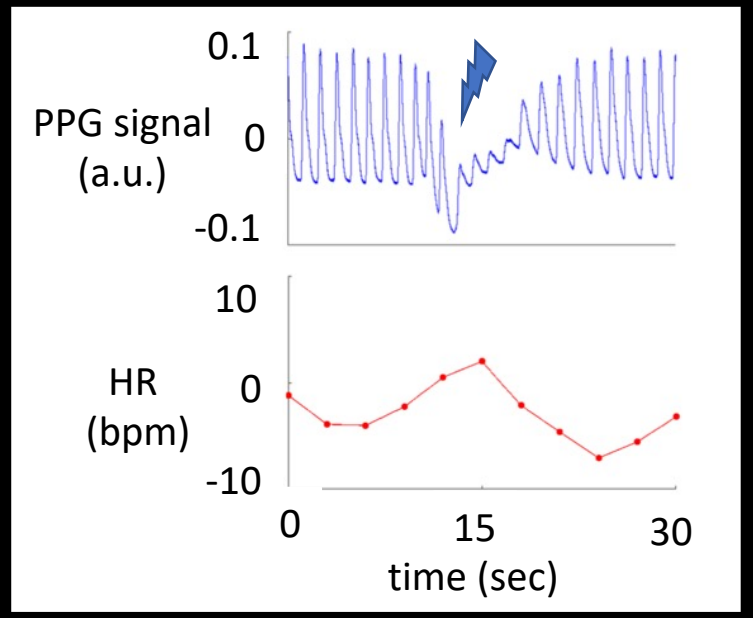
Tong et al. 2013

fMRI studies used finger-skin vascular tone

PPG-AMP & fMRI correlation



> During drowsiness and light sleep strong correlations across whole brain (Ozbay et al. 2018).



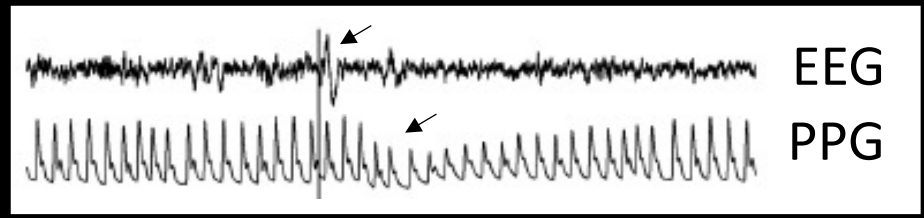
> Increases in sympathetic tone
> Peripheral vasoconstriction

- Mental state
  - Awake
  - Drowsy
  - Sleeping
  - Focus
  - Relaxed
  - Alert
  - Stress
  - Emotional ..

Variation in arousal state

- Systemic physiology
  - Sympathetic activity

Aim: understand the effects of sympathetic activity contributing to the fMRI signal with use of simultaneously acquired fMRI, EEG and PPG data during autonomic arousals.



Acoustic noise induced arousal during NREM sleep (Catcheside et al. 2002).

EEG/fMRI sleep study

Data selection was primarily based on isolated drops in PPG amplitude (PPG-AMP) during segments (5-8 mins) of NREM2 sleep (n=7).

fMRI

3T, TR=3s, TE=36ms, in-plane res=2.5 mm, slice thickness=2 mm, slice gap=0.5 mm, acceleration factor=2

