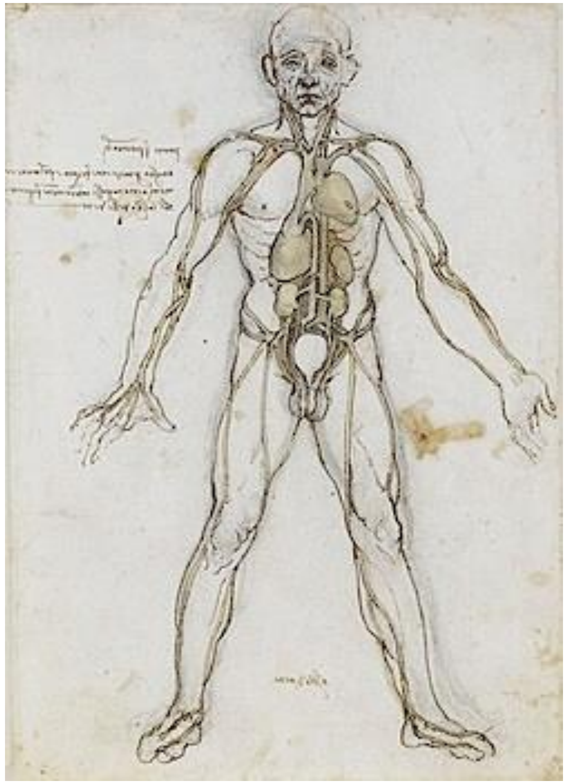


The use of Peripheral Measures in fMRI

08/06/26 Burak Akin

SFIM

What is happening inside brain?

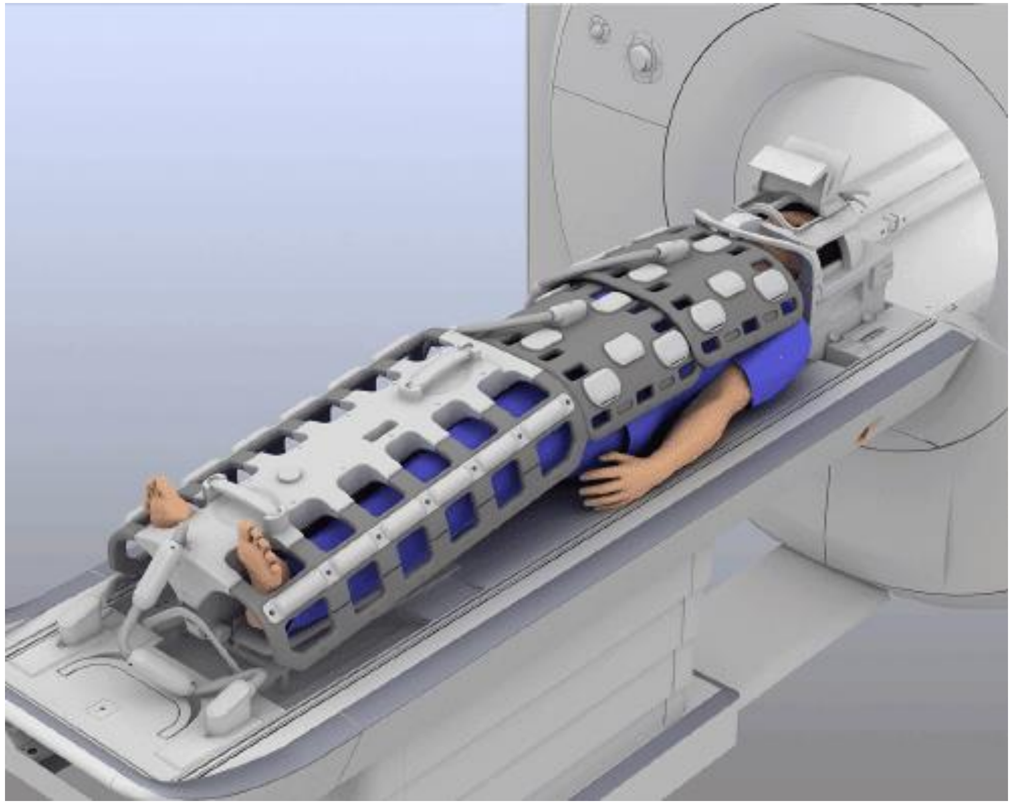
Historically, everything outside the head was considered either

- nuisance,
- confound,
- or unrelated.

Maybe the right question is what is happening inside brain-body system?

Why don't we scan whole body?

There are several impracticalities…



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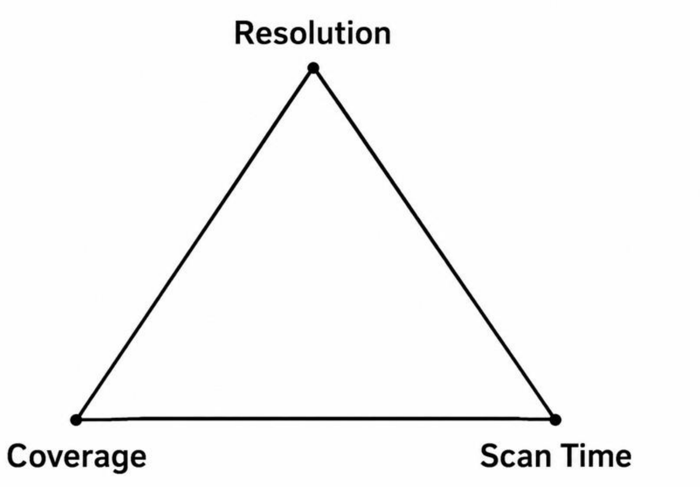
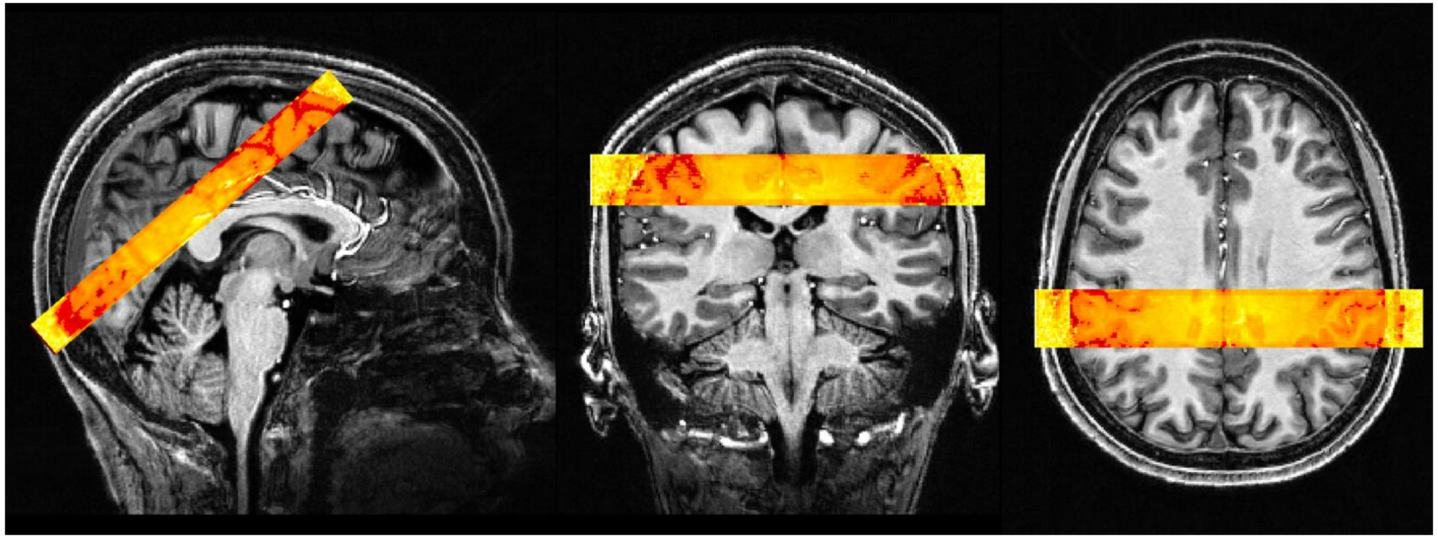
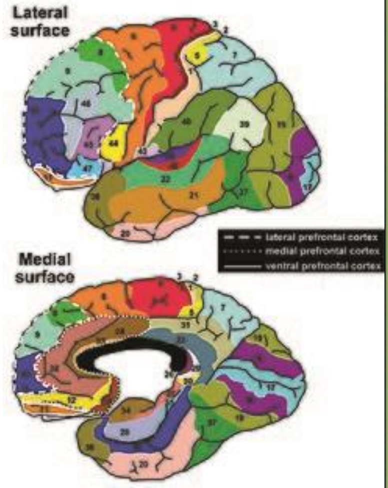
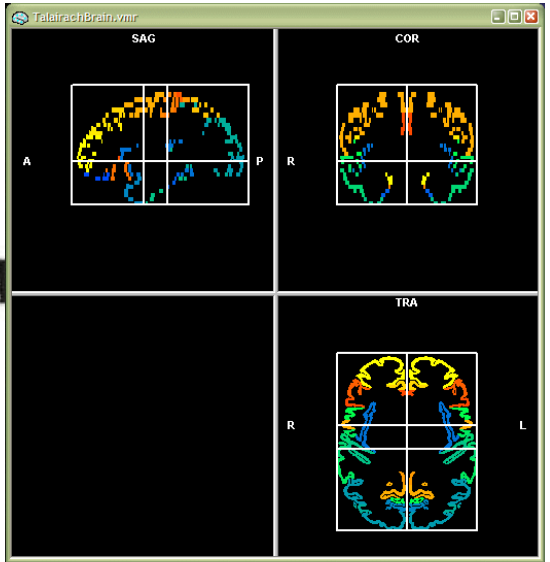
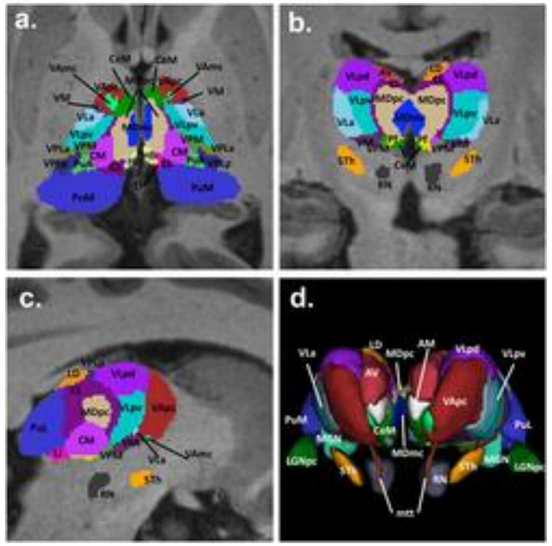
Scanner limitations…

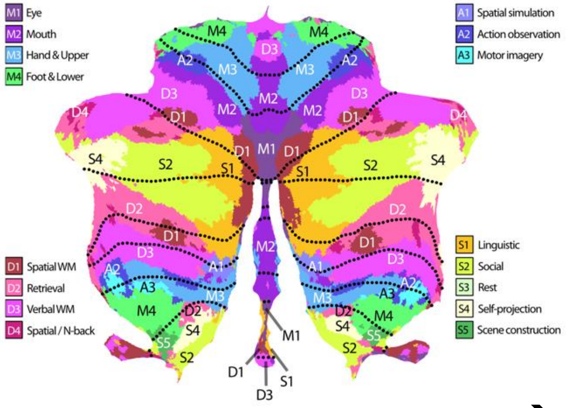












History of atlases →

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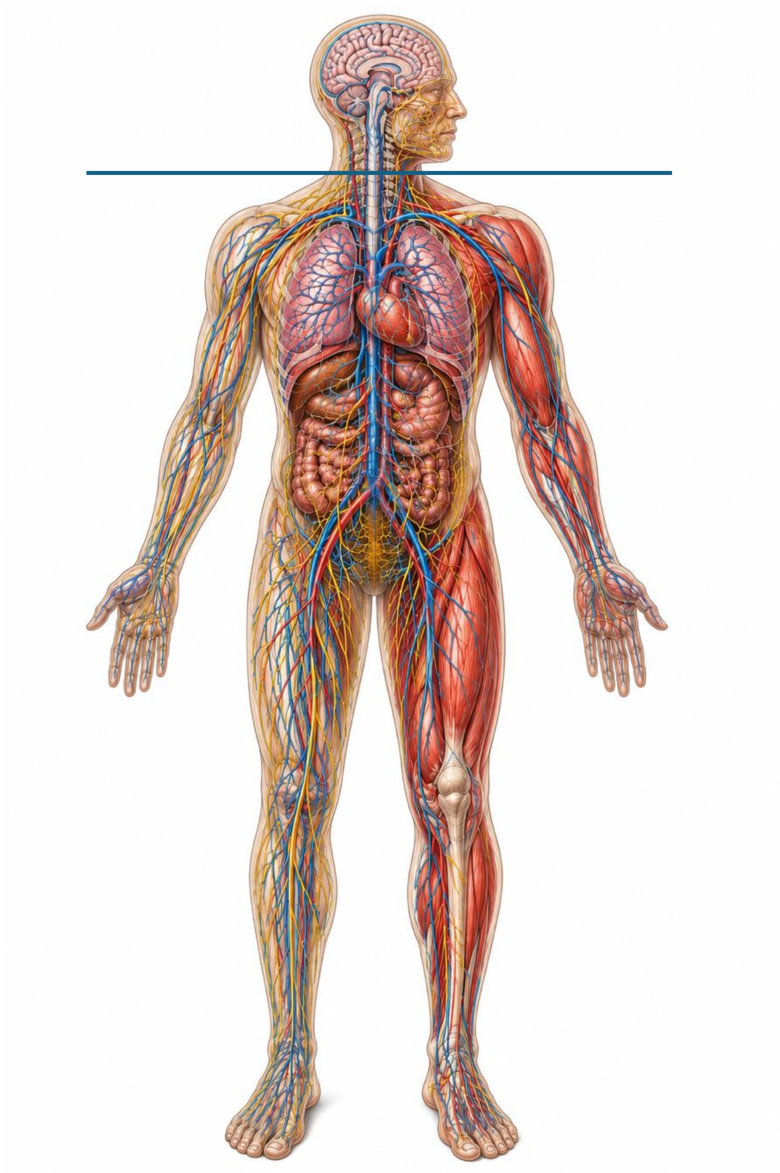
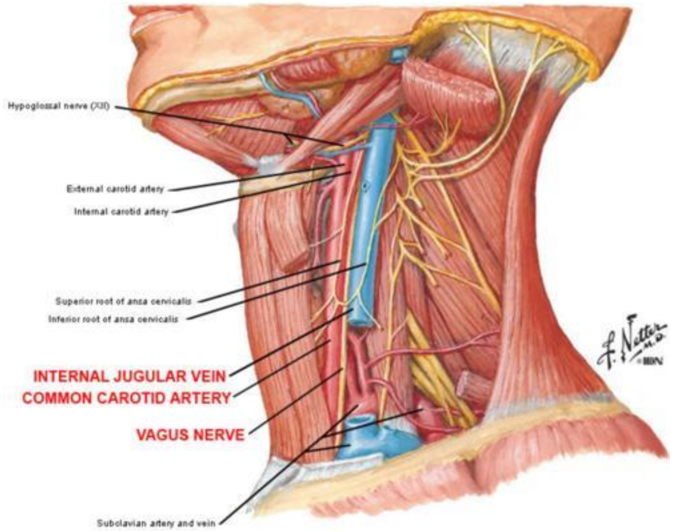
Brain-Body interactions (Arteries and Veins)





Carotid artery
- Blood Pressure
- Pulse Wave
- Perfusion

Jugular vein
- Venous Drainage
- Venous Pulsatility
- BOLD Susceptibility

Trachea
- Respiration • CO_2

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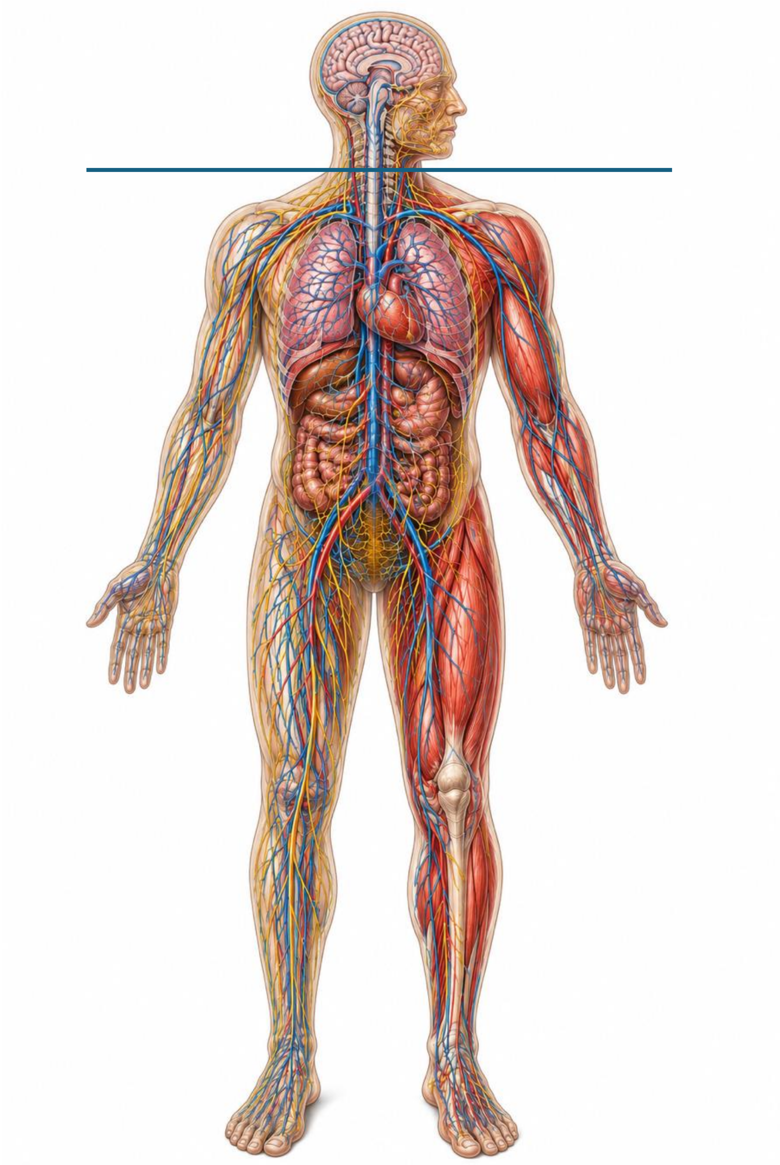
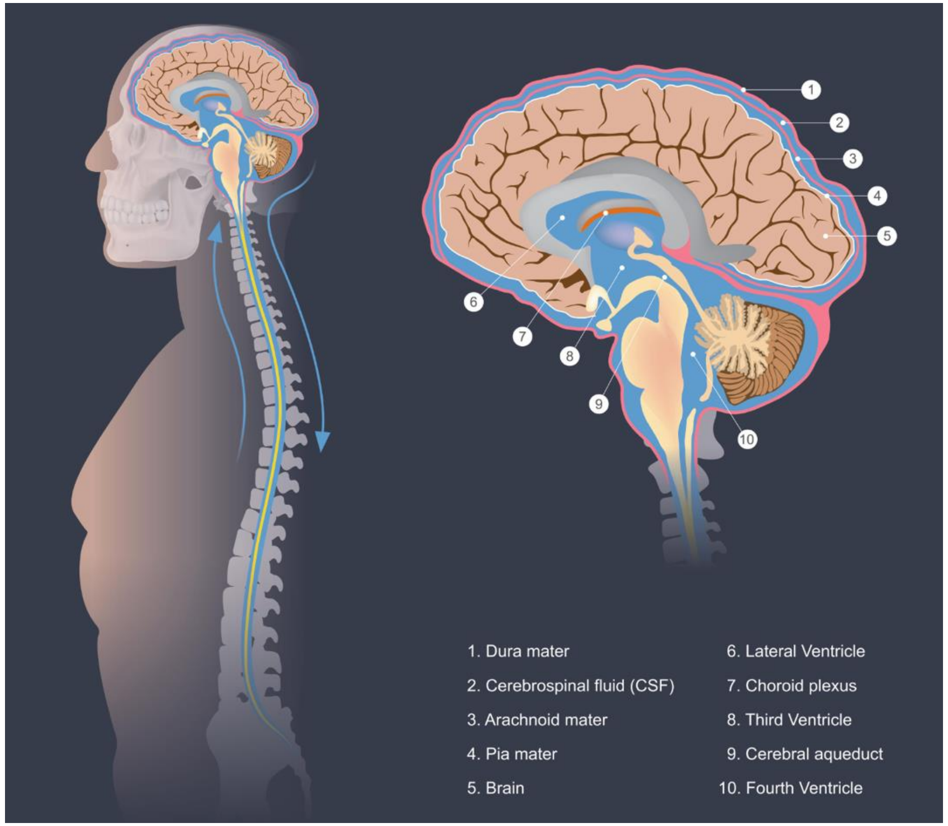
Brain-Body interactions (Cerebrospinal Fluid)