Physiology

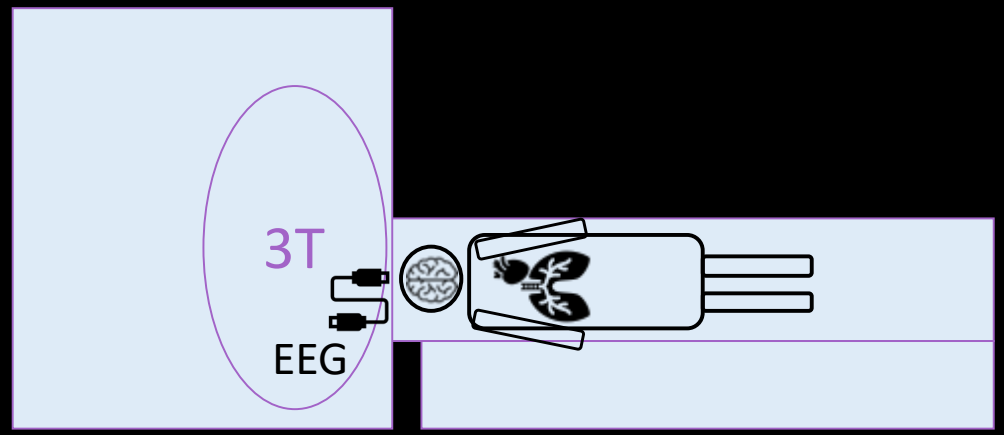
Respiratory bellow & pulse oximeter

(respiratory volume, heart-rate, PPG-AMP

EEG

64 channel

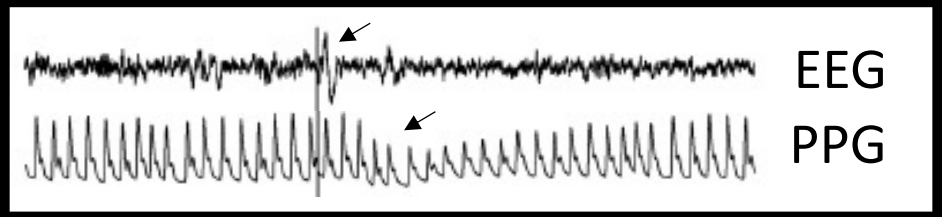
Manual sleep scoring **(**based on 30-s epochs)



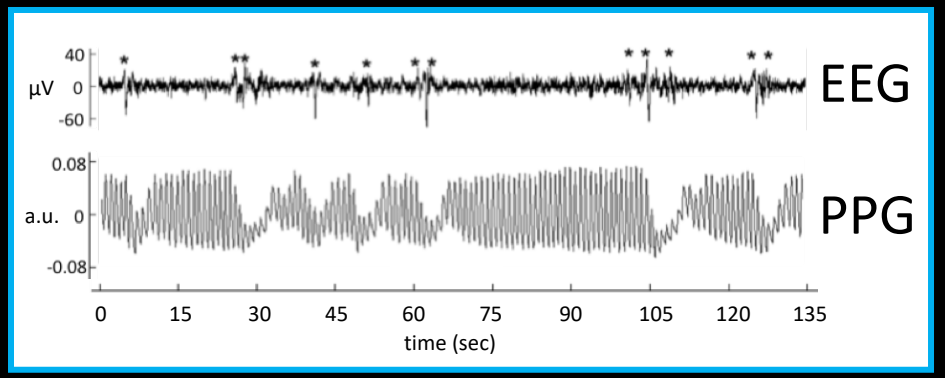
Moehlman et al. 2019

Signal (cor)relations

EEG & PPG

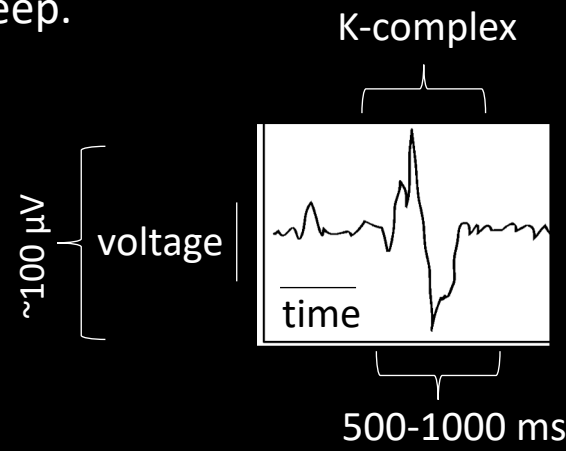


Acoustic noise induced arousal during NREM sleep (Catcheside et al. 2002).



We observed high co-occurrence of spontaneous subcortical arousals with episodic drops in finger-skin vascular tone during NREM2.

A K-complex (Kc), signature of sub-cortical arousal, is an EEG waveform that occurs primarily during stage 2 of NREM sleep.



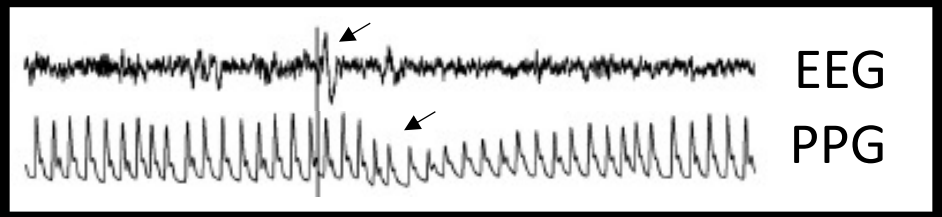
They have been closely associated with episodes of increased sympathetic activity (Colrain 2005).

Low frequency: ~ 0.5-2 Hz (Bastien et al. 2000).

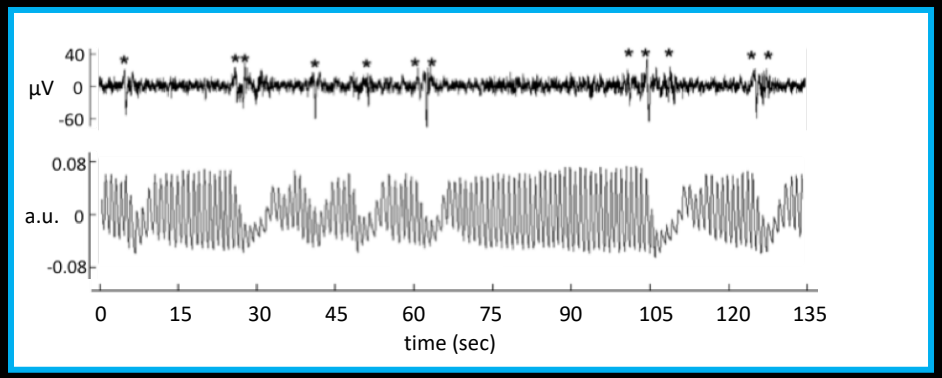
7 subjects
~200 Kcs (Combrisson et al. 2017)
~90 % match with PPG-AMP

Signal (cor)relations

EEG & PPG



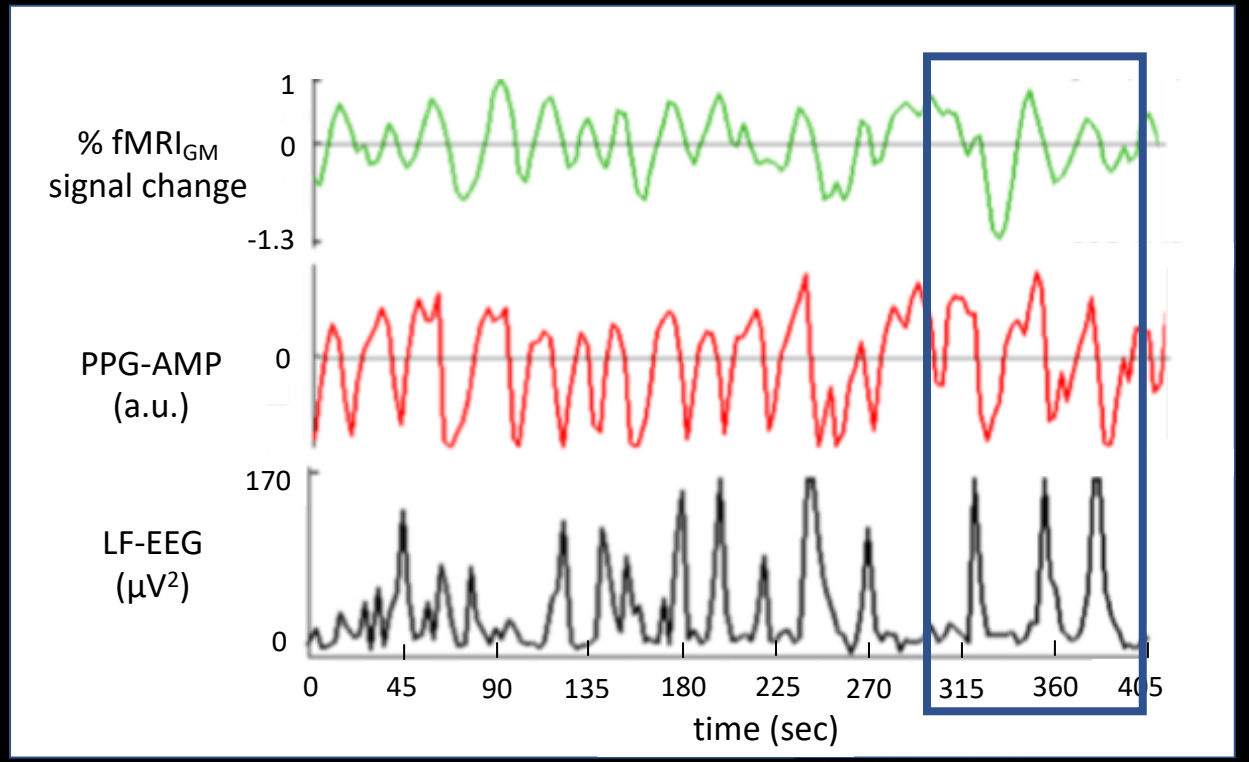
Acoustic noise induced arousal during NREM sleep (Catcheside et al. 2002).