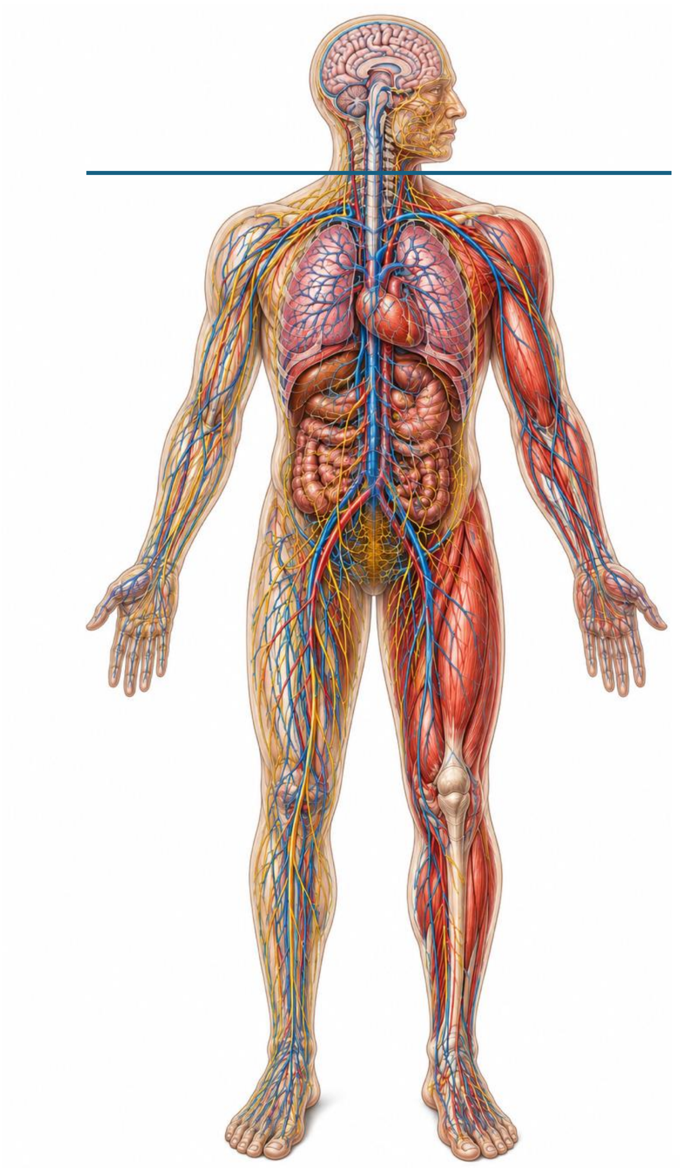


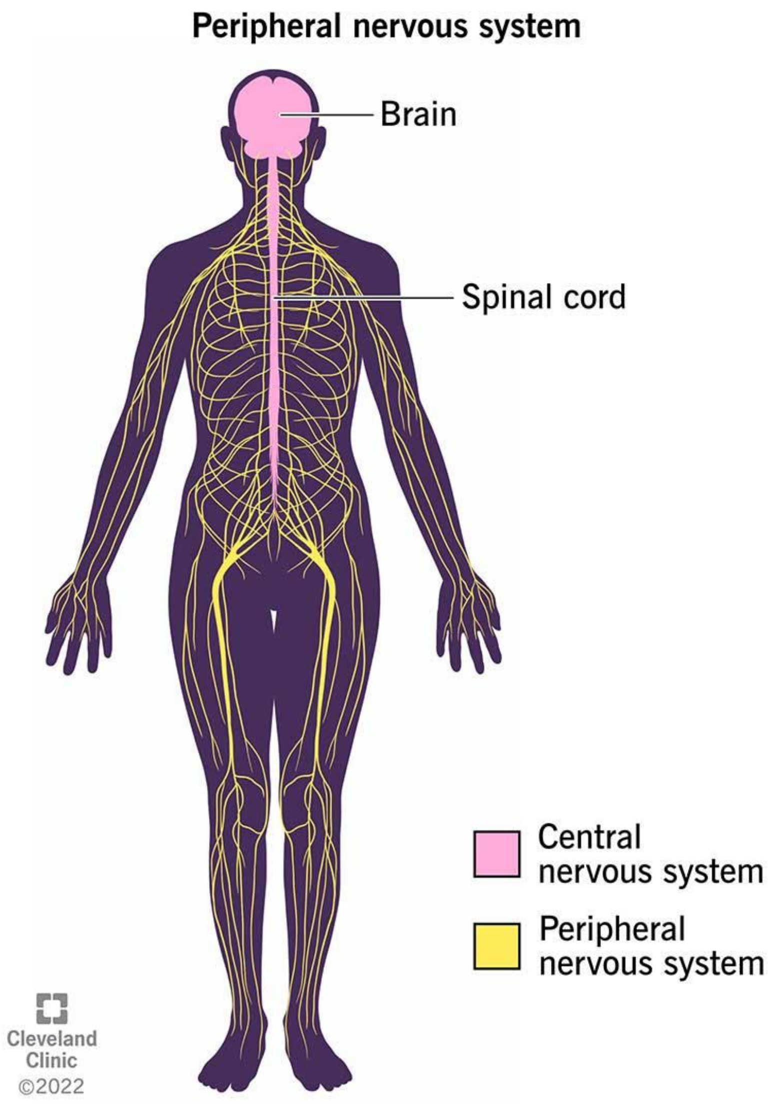
- Spinal CSF
- CSF Oscillations
- Brain Motion
- Glymphatic Flow

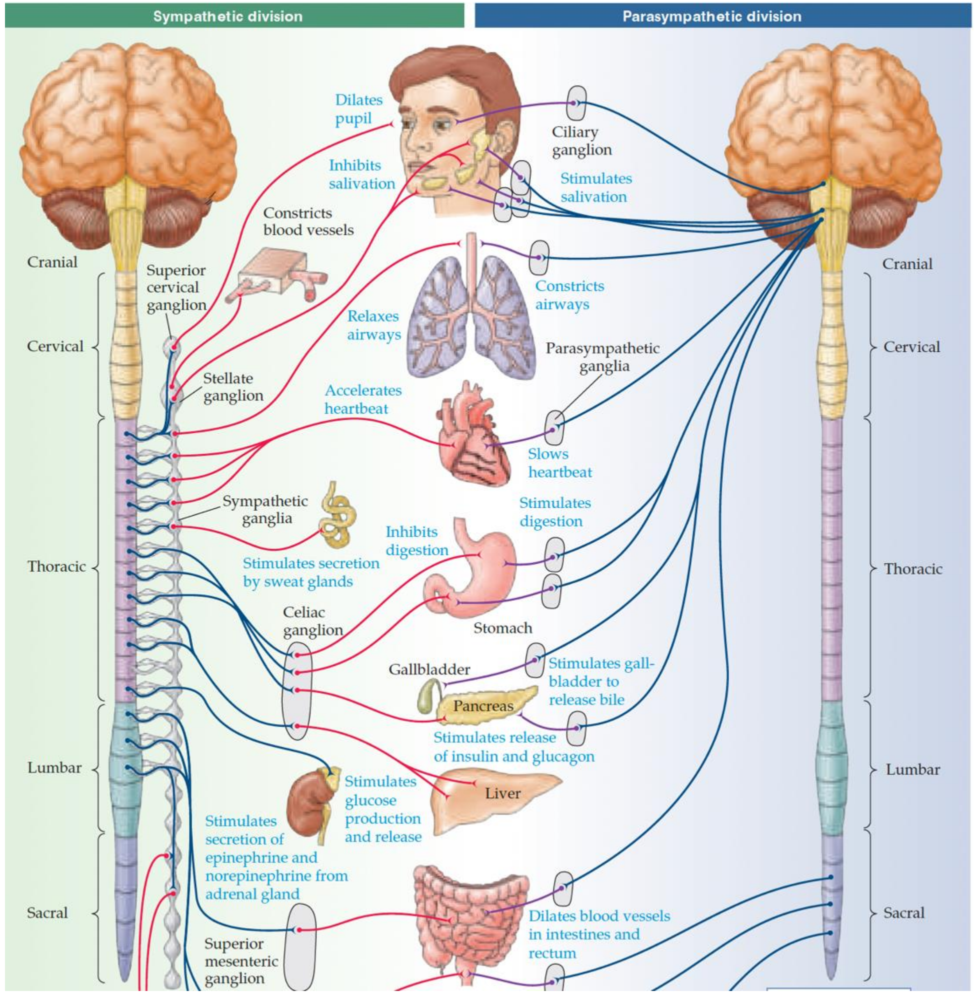
The Glymphatic System – A Beginner's Guide

Nadia Aalling Jessen [1,1], Anne Sofie Finmann Munk [1,1], Iben Lundgaard [1,1], Maiken Nedergaard [1]

Brain-Body interactions

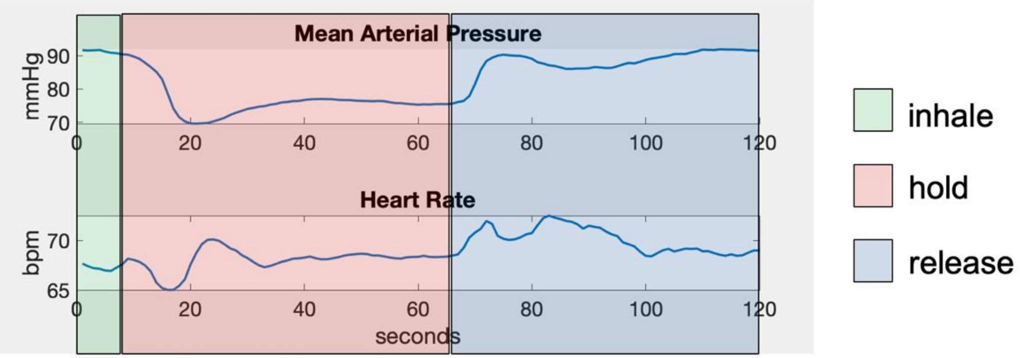




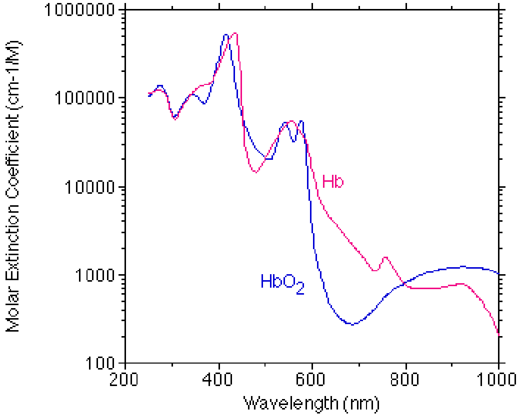


How to measure peripheral signals?

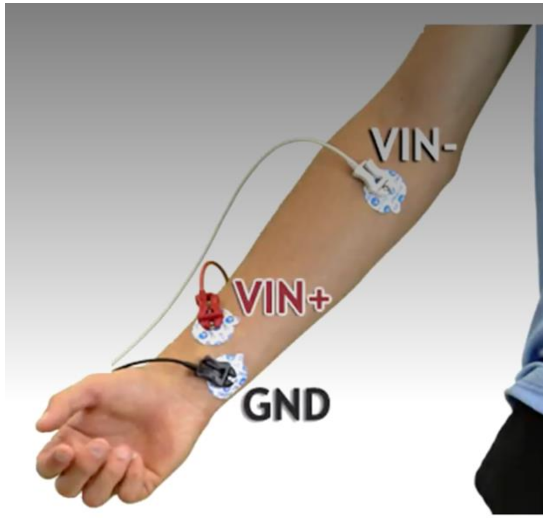
Blood Pressure Monitor (Caretaker)



NIRS finger probe (Artinis)



EMG monitor

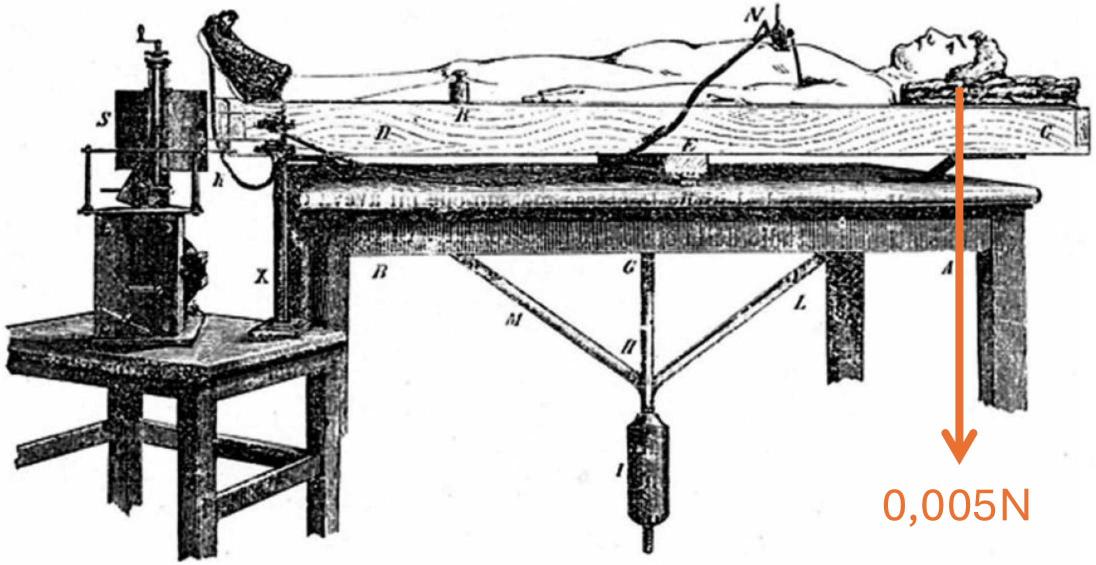


Pressure Pad

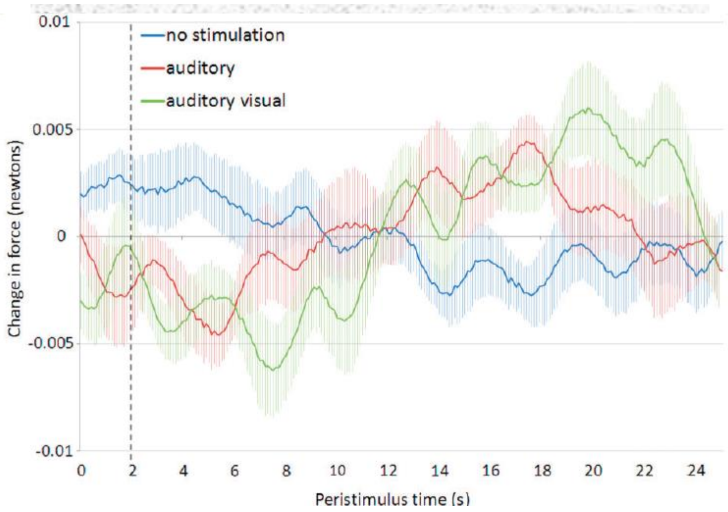
The man who weighed thoughts

Early cerebral blood flow(CBF) measurements

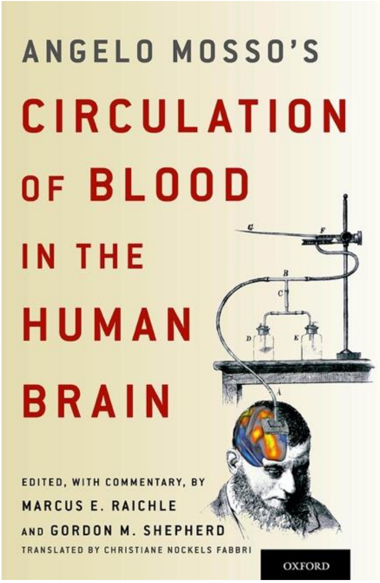
Angelo Mosso (1846 -1910)



0,005N



Field et.al 2014



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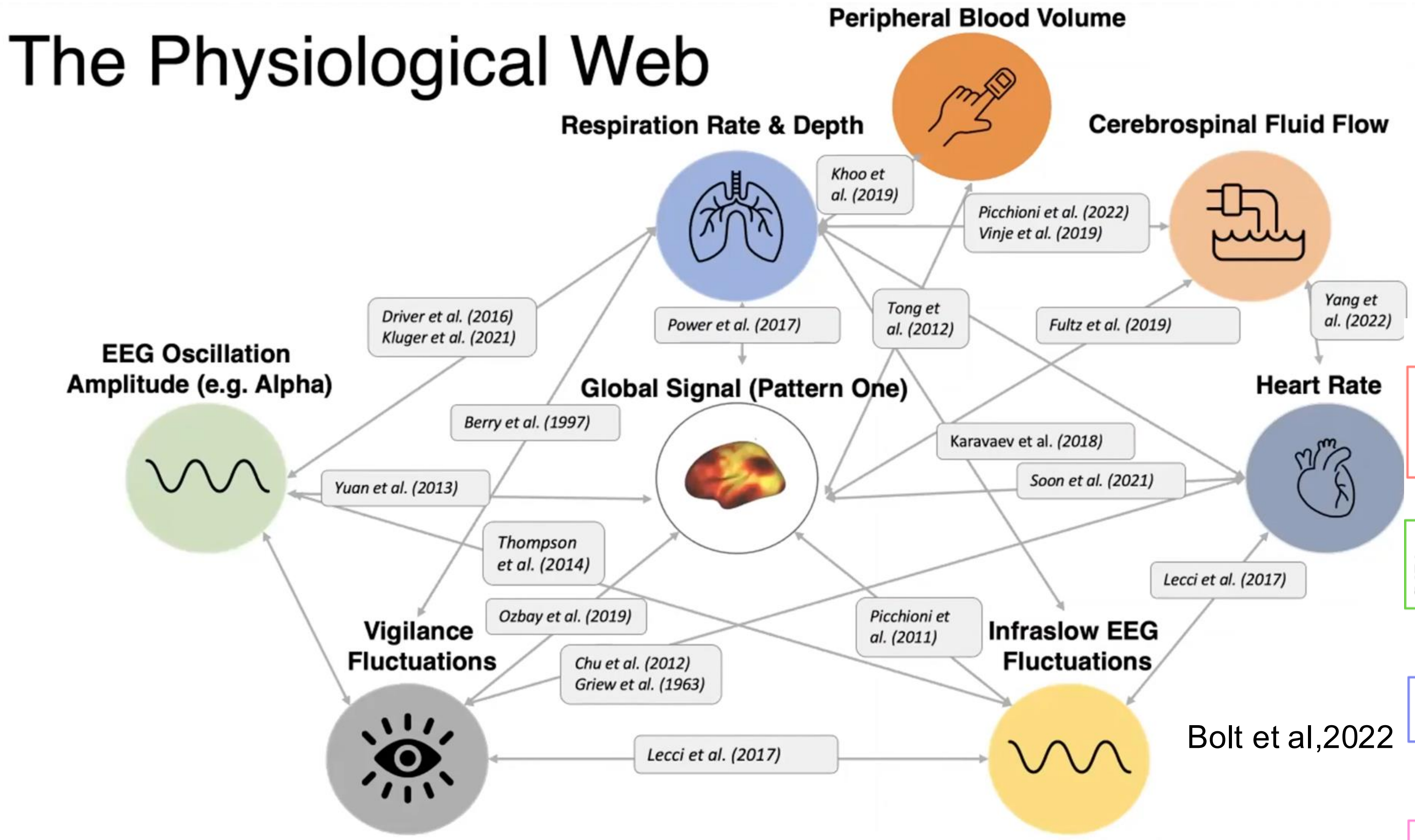
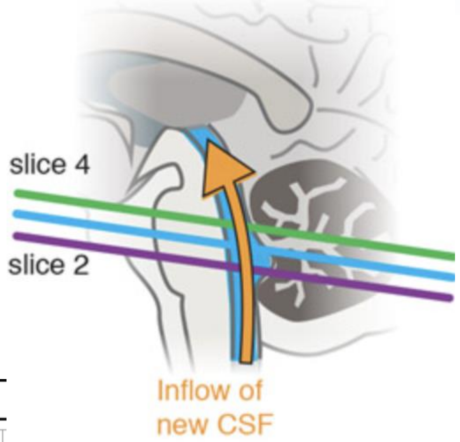
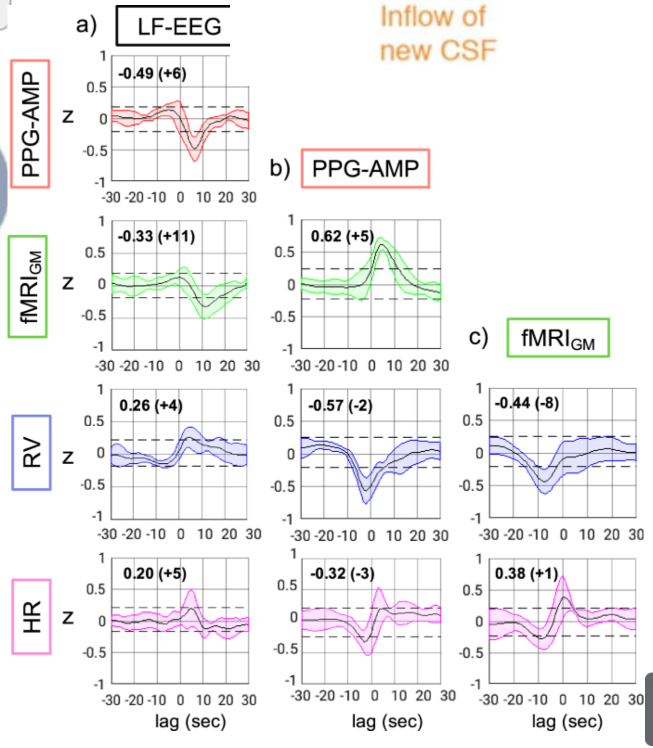
Physiology …