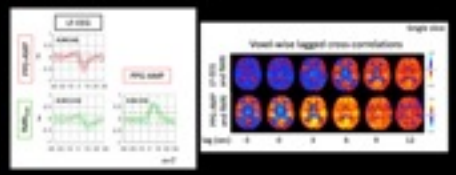
We observed high co-occurrence of spontaneous subcortical arousals with episodic drops in finger-skin vascular tone during NREM2.

EEG & PPG & fMRI

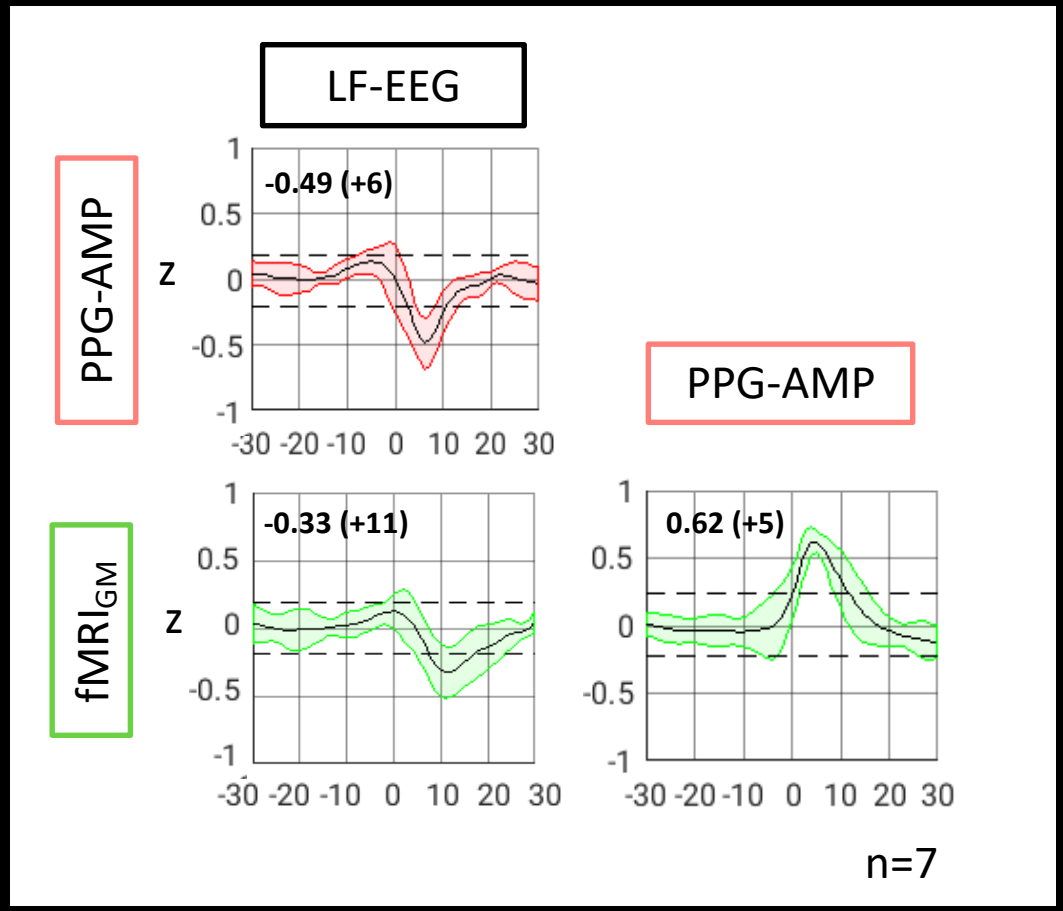
LF-EEG: low frequency (0.5-2Hz) EEG power
PPG-AMP: PPG amplitude
$fMRI_{GM}$: fMRI in whole brain grey matter (GM)

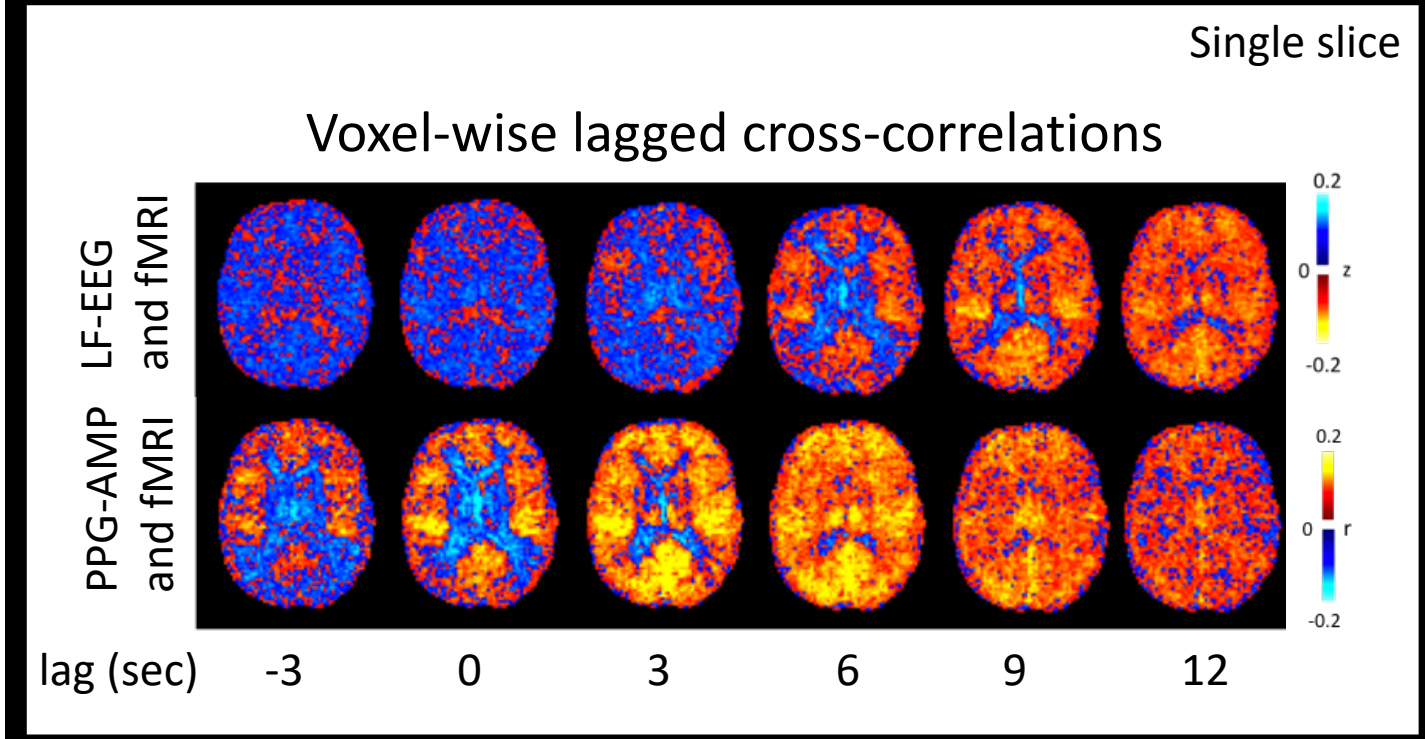


Lagged cross-correlations

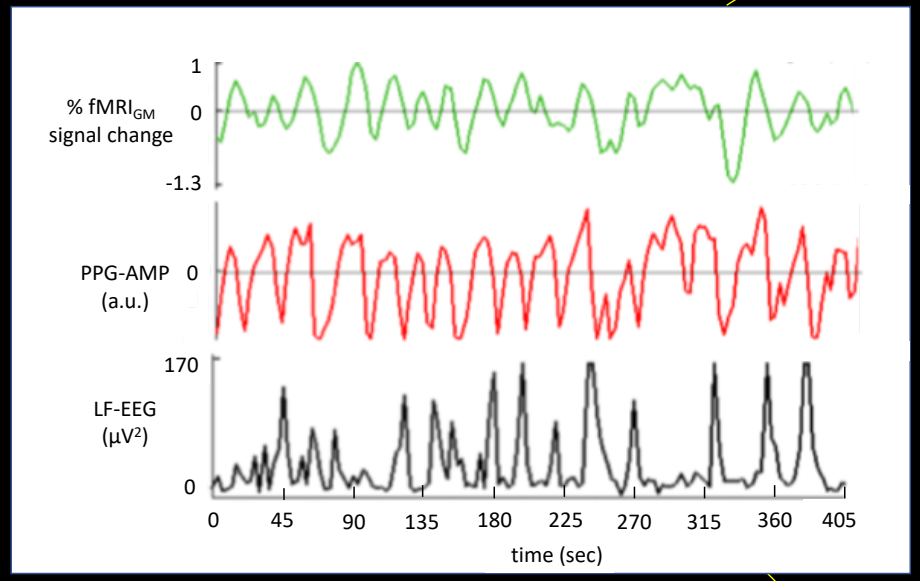


Lagged cross-correlations

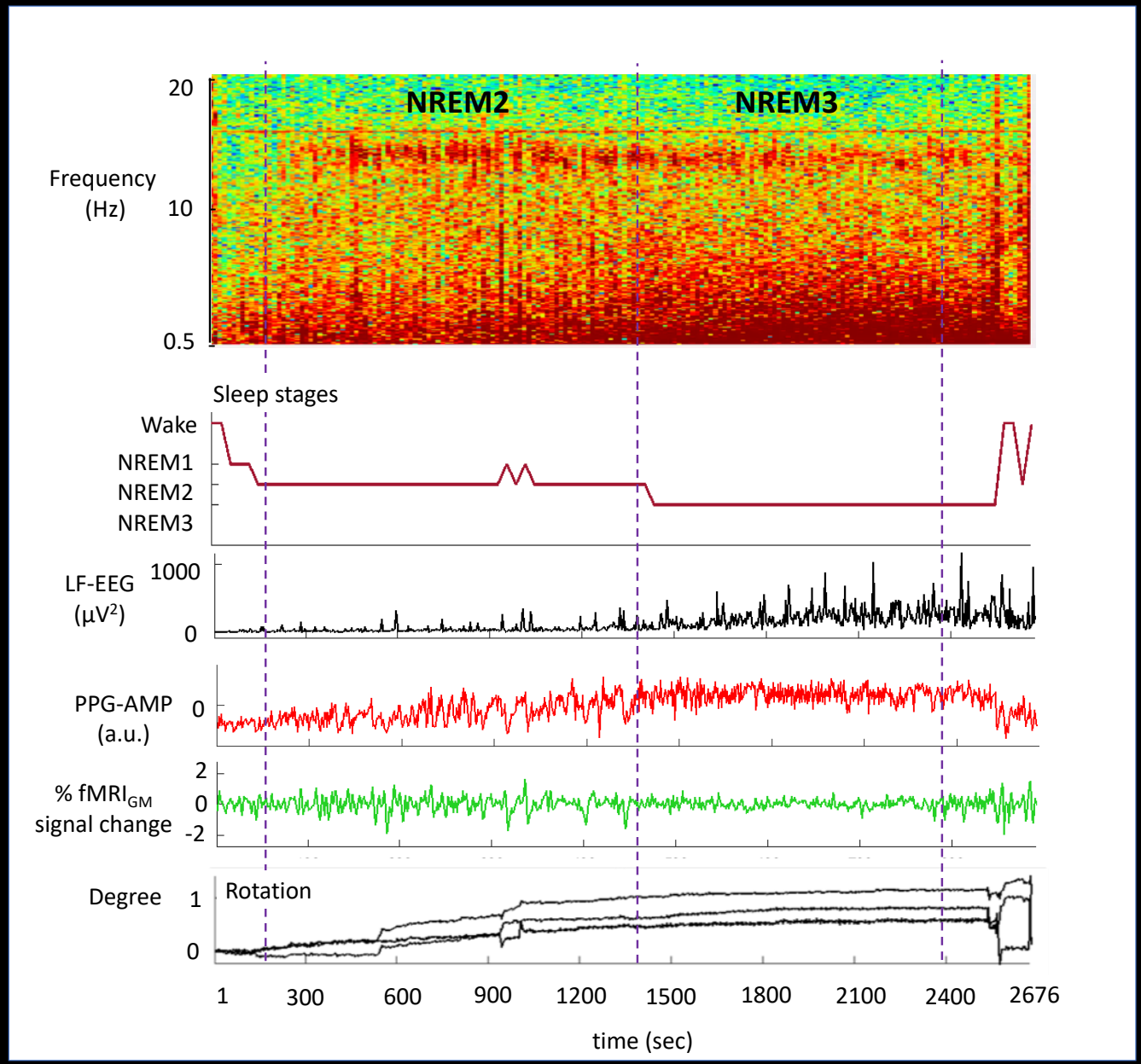




EEG & PPG & fMRI



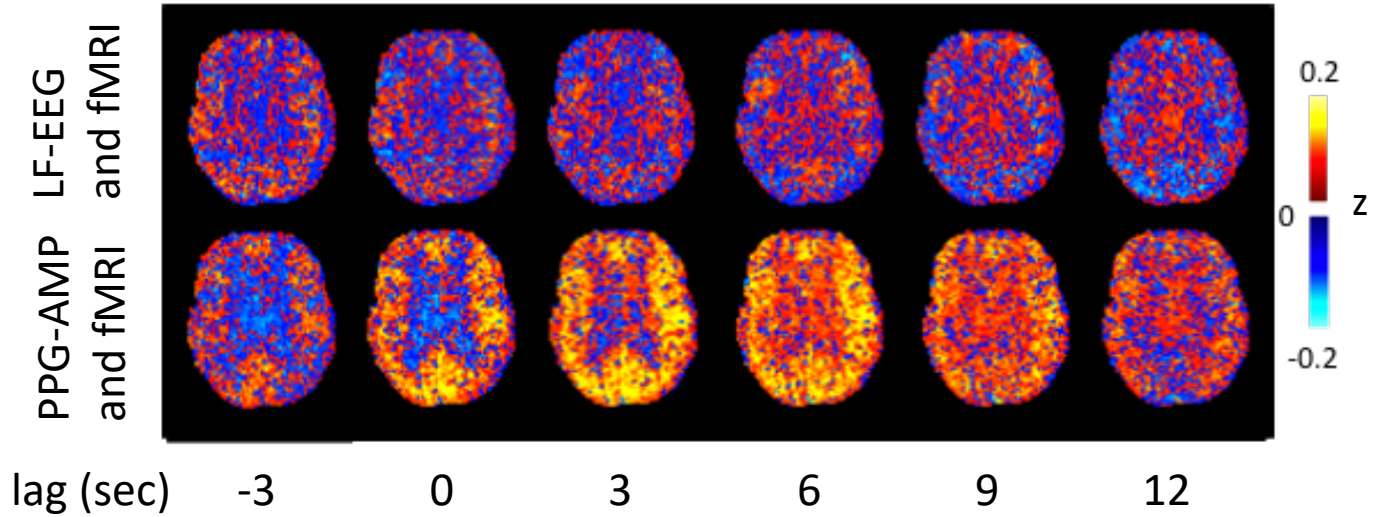
NREM2