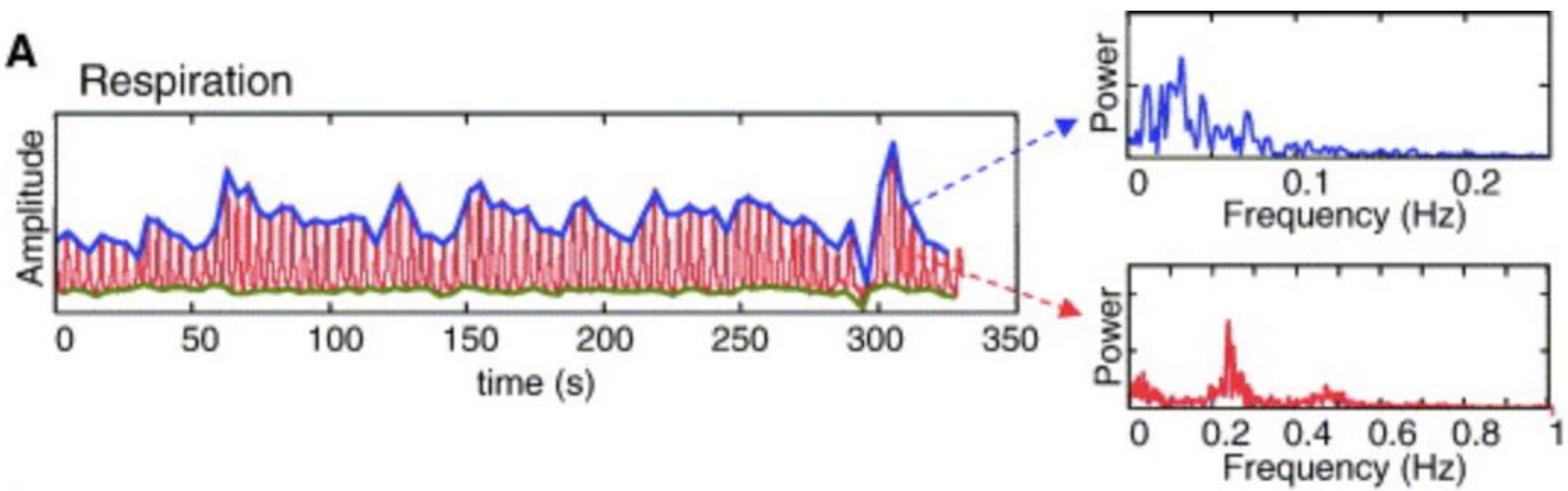


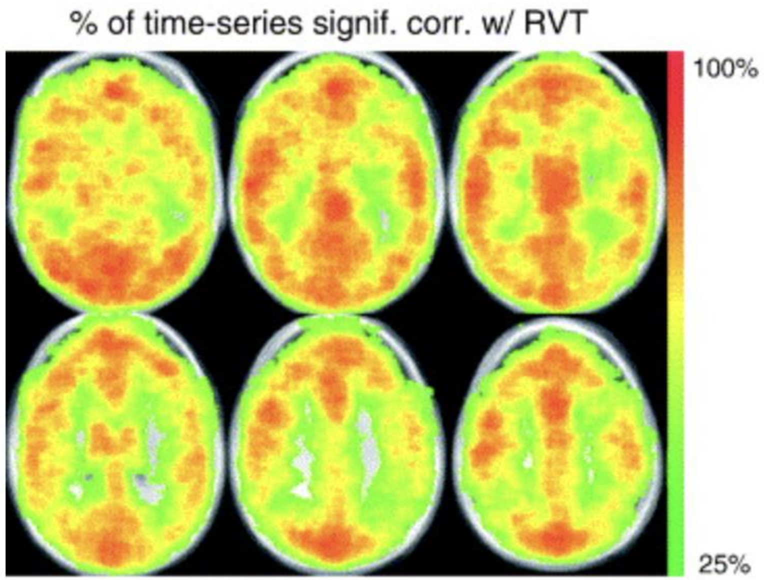
Bolt et al,2022

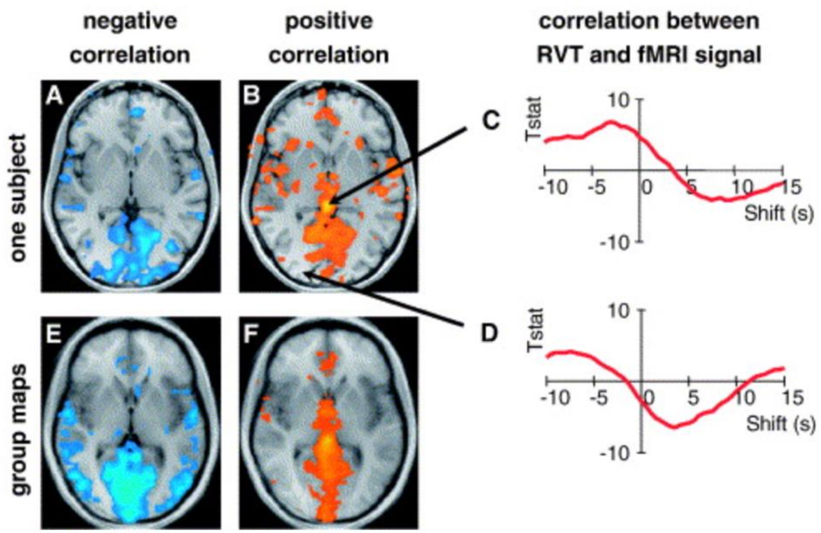




Respiration changes



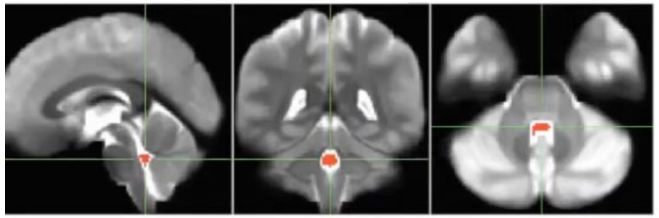




Including these respiration fluctuations as regressors in the analysis, however, should be done with caution in cases where the breathing pattern is likely to vary in synchrony with the task

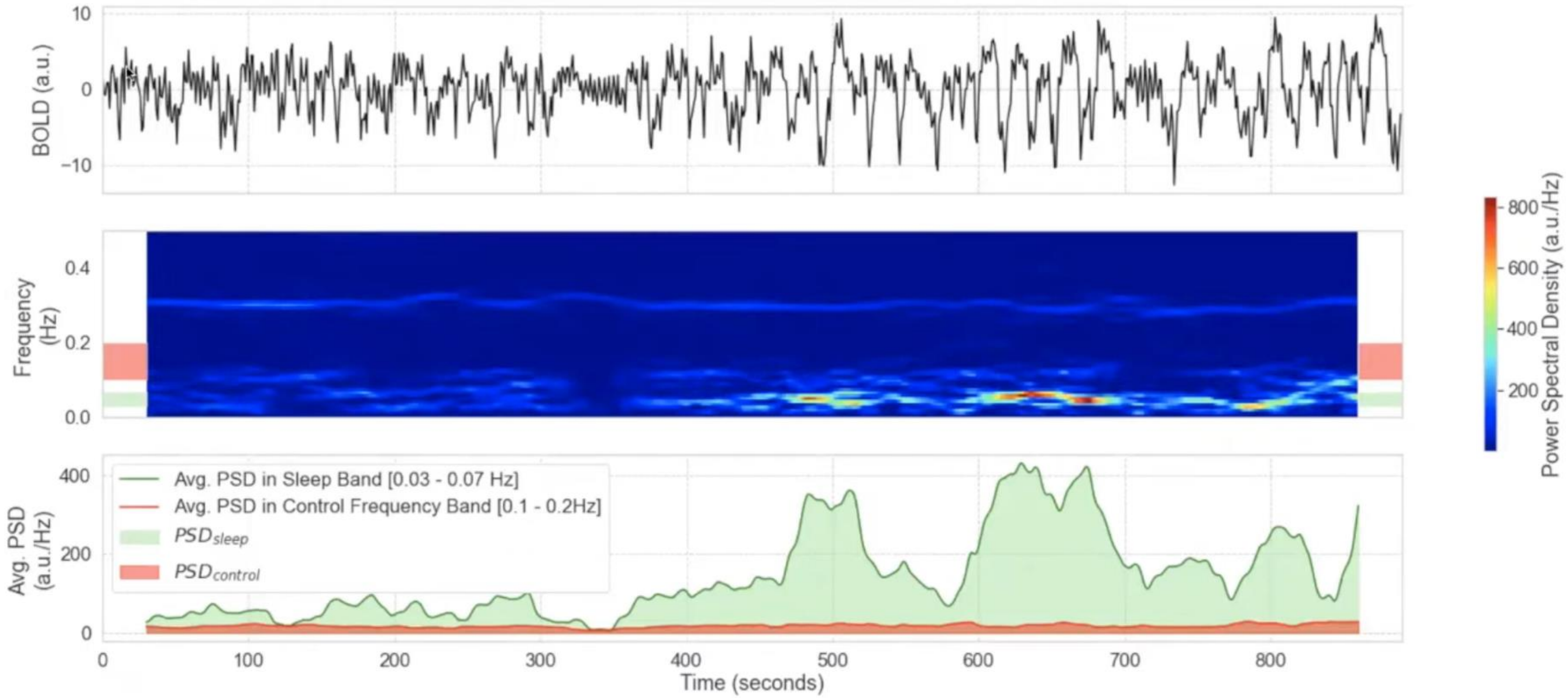
Rasmus Birn 2006

4th Ventricle coupling



Global changes with arousal

Power around 0.05 Hz in 4th Ventricle



J. Gonzalez-Castillo, I. Fernandez, D.A. Handwerker, P.A. Bandettini, Ultra-slow fMRI fluctuations in the fourth ventricle as a marker of drowsiness, NeuroImage 259, 119424 (2022)

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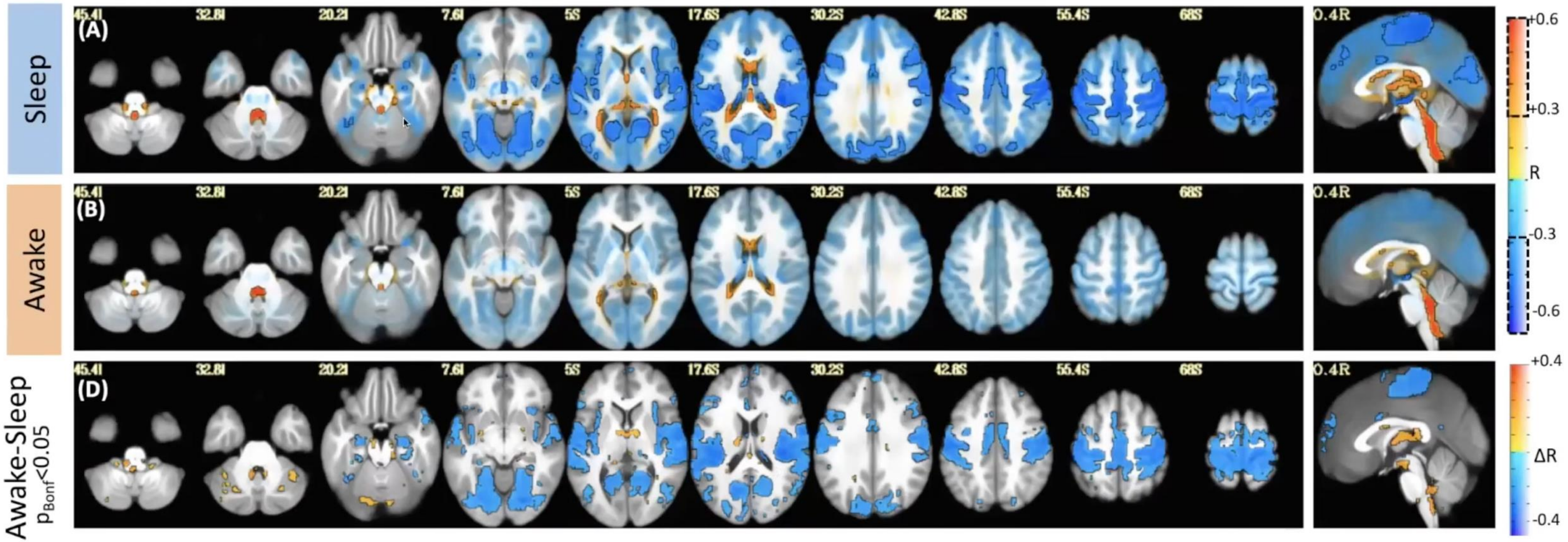

J. Gonzalez-Castillo, I. Fernandez, D.A. Handwerker, P.A. Bandettini, Ultra-slow fMRI fluctuations in the fourth ventricle as a marker of drowsiness, NeuroImage 259, 119424 (2022)

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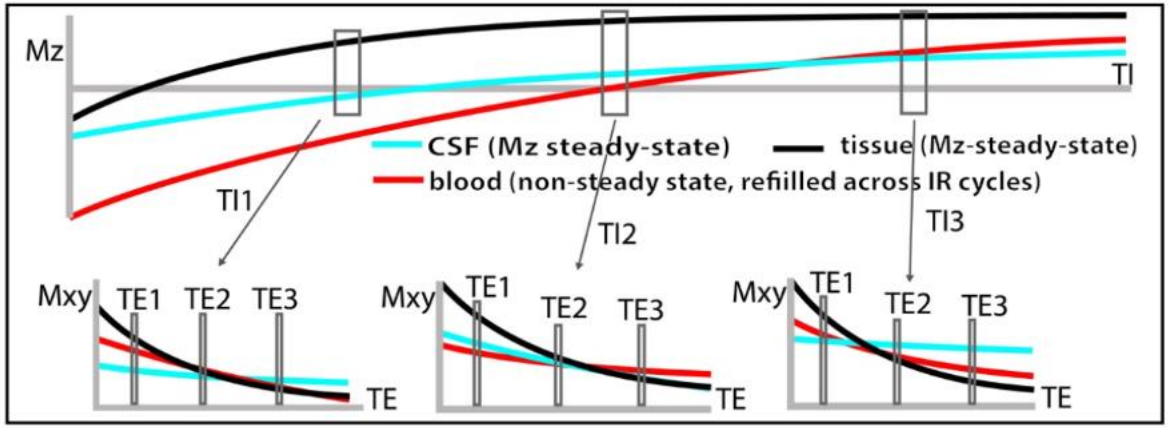
Breath hold task with Multi-Echo Multi Inversion

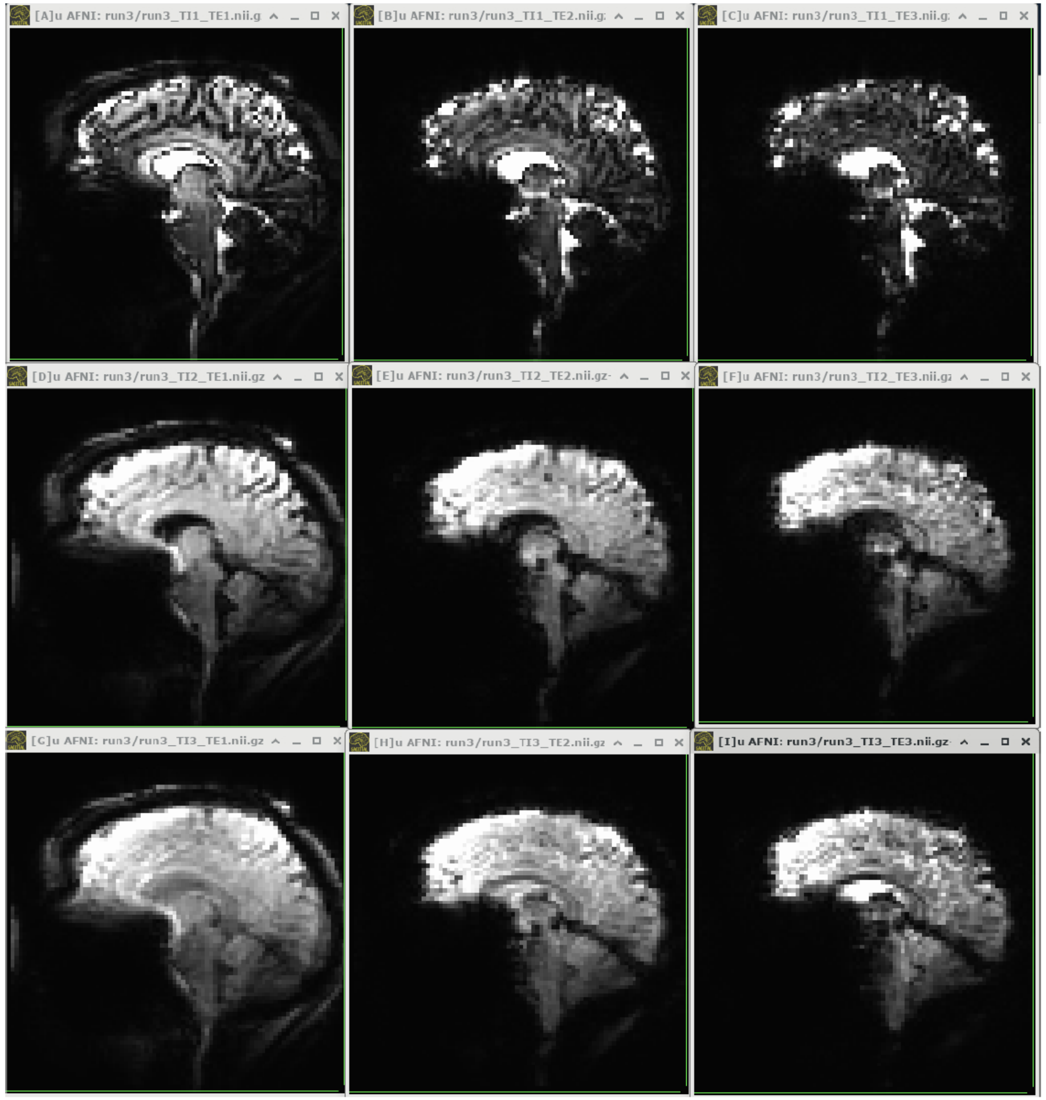


TE=8ms TE=30ms TE=52ms

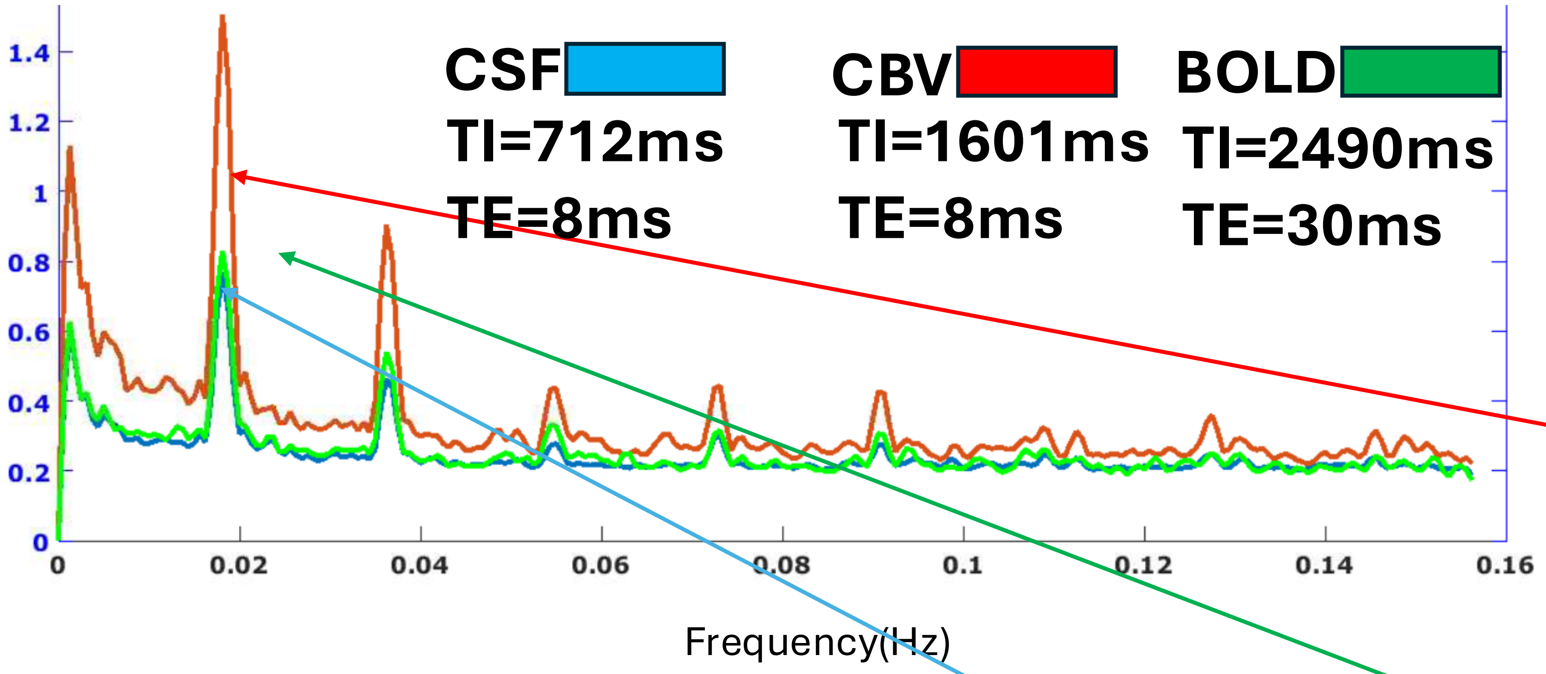
TI=712ms

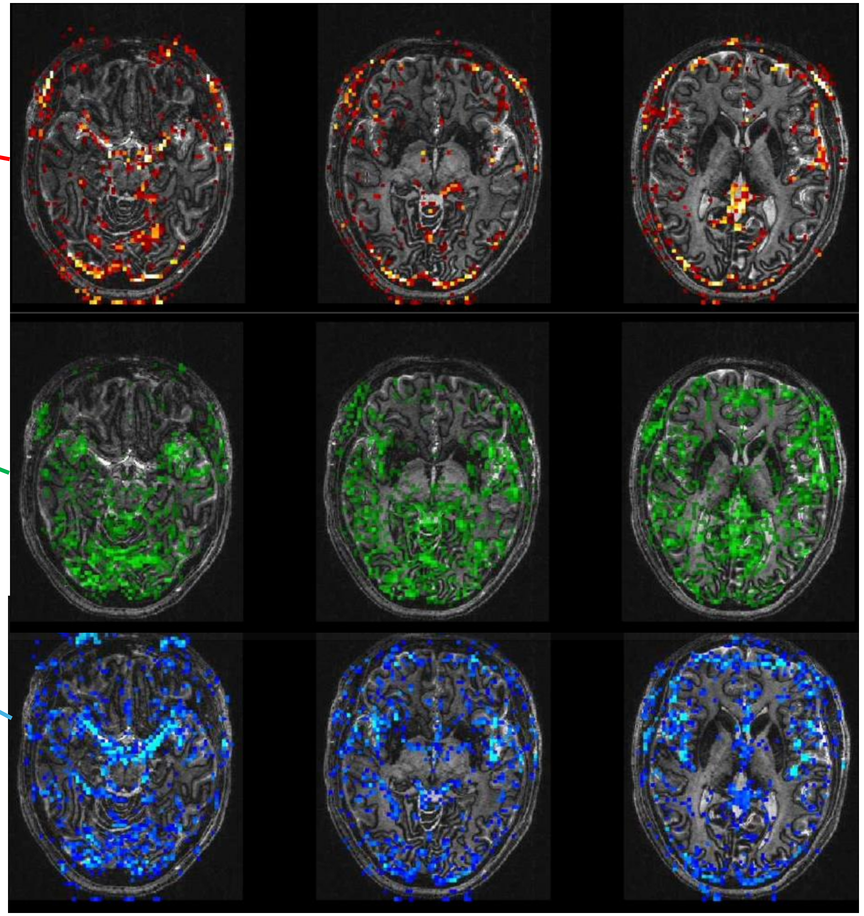
TI=1601ms

TI=2490ms



Breath hold task with Multi-Echo Multi Inversion



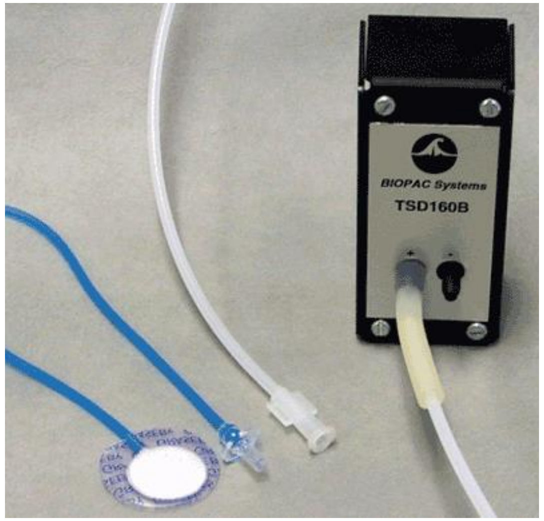


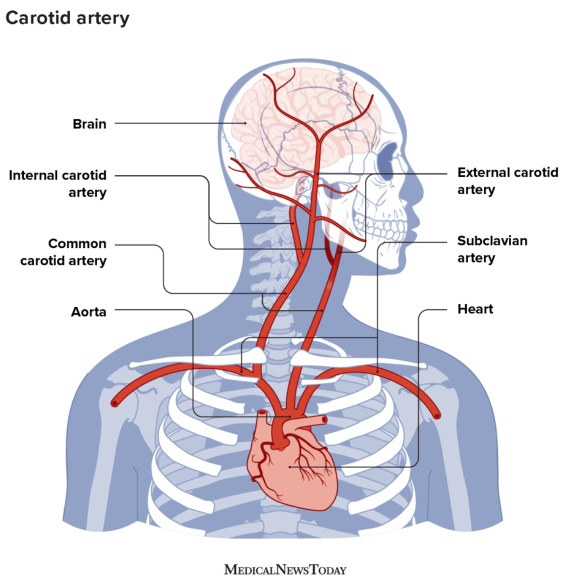
Power in the bin

0.018Hz(55sec)