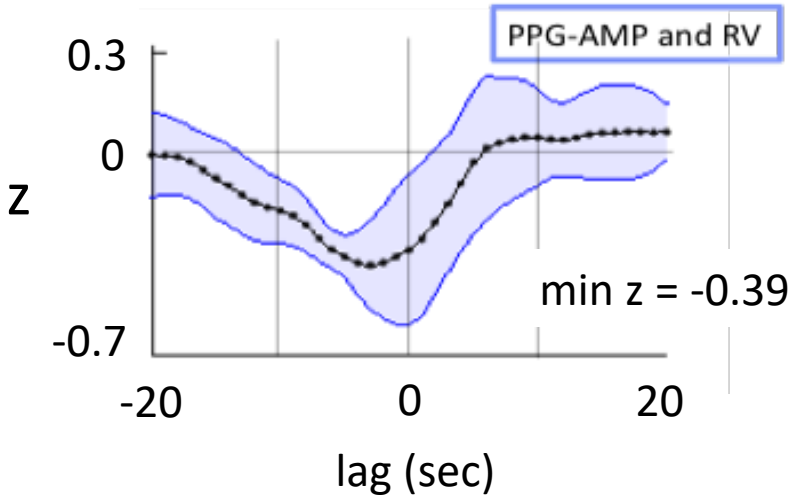
Fluctuations in sympathetic tone are not exclusive to NREM2 sleep

Wake

Voxel-wise lagged cross-correlations



Lagged cross-correlations



Sleep scored (W=>80%, NREM1<20%), each 5 mins', n=4

Fluctuations in sympathetic tone are not exclusive to NREM2 sleep

> Errors in mental task performance showed a trend toward larger pupils (Critchley 2009).

> Painful stimulation correlated with the task induced deactivation (Maihöfner et al. 2011).

> Finger vasoconstriction was observed after deep inspiration (Gilliatt 1948).

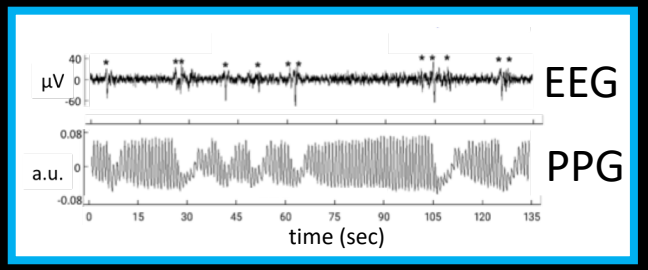
Conclusions

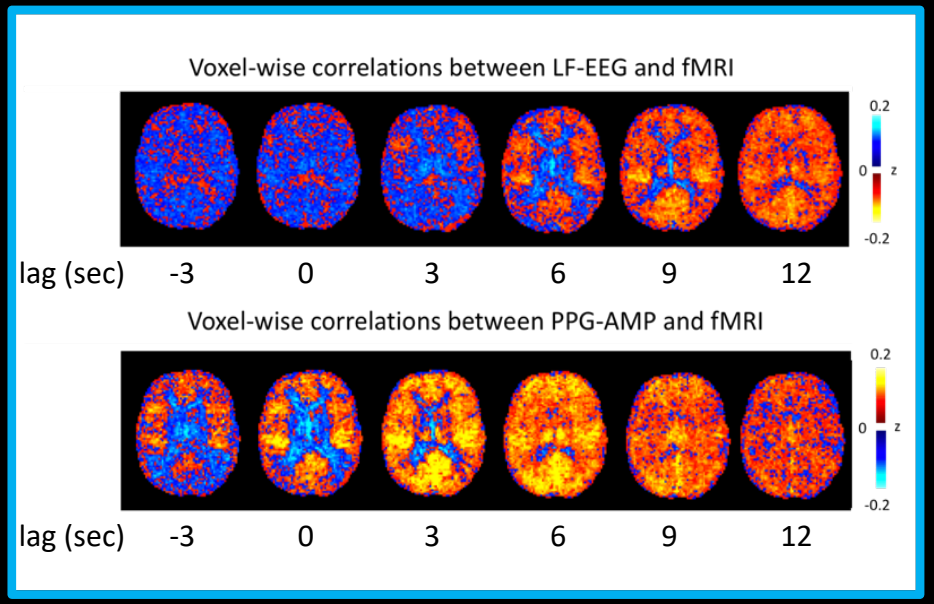
> Evidence for a contribution of the sympathetic activity to the fMRI

> High temporal coincidence of K-complexes and transient drops in the PPG-AMP as well as the fMRI signal during sub-cortical arousal changes

> *Large variations in fMRI global signal during sleep and wakefulness, signal reductions observed with task changes*

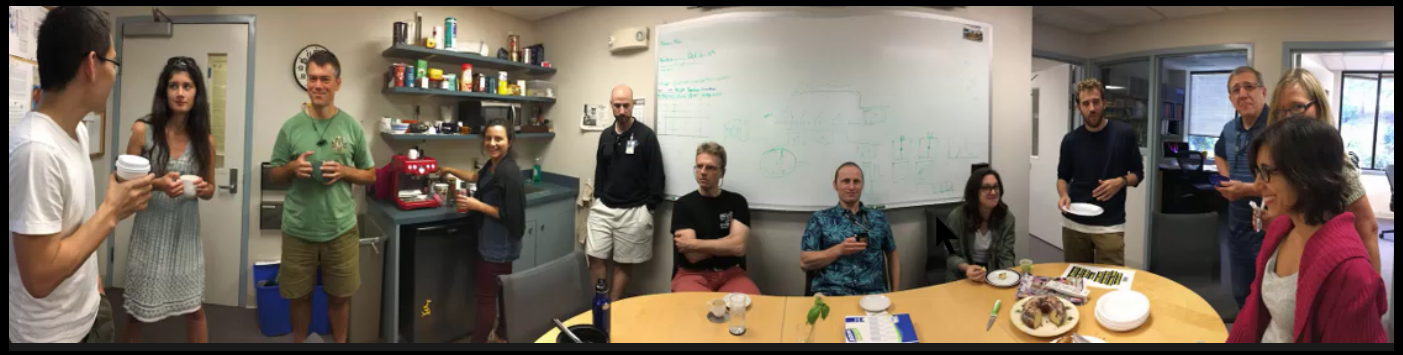
> Close integration of brain stem systems that regulate sympathetic nervous activity and intracortical neuronal activity: separation of these two sources of fMRI activity is challenging and will require further research.





THANKS !

Jeff H Duyn
Dante Picchioni
Catie Chang
Hendrik Mandelkow
Jacco A de Zwart
Peter van Gelderen
Miranda G Chappel-Farley
Thomas M. Moehlman
..



National Institute of Neurological Disorders and Stroke