2sec fixation
5sec inspiration
15sec hold
3sec expiration
30 sec free breathing

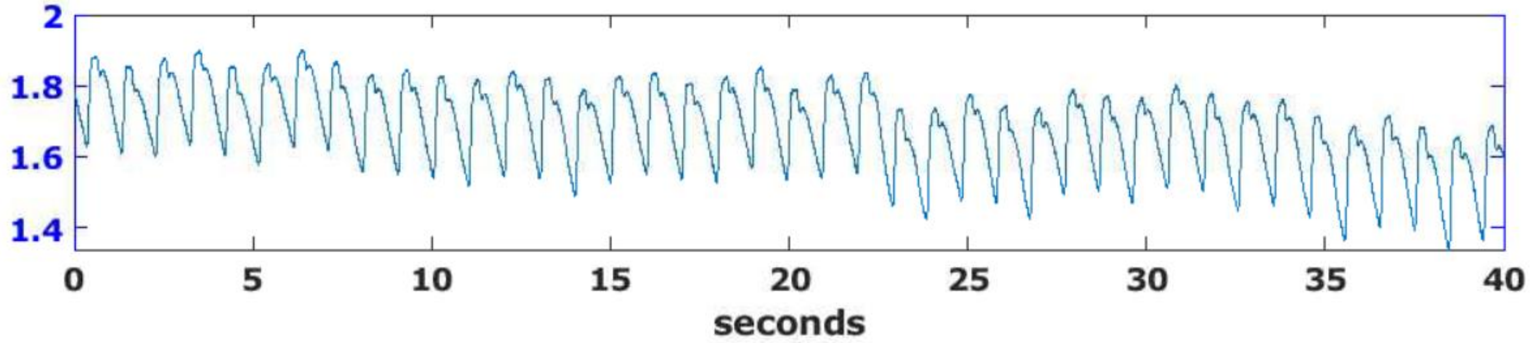
MRI compatible – Pressure pad



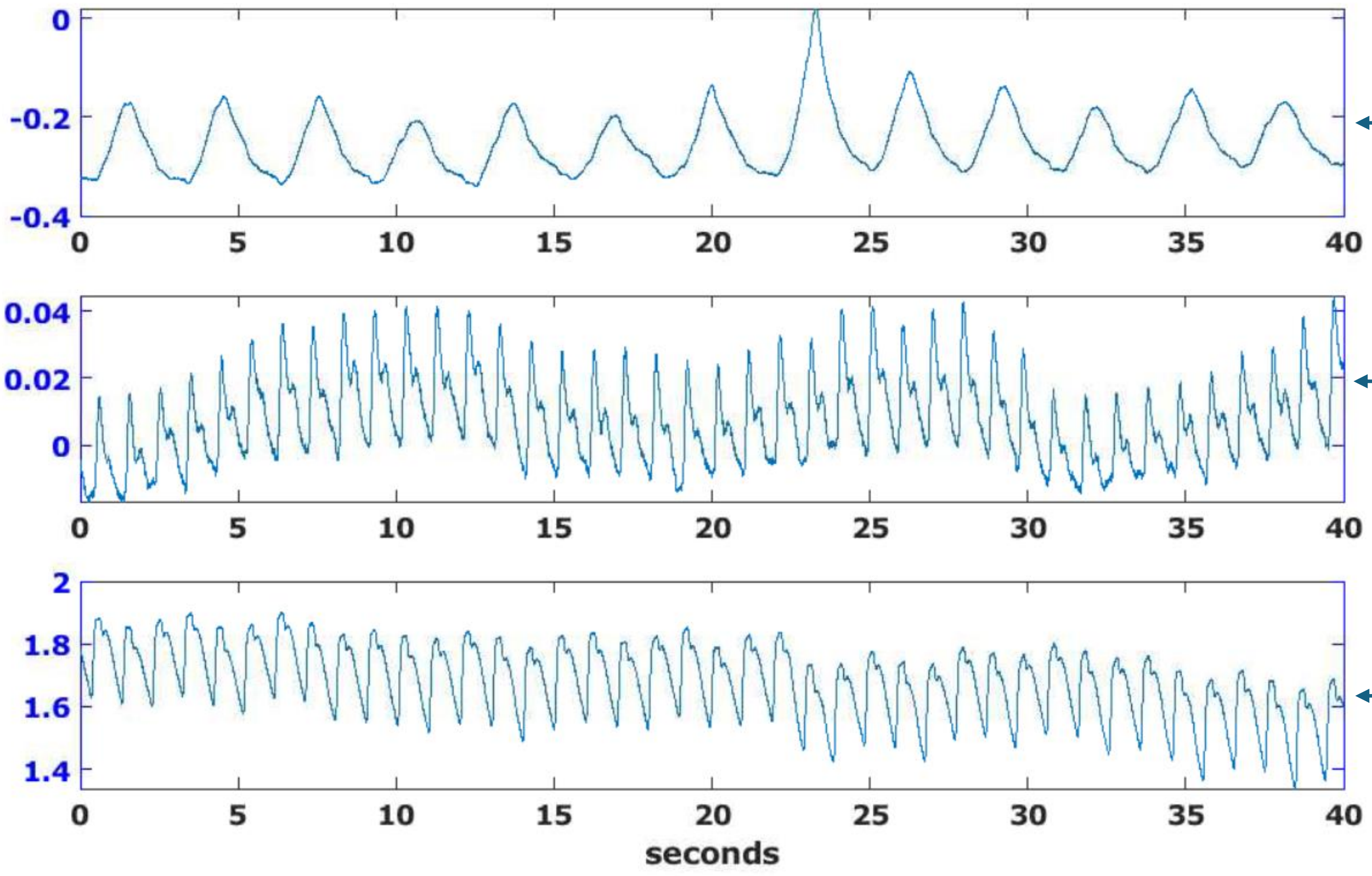


placed on carotid artery

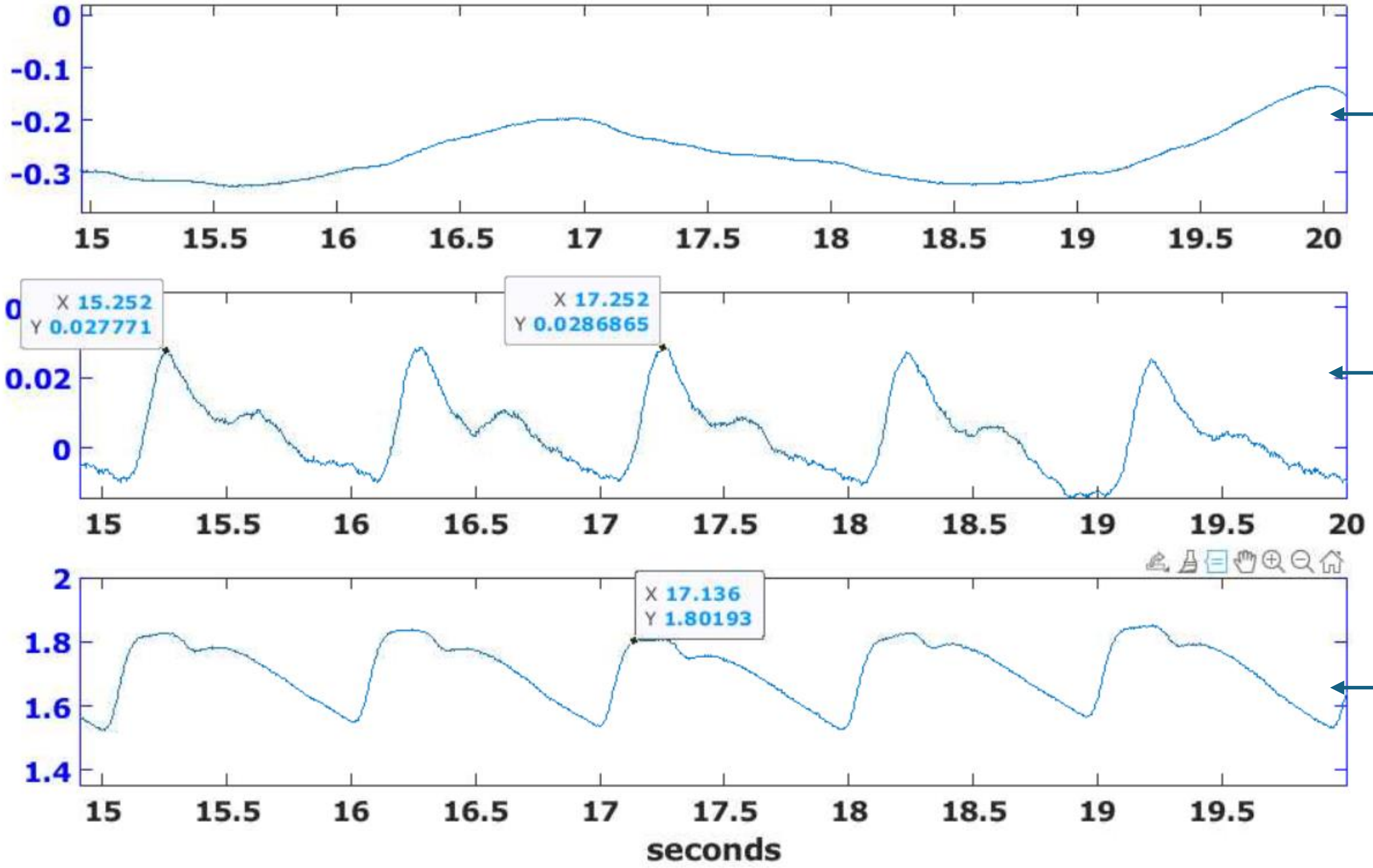
Small pressure pad for surface pulsations



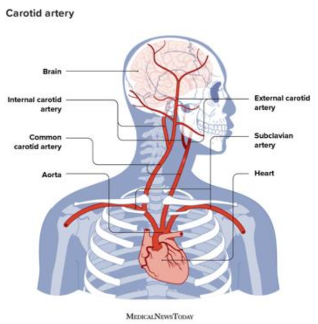
MRI compatible – Pressure pad

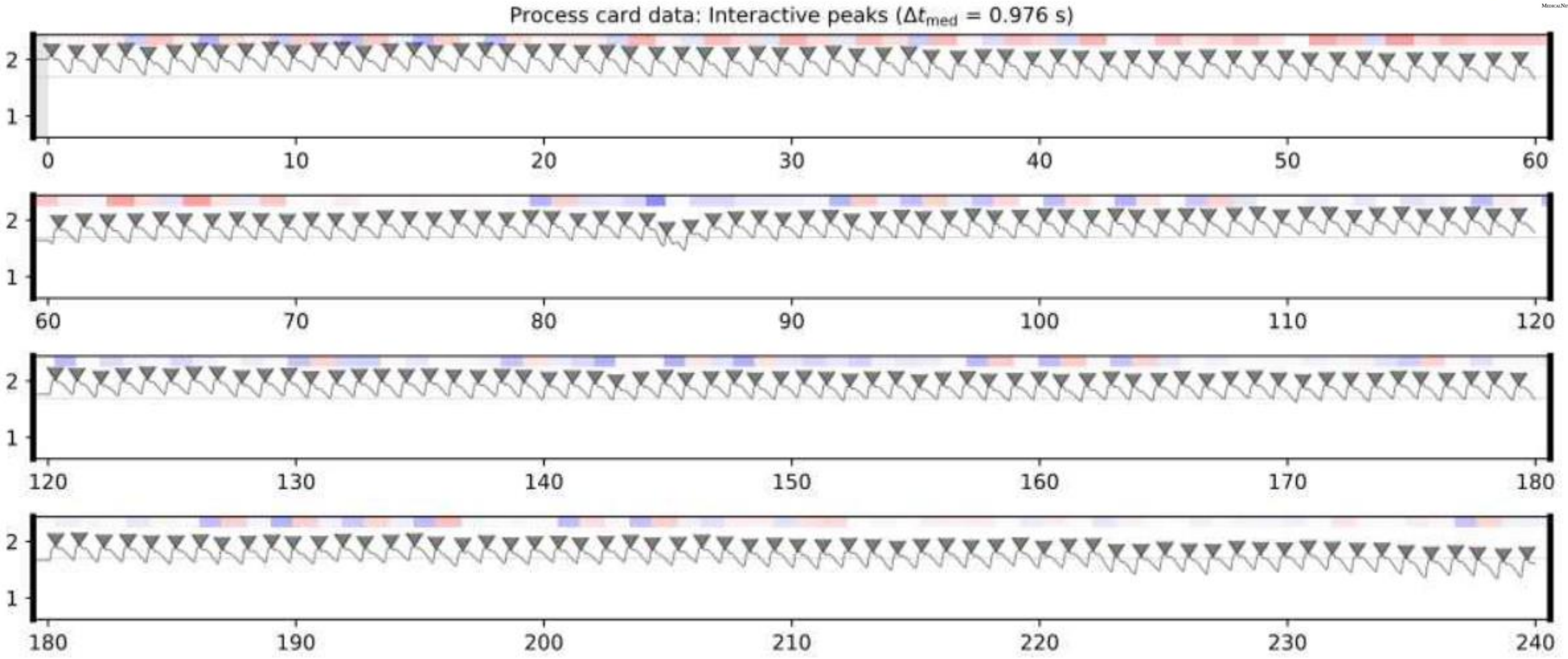


MRI compatible – Pressure pad



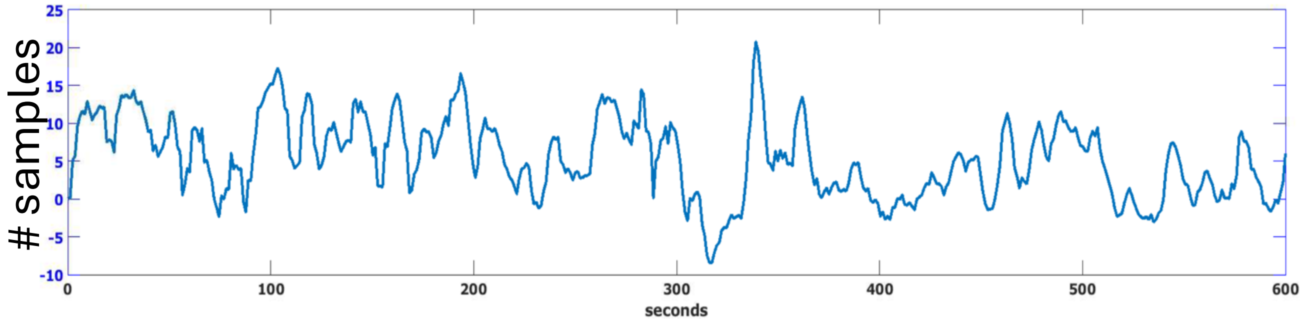
Arterial pulsation- peak detection

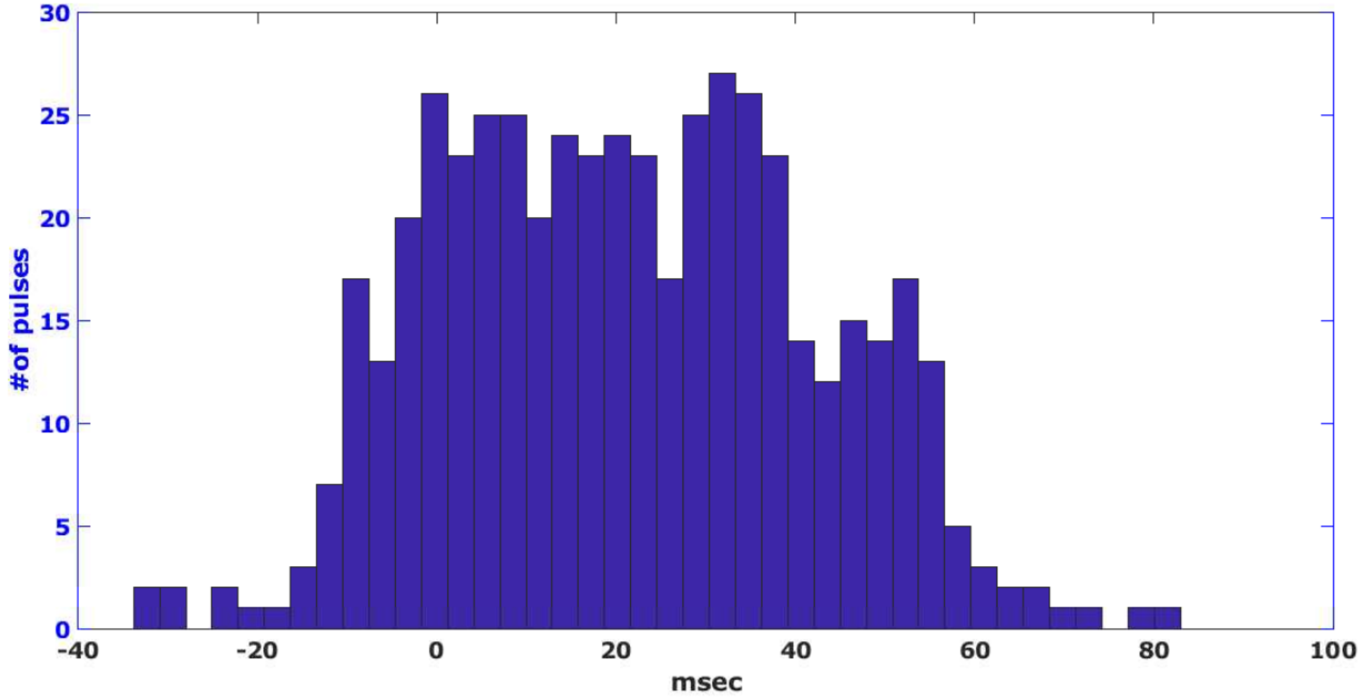




MRI compatible – Pressure pad

PTT(pulse transit time) neck – finger, 250samp/sec

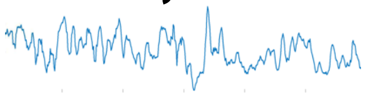


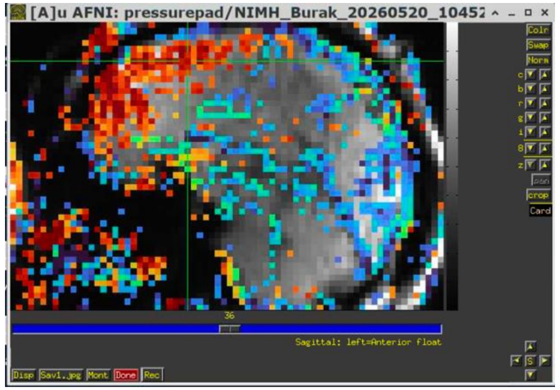


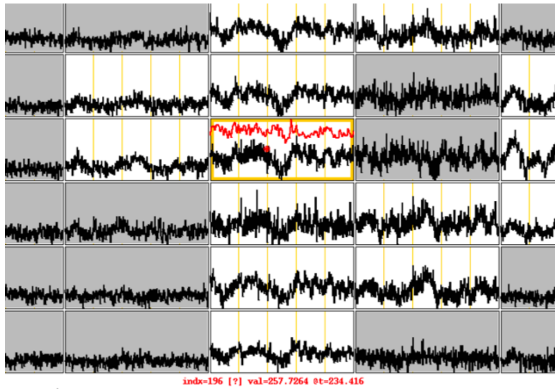
Event	Time after R-wave
ECG R-wave	0 ms
Aortic valve opens (pre-ejection period, PEP)	~50–100 ms
Pressure wave enters ascending aorta	~60–100 ms
Common carotid artery	~70–120 ms
Internal carotid artery	~80–130 ms
Cerebral arteries (MCA, ACA)	~90–150 ms
Finger PPG	~180–300 ms
Toe PPG	~250–400 ms

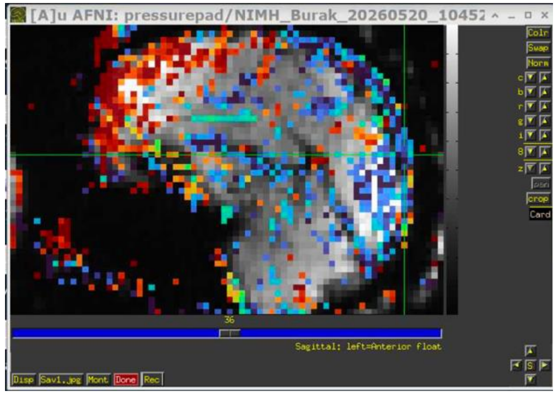
TR 1,2sec TE1 → 13ms , TE2→31ms, TE3→ 49 ms

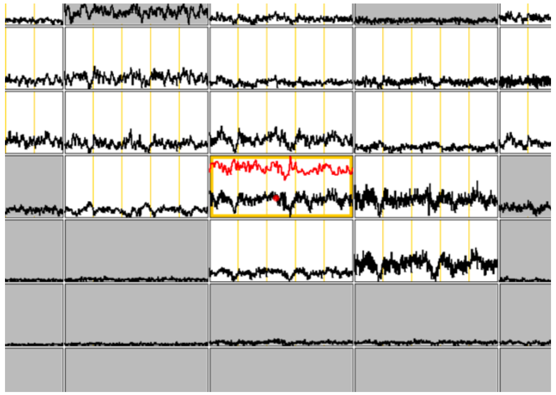
PTT(pulse transit time)

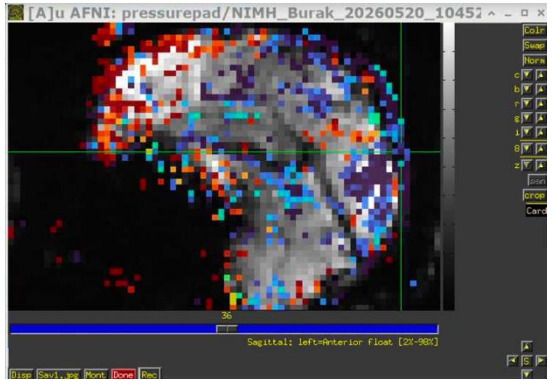


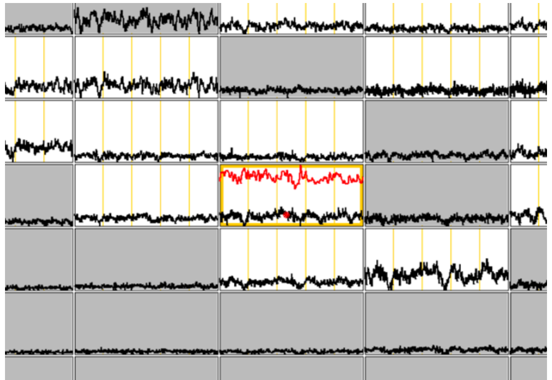






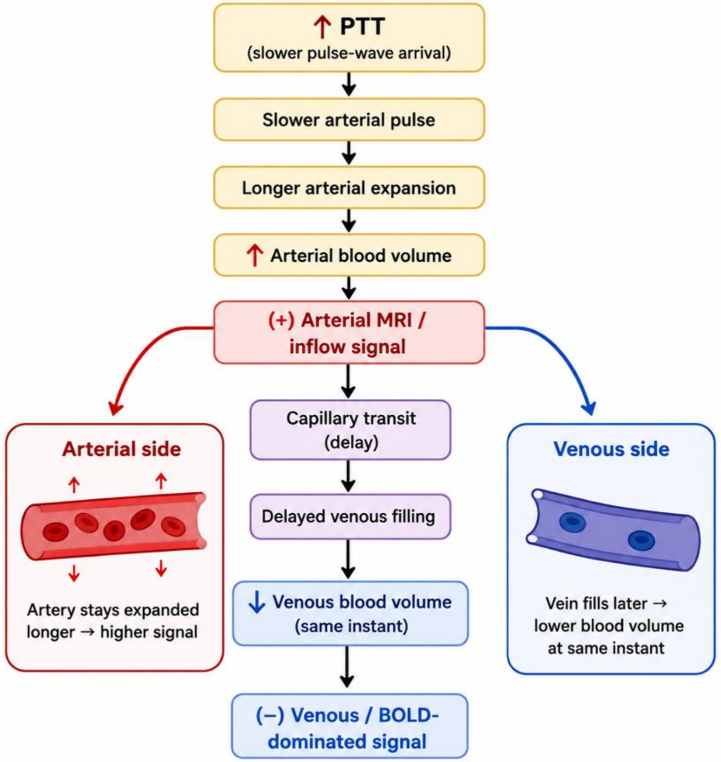




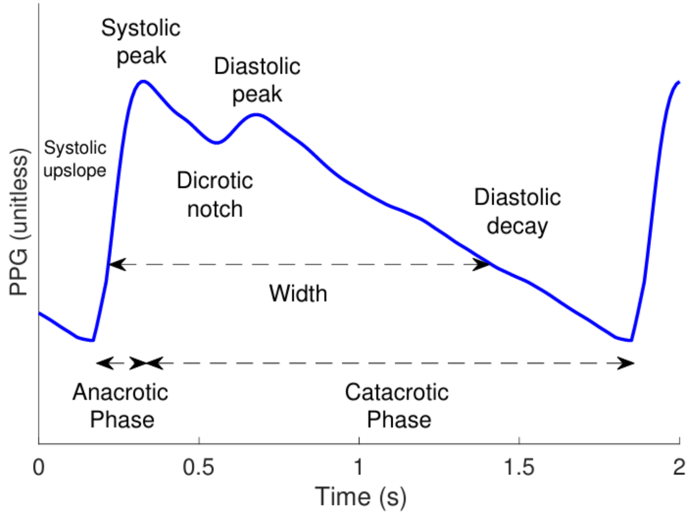


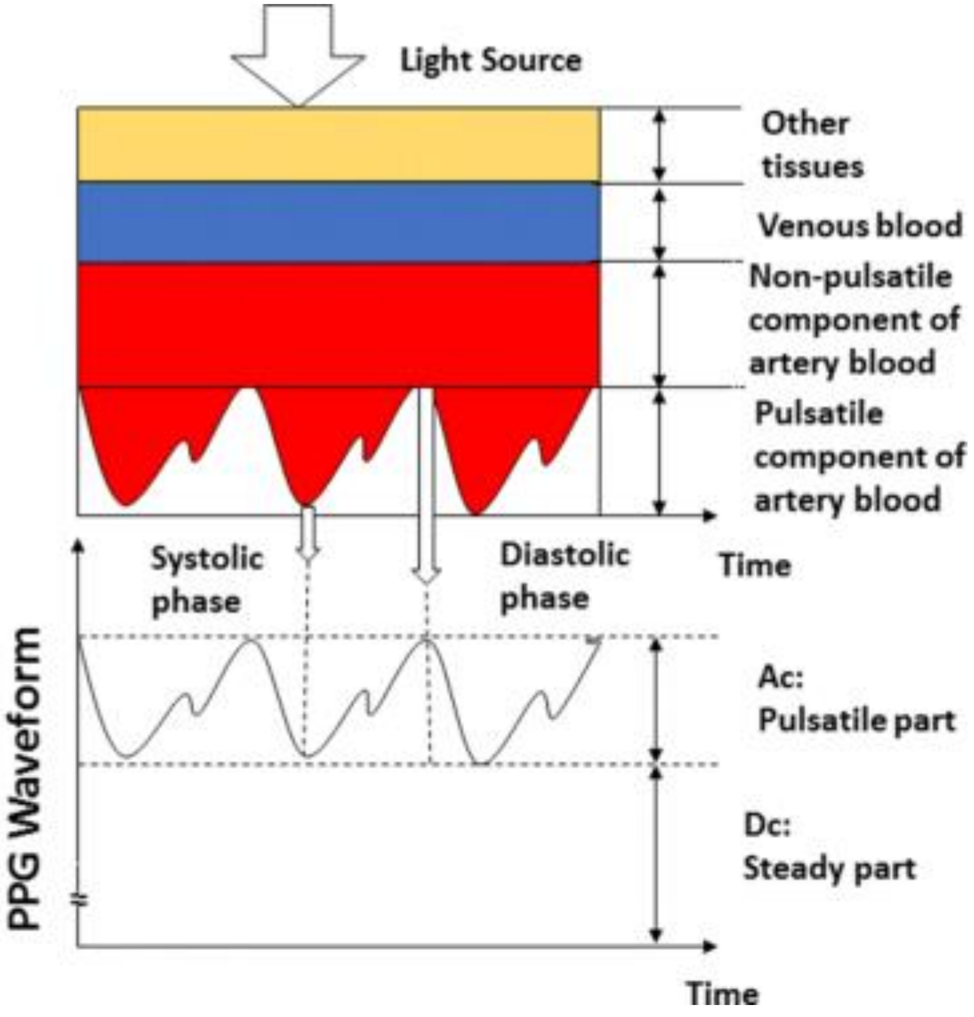
PTT is inversely related to pulse-wave velocity. When PTT increases (slower pulse wave), the pressure wave may reach different vascular territories at different times.

Frontal cortex is dominated by arterial inflow, posterior cortex has stronger venous contribution



Pulse Oximeter

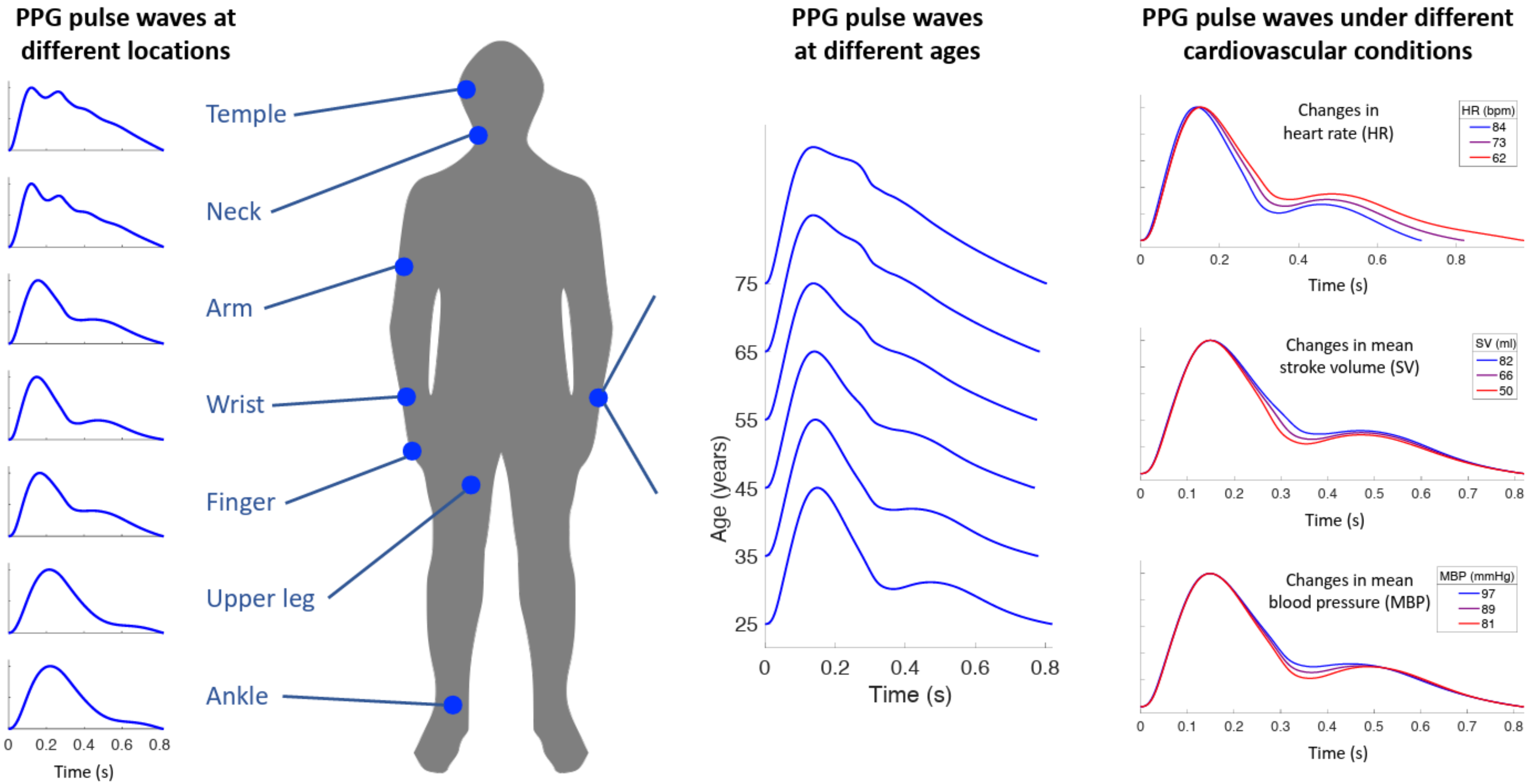




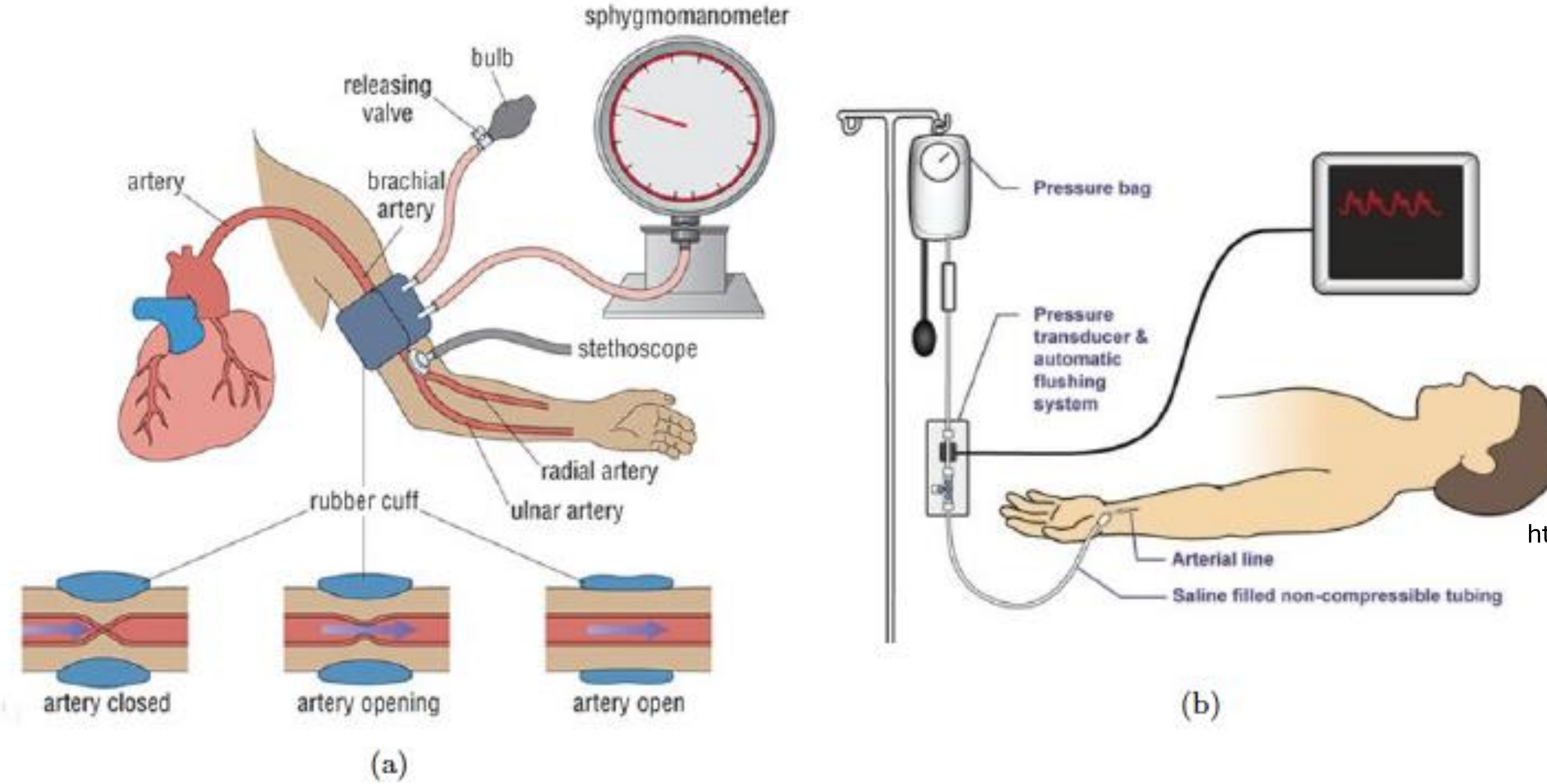
Pulse Oximeter

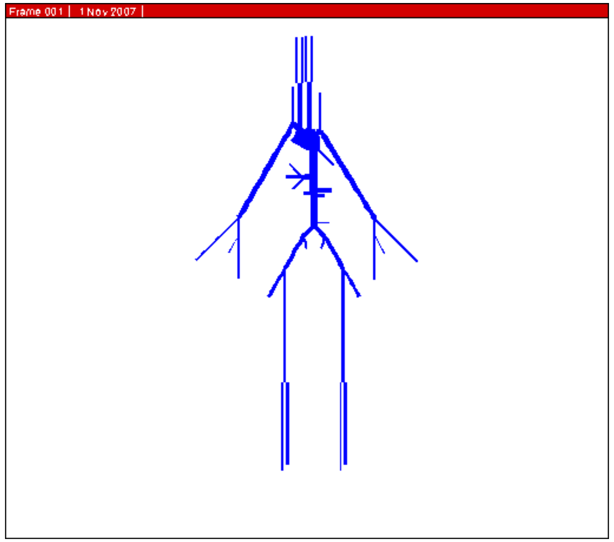
Photoplethysmography Signal Processing and Synthesis

Elisa Mejía-Mejía, John Allen, Karthik Budidha, Chadi El-Hajj, Panayiotis A. Kyriacou and Peter H. Charlton*



Measuring Blood Pressure





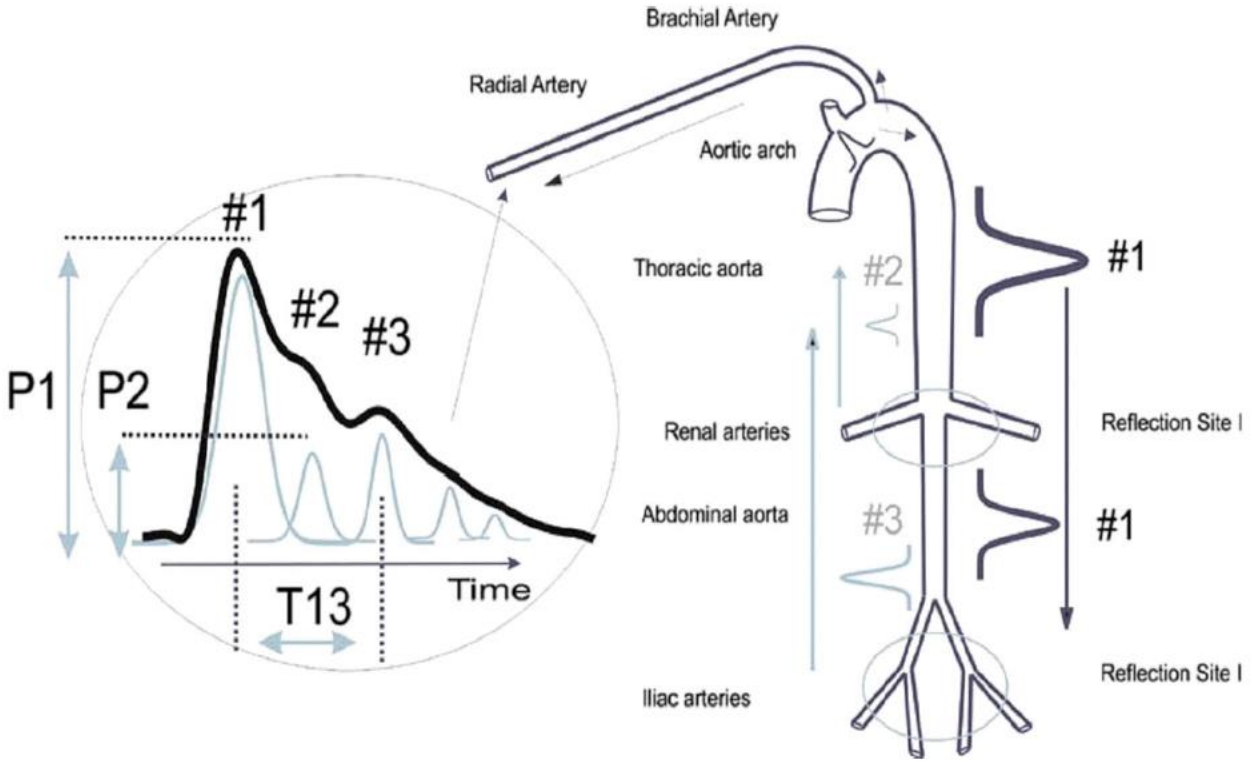
http://haemod.uk/nektar

Figure 1: a. Non-invasive blood pressure measurement b. Invasive blood pressure measurement a) (http://www.open.edu/openlearncreate/mod/oucontent/view.php?id=287&extra=thumbnail_idp2983376) (https://trynotlaughs.us/galleries/non-invasive-bp-monitoring.html)

National Institute of Mental Health

Measuring Blood Pressure

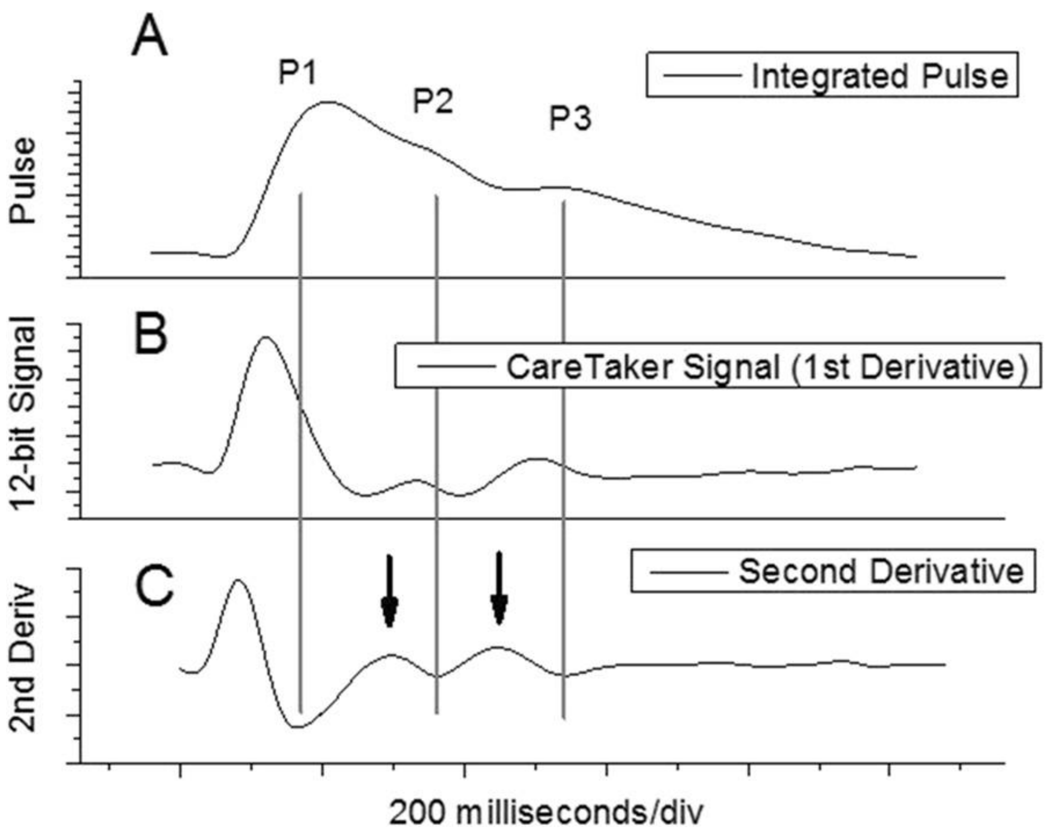
”Continuous” Non-invasive blood pressure monitor(NIBP)



Gratz et, al.2017

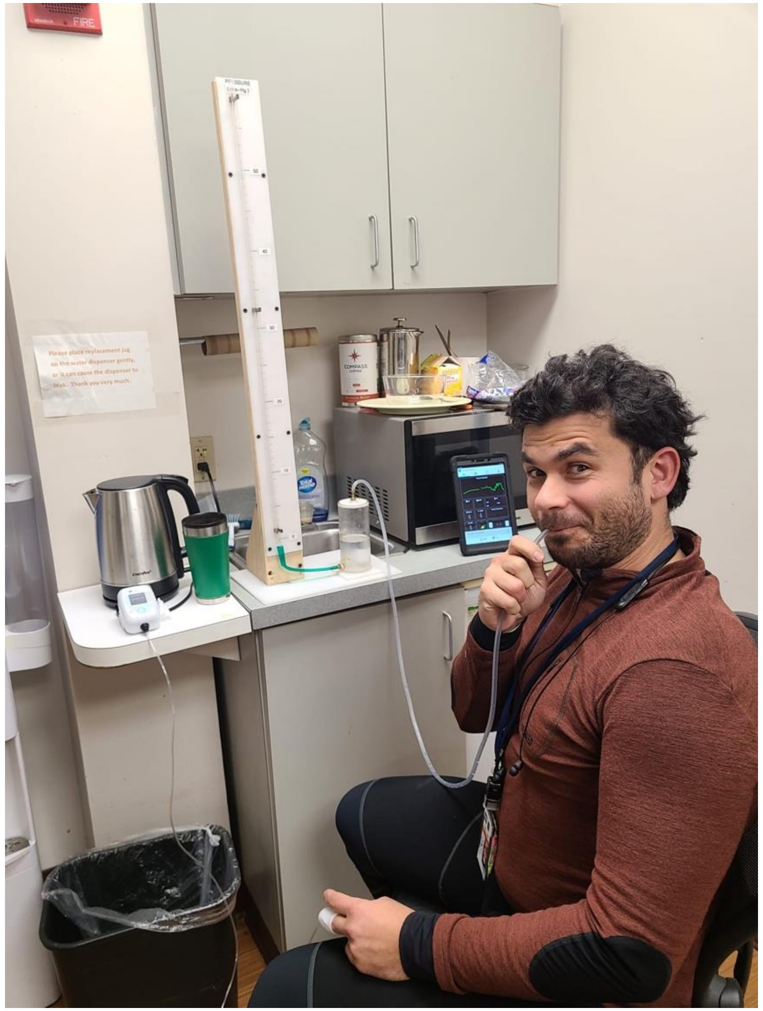
Measuring Blood Pressure

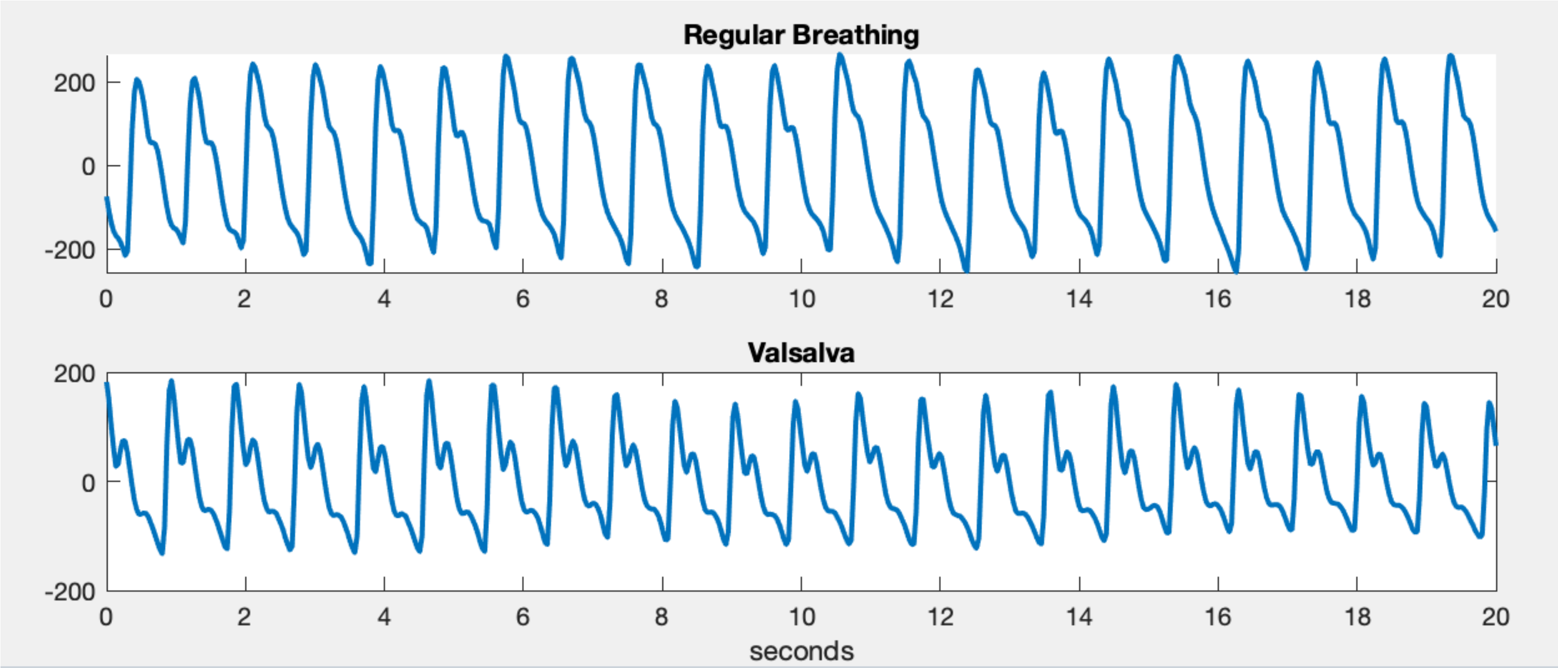
"Continuous" Non-invasive blood pressure monitor(NIBP)



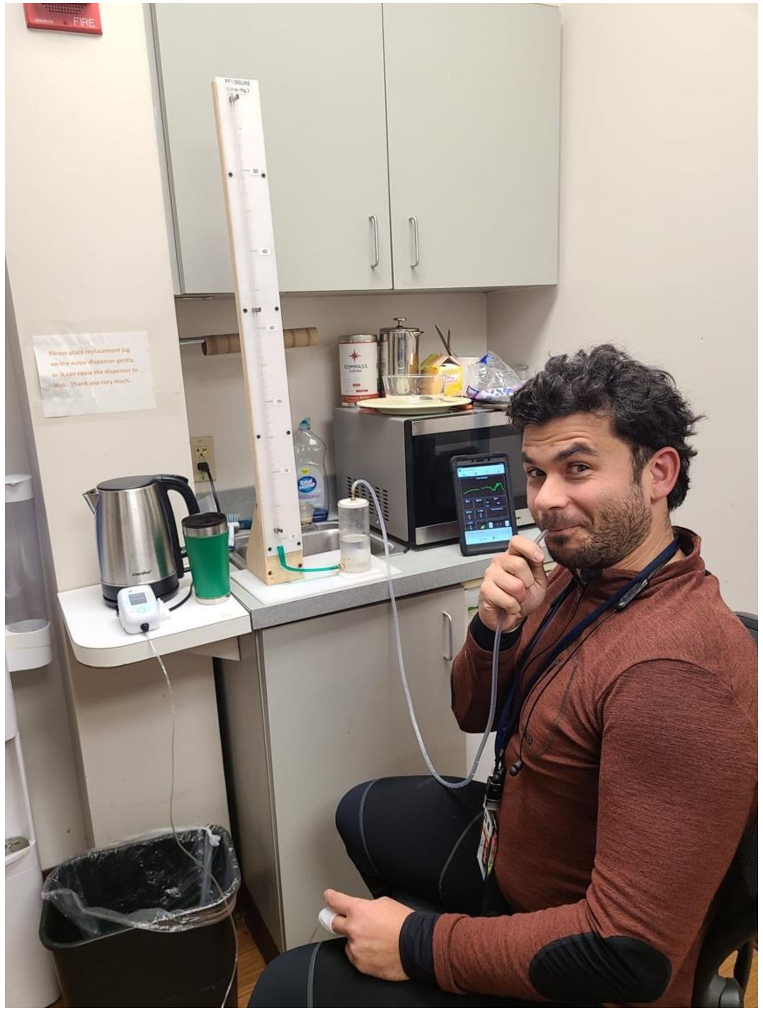
Baruch et, al.2014

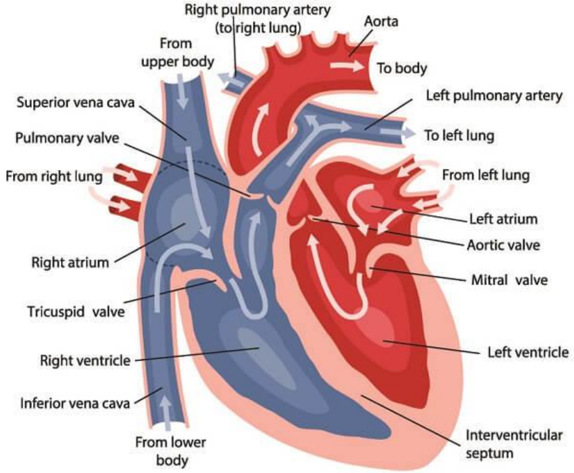
How breathing modulate blood pressure?

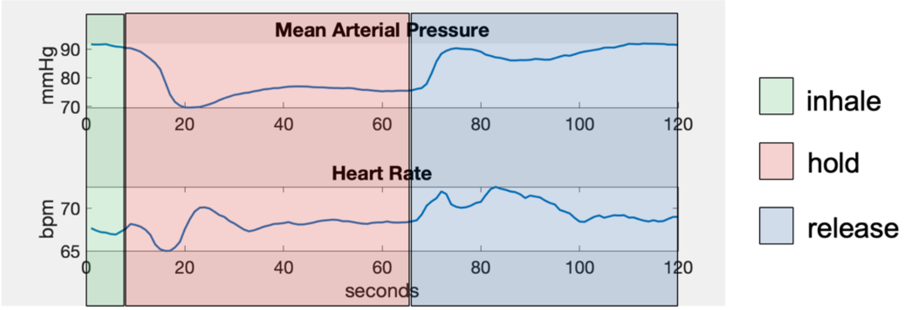


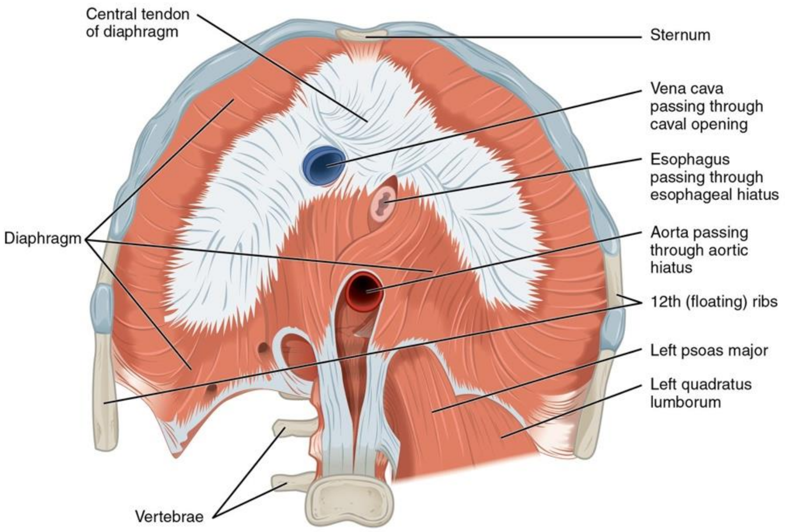


How breathing modulate blood pressure?









Diaphragm (inferior view)

Different frequency bands of MAP

- 0-0.15 Hz(Vascular Tone) ,
- 0.2-0.6 Hz (Sympathetic, ,Respiration, Myogenic),
- 0.6Hz above Renin Angiotensin (Strauss et.al 2007)

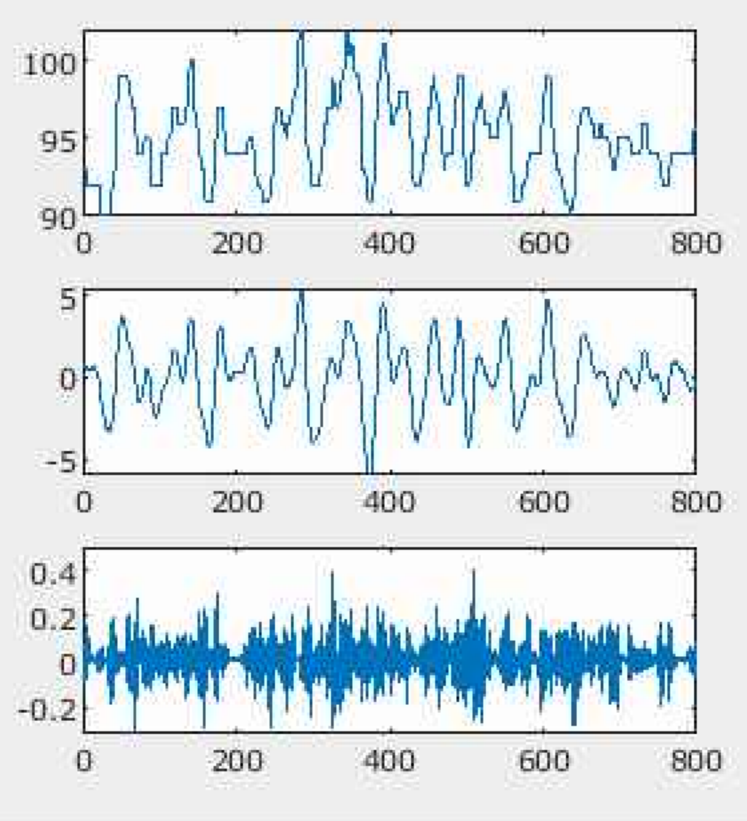
Raw

Vascular tone

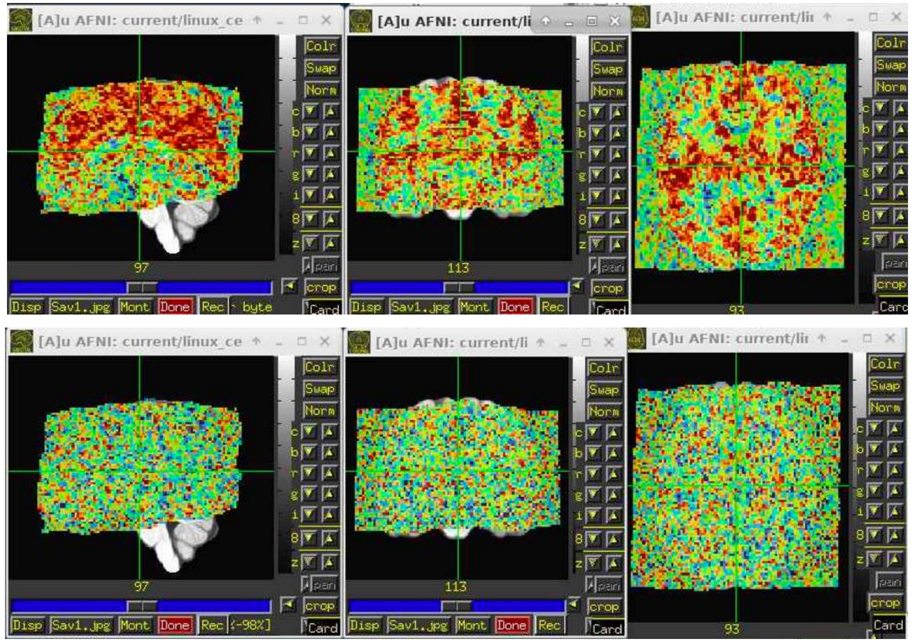
(0- 0.15Hz)

Sympathetic

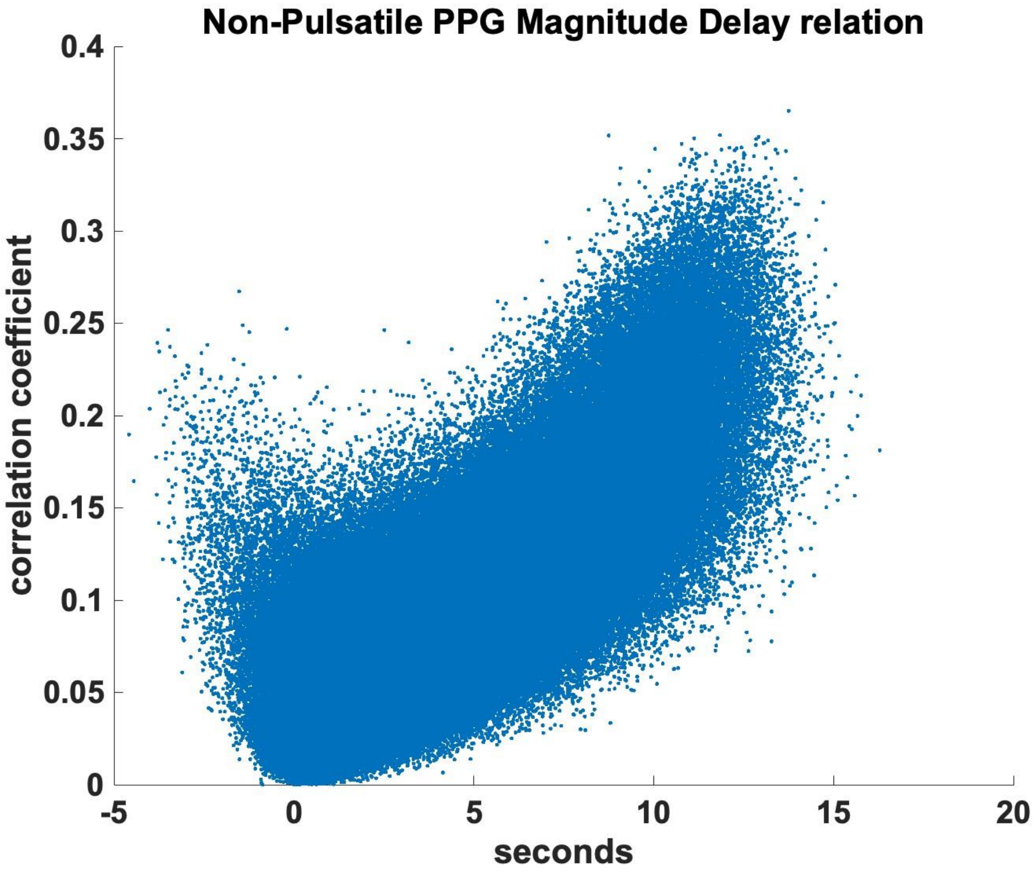
(0.2- ~Hz)

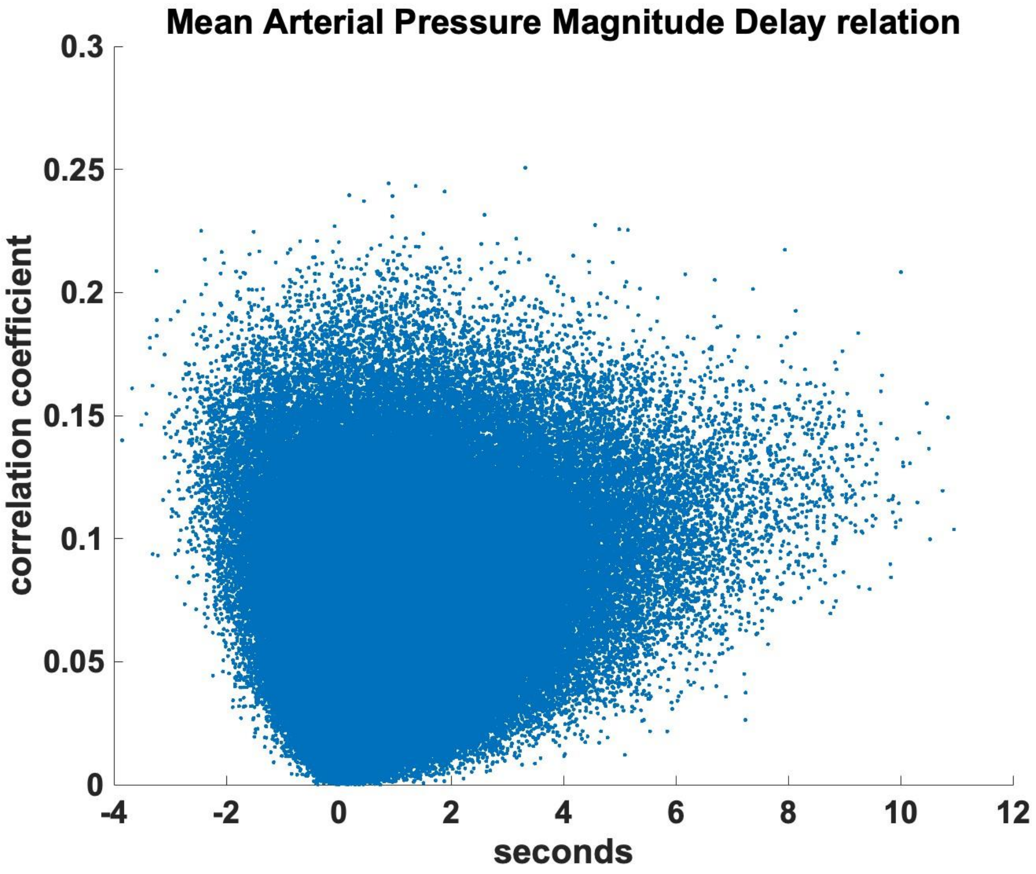


- Caretaker non-invasive BP monitors sampling is “beat to beat”
- Sampling is heart rate dependent
- Assuming 70bpm → 0.58Hz and lower
- Assuming 60bpm → 0.5Hz and lower
- Assuming 50bpm → 0.42Hz and lower



Optimal Correlation and Delay relation

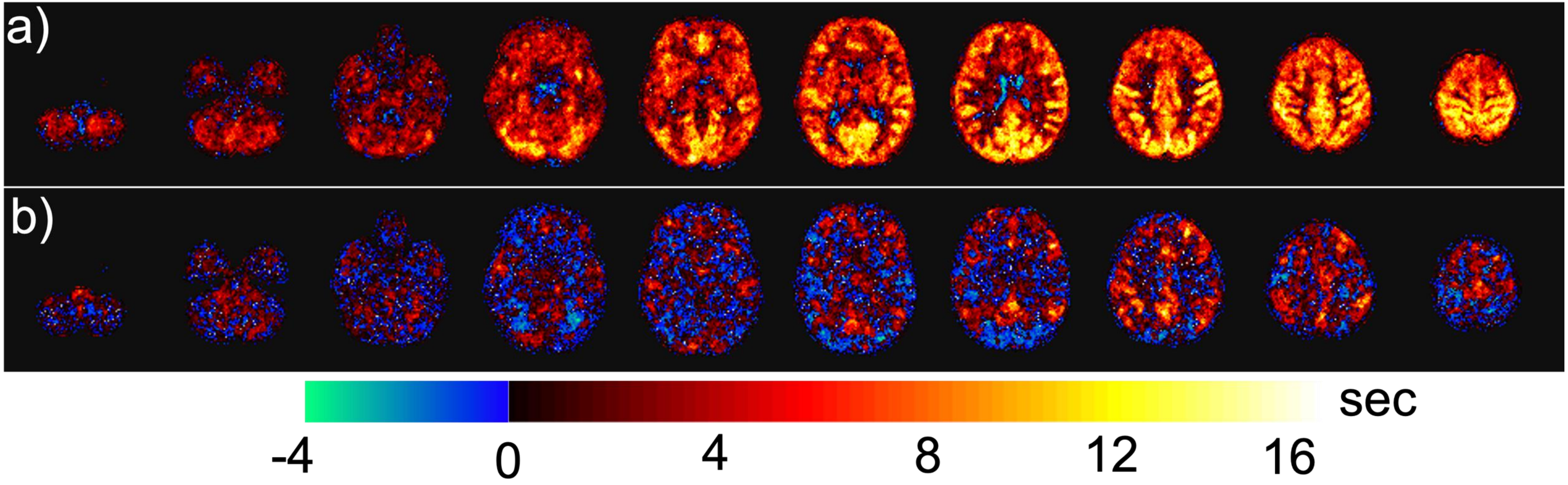




Delayed Structure

Non pulsatile PPG

Blood Pressure



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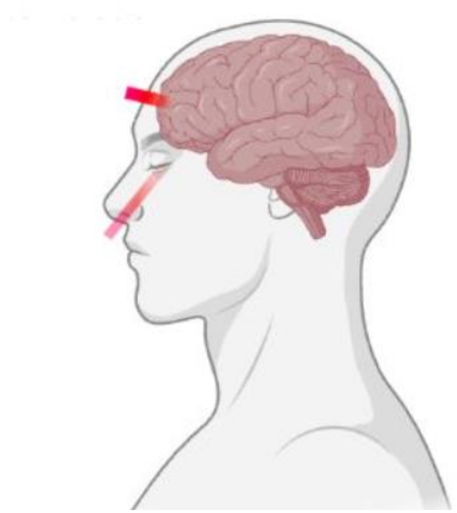
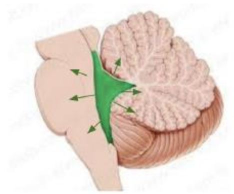
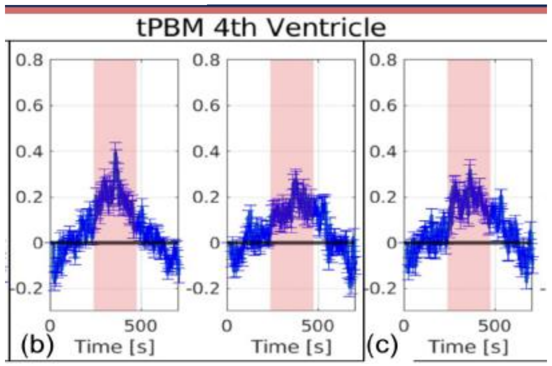
External modulation

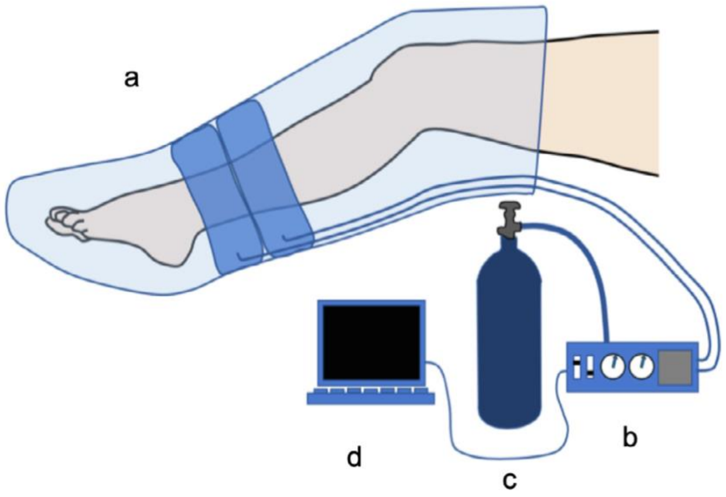
Light Stimulation

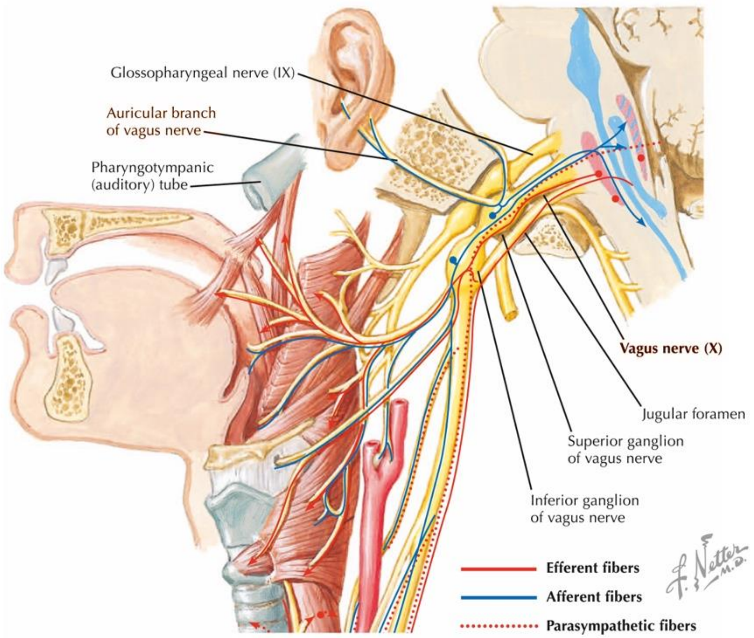




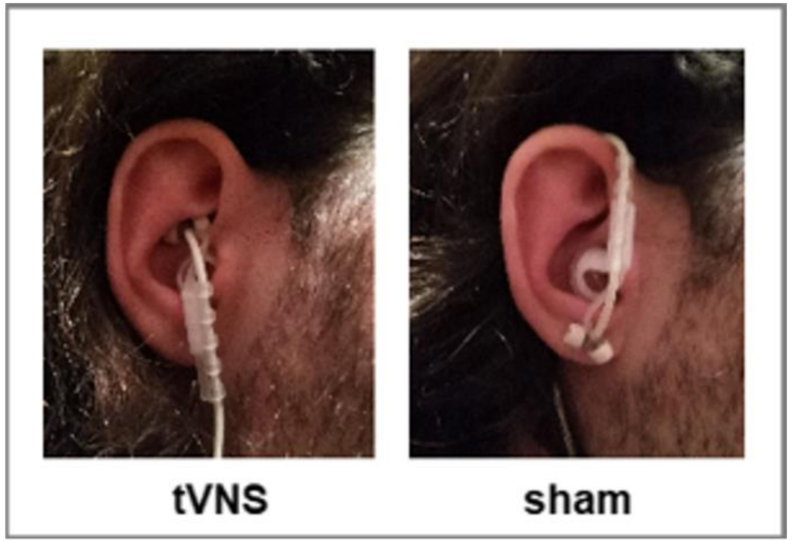


Pressure Cuff



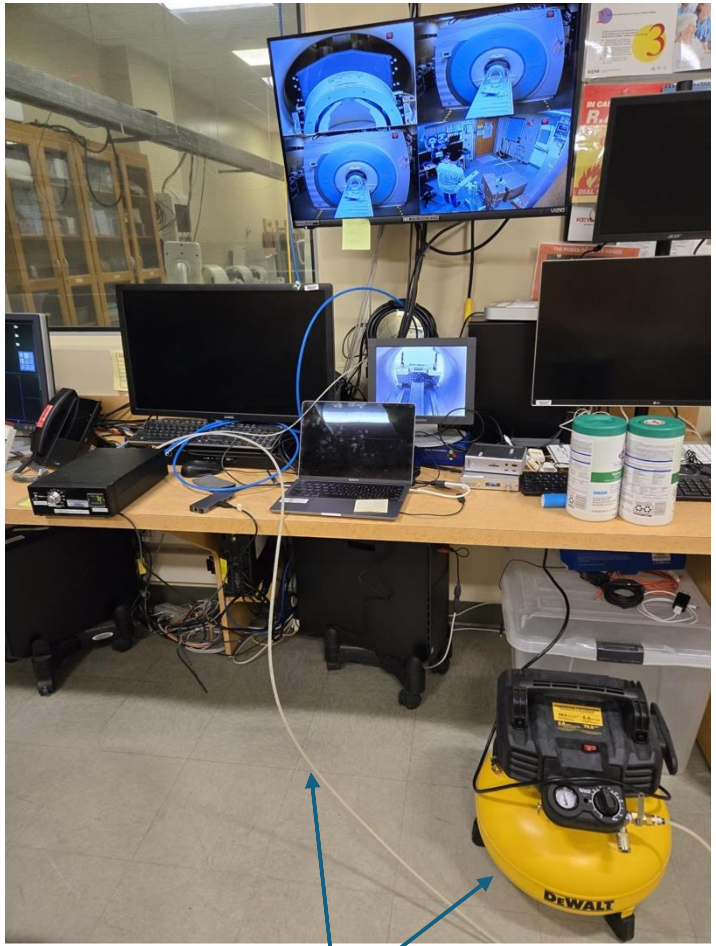


Vagal nerve stimulator(tVNS)



Obst et al., 2021

MRI compatible - Leg pressure cuff setup

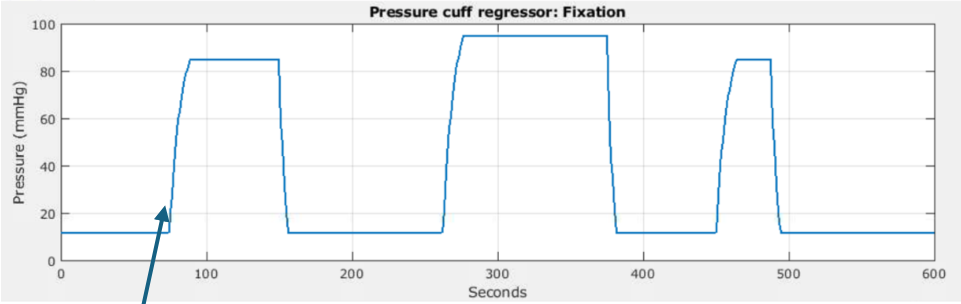


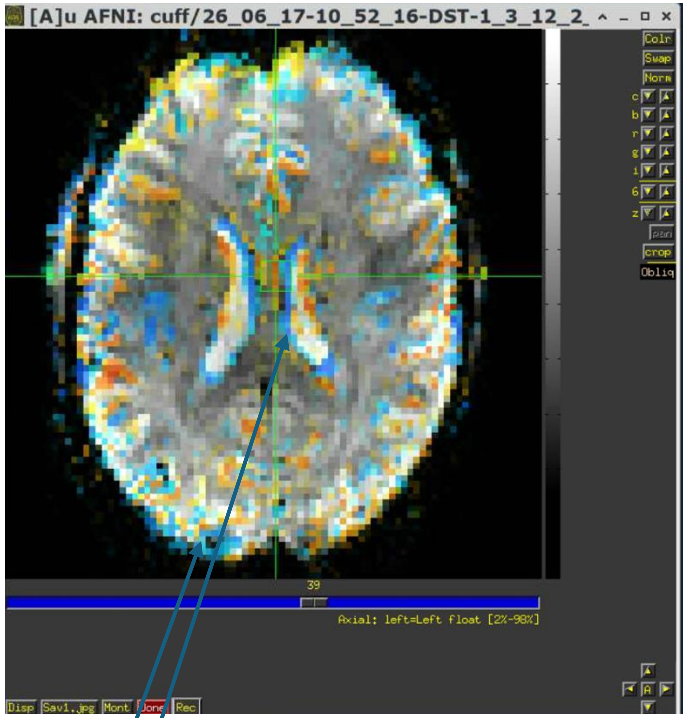
Leg Cuff has 7 inflatable compartments, mid two sections over the calf muscle are inflated during the scan

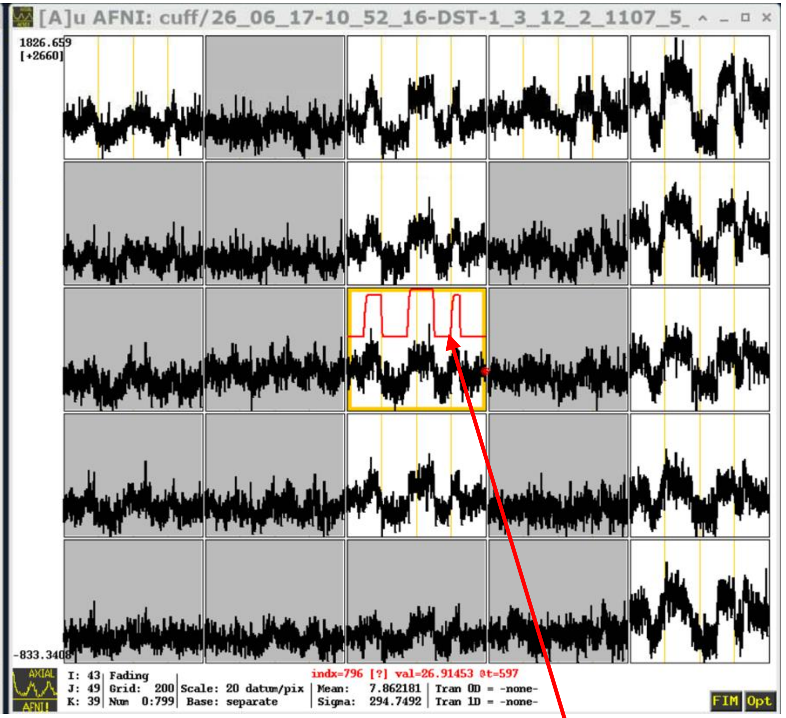
Control unit has real-time display and log of the pressure values in mmHg, max is the 100mmHg

A galloon air compressor is set to 60psi, connected with hose to control unit and runs through waveguide into 7T scanner

Cuff induced changes on fMRI time series (compliance response?)





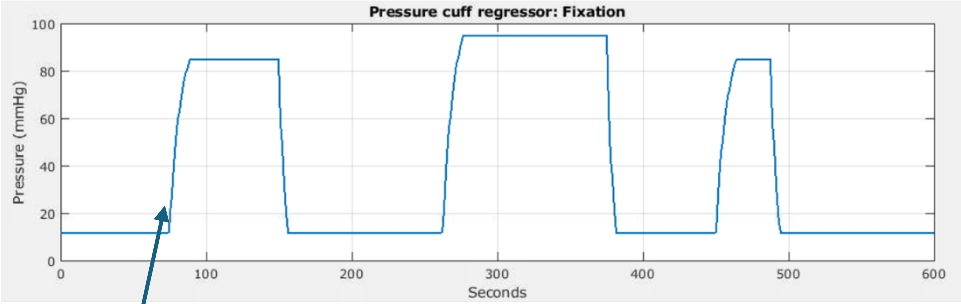


Leg Cuff pressure is modulated 3 different times during 10min resting state scan as above.

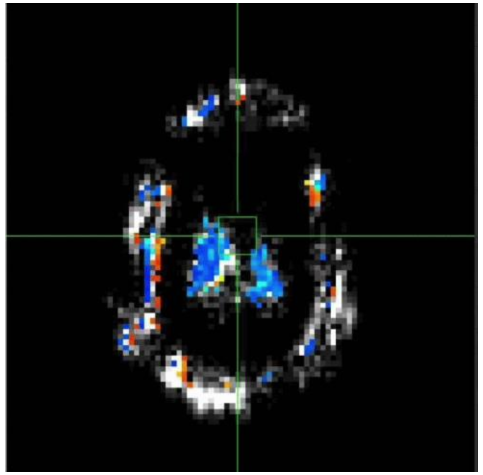
Ventricular wall and perivascular CSF spaces follows anti-correlation with cuff pressure

Cuff pressure as a seed time course

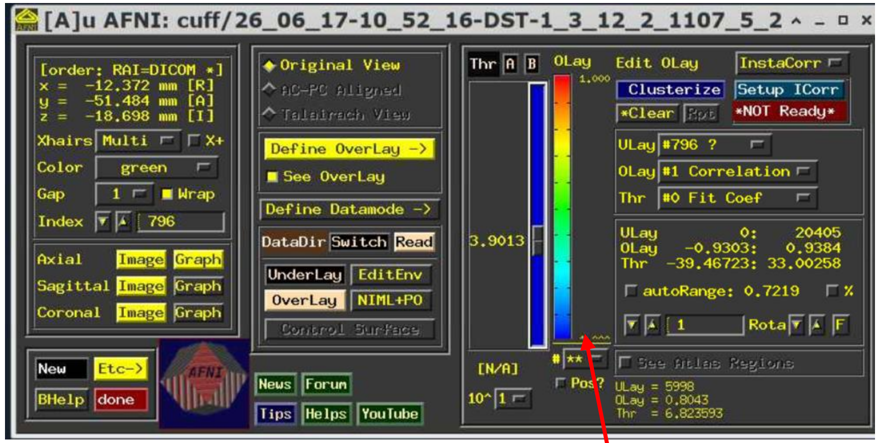
Cuff induced changes on fMRI time series (compliance response?)



Leg Cuff pressure is modulated 3 different times during 10min resting state scan as above.

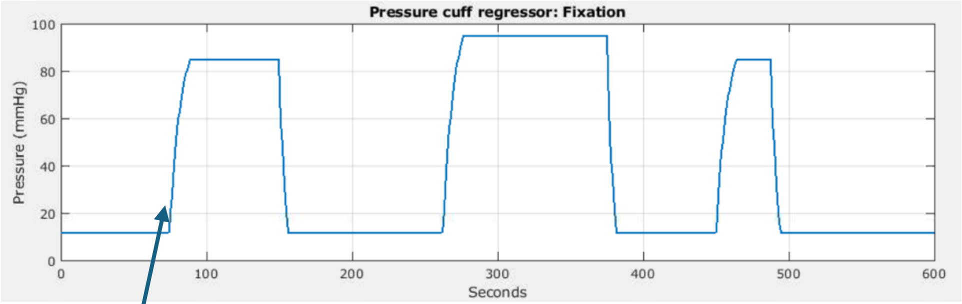


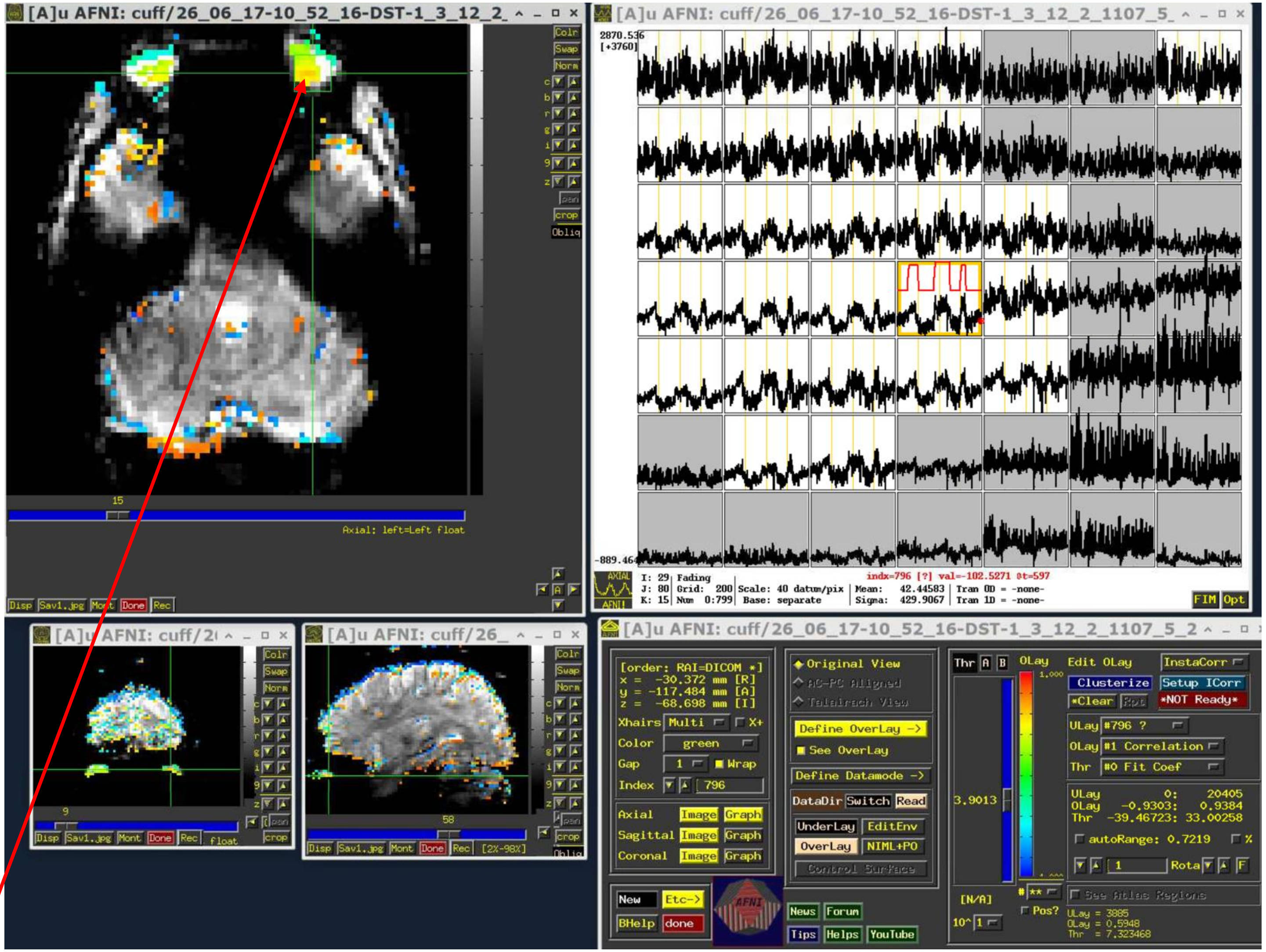
Significant voxels t>4



Red shows positive correlation with cuff pressure and blue shows negative

Cuff induced changes on fMRI time series (compliance response?)

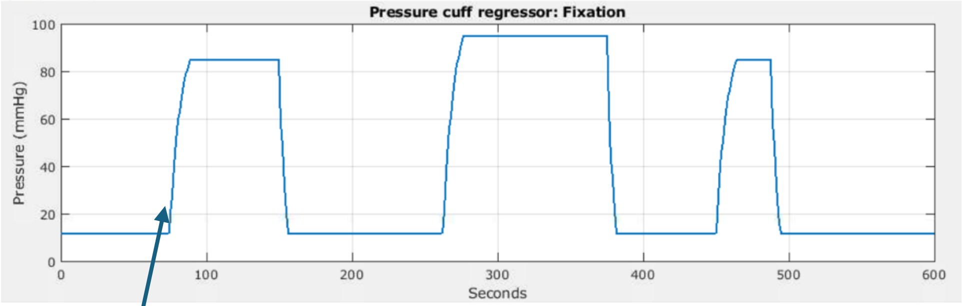




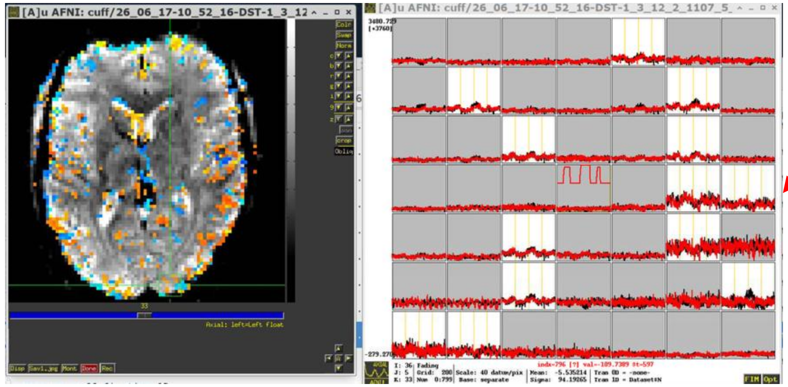
Leg Cuff pressure is modulated 3 different times during 10min resting state scan as above.

Intra ocular globe tension, posterior globe is following cuff pressure while anterior chamber/cornea is anti correlated

Cuff induced changes together with Visual Checkerboard

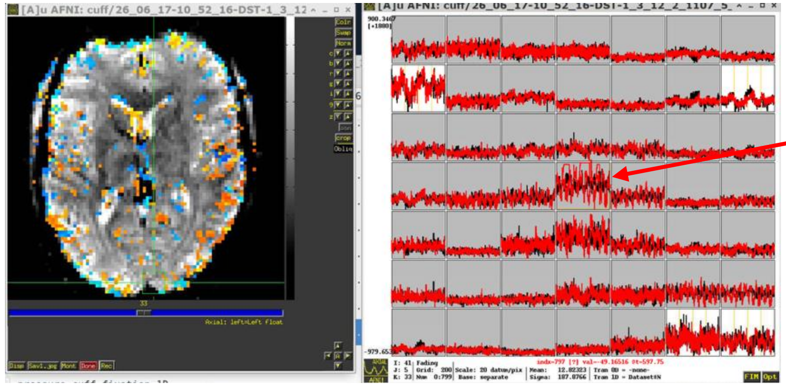


Leg Cuff pressure is modulated 3 different times during 10min resting state scan as above.

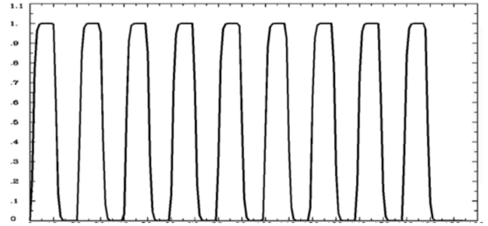


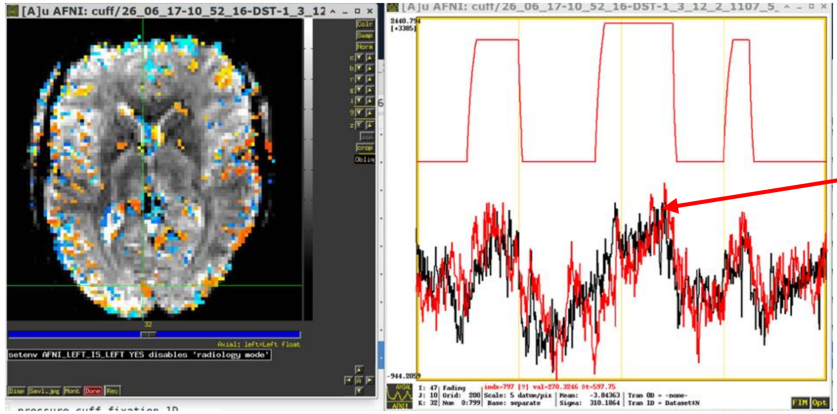
Red shows time series from visual checkerboard and simultaneous with cuff modulation,

Black time series are resting state with cuff modulation



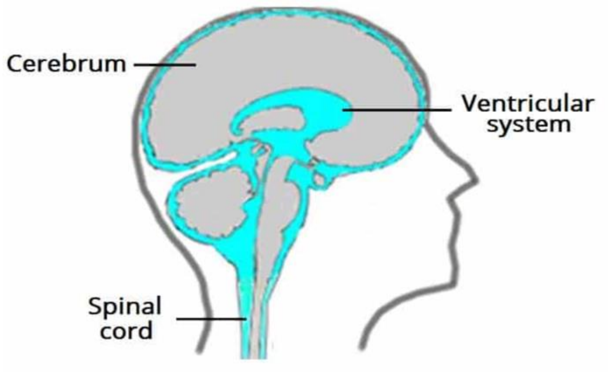
Visual Task related voxel, not significant with cuff(vascular task)

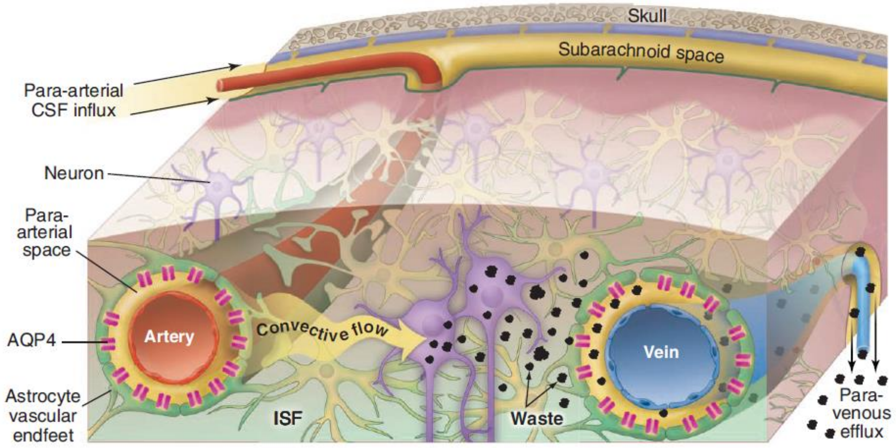




Significant with cuff(vascular task) but also has additive visual checkerboard on it.

Sources of Motion





Go with the flow. Convective glymphatic fluxes of CSF and ISF propel the waste products of neuron metabolism into the paravenous space, from which they are directed into lymphatic vessels and ultimately return to the general circulation for clearance by the kidney and liver.

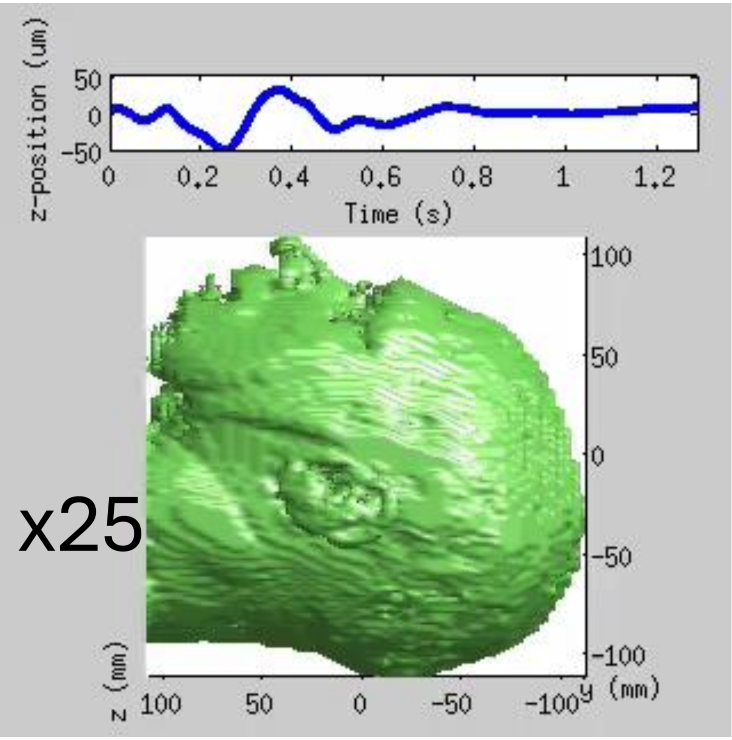
Lymphatic draining system of the brain tissue, so called glymphatic system

Arterial pulsations propulse water through aquaporin channels

An intercellular "glymphatic" pathway clears cell waste from the brain and may reveal new targets for treating neurodegenerative diseases.

Garbage truck of the brain. Nedergaard M Science. 2013

Sources of Motion



Craniotomy @ Northwestern Medicine

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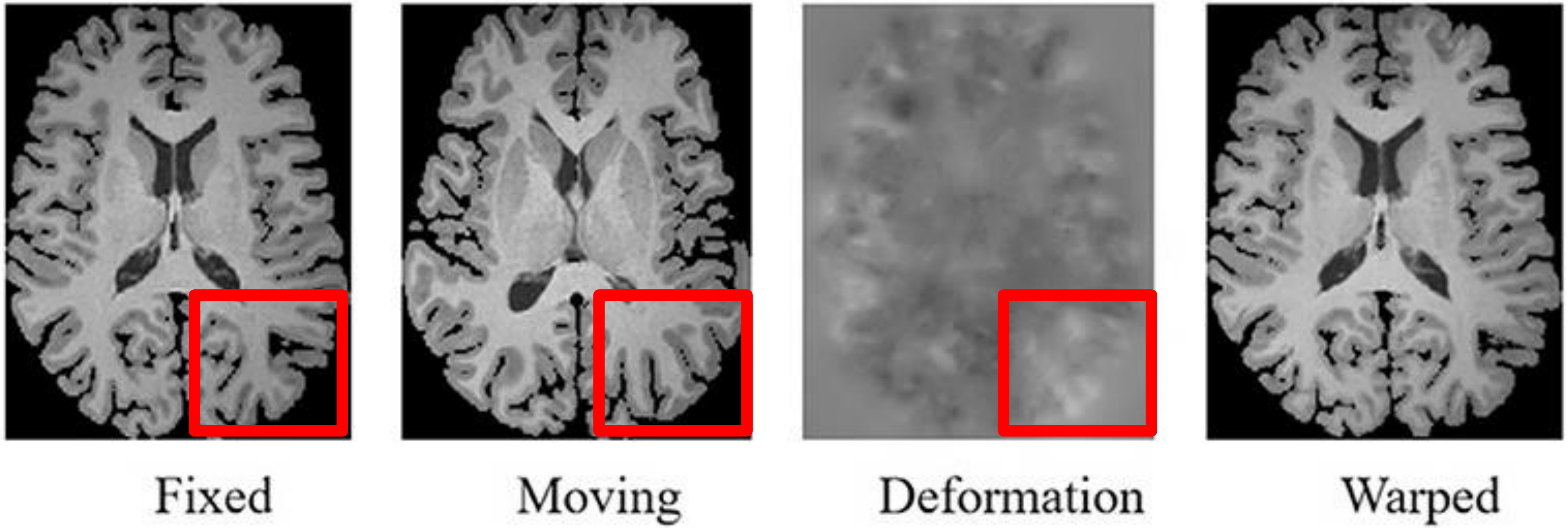
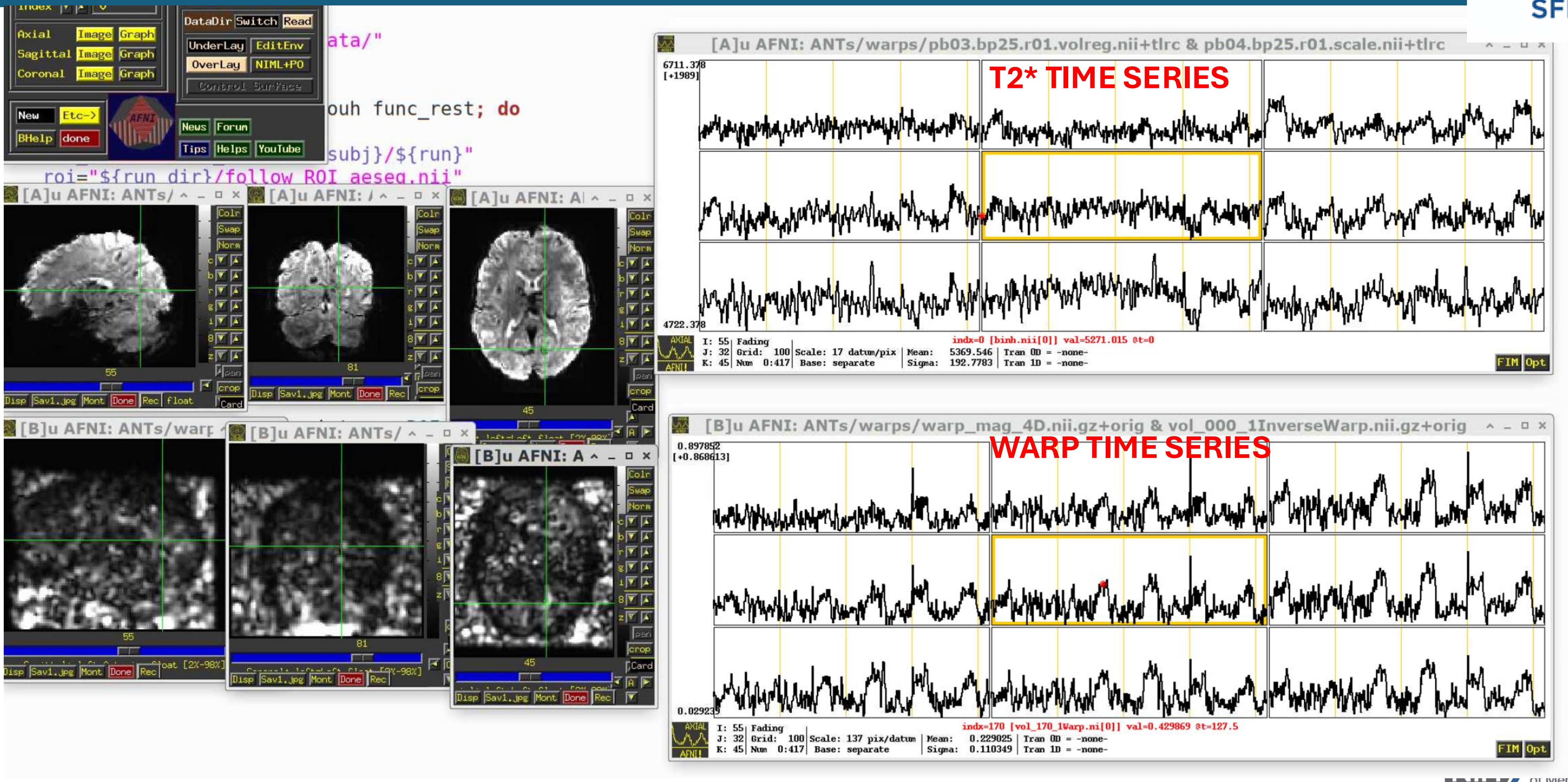
Non-linear registration



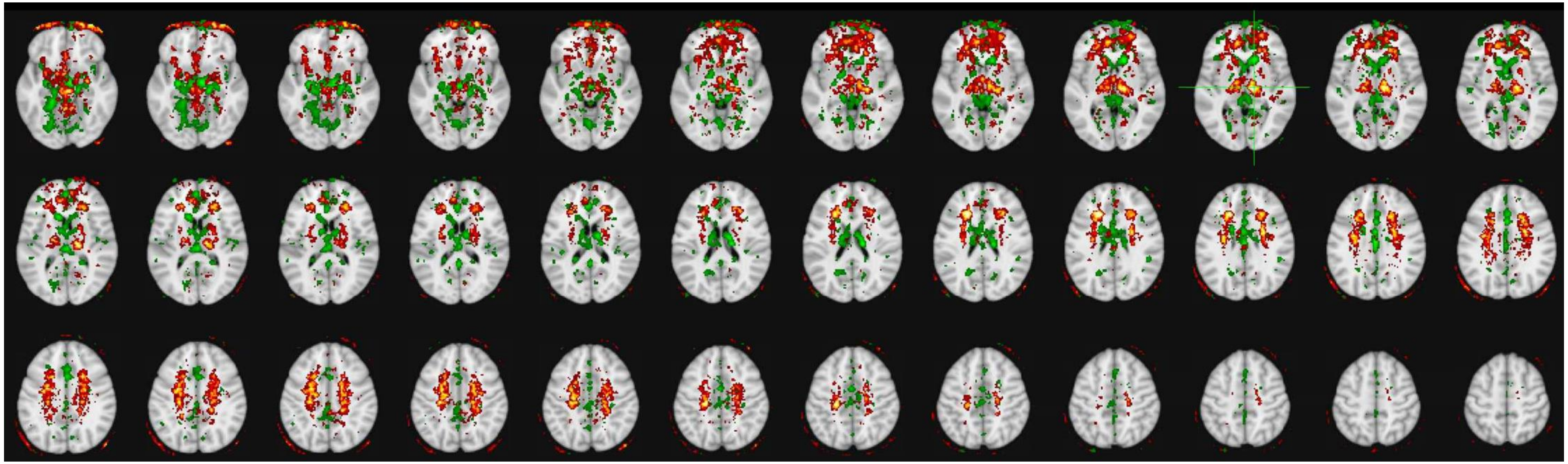

```
antsRegistration \
  --dimensionality 3 \
  --float 1 \
  --collapse-output-transforms 1 \
  --output [ "${OUTDIR}/warps/vol_${v}_", "$OUTWARP", 0 ] \
  --interpolation Linear \
  --winsorize-image-intensities [0.01,0.99] \
  --use-histogram-matching 0 \
  --initial-moving-transform [ "$REF", "$MOV", 1 ] \
```

```
--transform SyN[0.03,2,0] \
--metric CC["$REF","$MOV",1,2] \
--convergence [10x5,1e-5,5] \
--shrink-factors 2x2 \
--smoothing-sigmas 1x1vox
```

Warp time series



Breathing– Warp field displacements

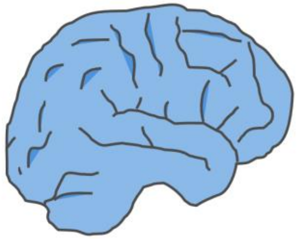


Closing remarks

- Measuring peripheral physiology provides essential context for interpreting brain activity.
- Understanding the origins of the MRI signal, together with physiological interactions, is key to understanding brain function.
- Multi-echo and multimodal imaging offer a path toward physiology-aware fMRI.
- Task design is becoming increasingly important, as neural and physiological manipulations can be studied simultaneously.
- The brain cannot be fully understood without understanding the body.

Thanks to colleagues…

SFIM



Any questions ?

NIH National Institute of Mental Health