BOLD and CBF responses during the Valsalva Manuever

Daniel A Handwerker[1], Wen-Ming Luh[2], Paula Wu[1], Peter A Bandettini[1,2]

1. Section on Functional Imaging Methods, LBC, National Institute of Mental Health, Bethesda, MD
2. Functional MRI Facility, National Institute of Mental Health, Bethesda, MD

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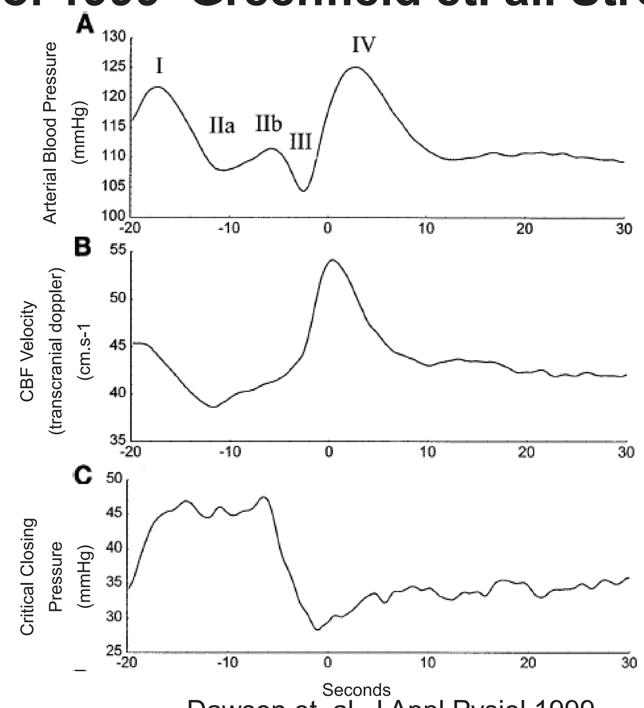
INTRODUCTION

Breath holding causes a whole brain BOLD response that can potentially be used to calibrate fMRI BOLD signal changes (Bandettini et al, NMR Biomed 1997, Davis et al, PNAS 1998) or as a clinical cerebrovascular reactivity measure. The Valsalva maneuver combines a breath hold with an increase in internal chest pressure. While a breath hold is often assumed to alter blood flow through hypercapnia (increase blood CO_2), increased chest pressure during a Valsalva maneuver alters blood pressure, heart rate, cerebral spinal fluid pressure, and cerebral blood flow (CBF) (Dawson et. al. J Appl Pysiol 1999 Greenfield et. al. Stroke 1984)



Dawson et. al. J Appl Pysiol 1999

We demonstrated that Valsalva maneuvers with graded chest pressure changes, even while keeping breath hold duration constant, systematically altered the BOLD signal magnitude (Handwerker et al ISMRM 2010). Here we examine this effect on cerebral blood flow (CBF) using arterial spin labelling (ASL). As part of this work, we identify chest-movement related fluctuations in the estimated CBF and examine the cause and potential ways to remove these fluctuations.

METHODS

GE 3T HDx scanner, 16 channel head coil, 9 axial, ASSET=2
FOV = 24cm, slice thickness=4.5mm, no gap, 64/64 grid, flip=90
slice TR =2000ms, TE=14.8ms

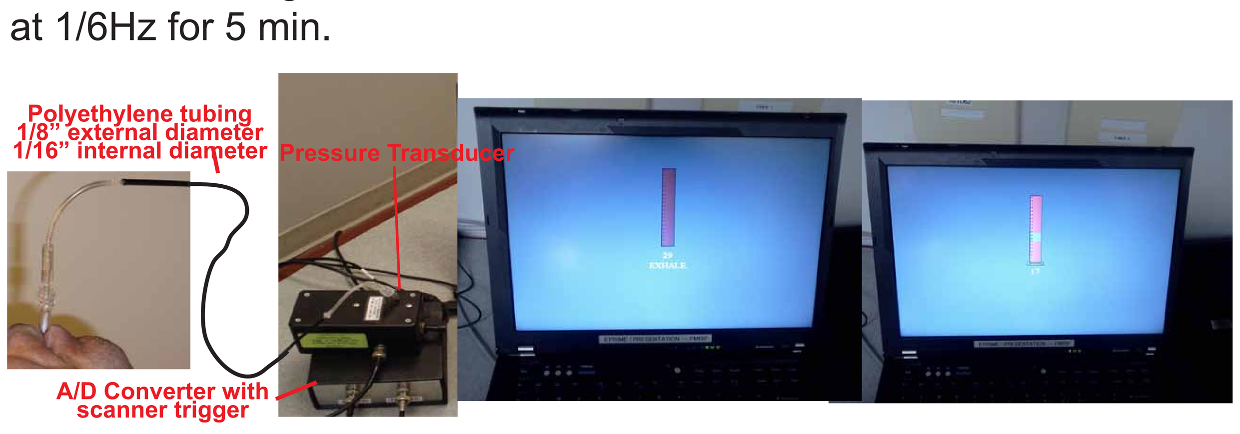
Data were collected from 10 healthy volunteers each with some variation in pulse sequences and tasks. The following two ASL scans were used:
PCASL: Pseudocontinuous ASL (Dai et. al. 2008)
Tagging duration = 800ms, post labeling delay = 900ms
Tag below Circle of Willis, presaturation pulse off

PASL: Pulsed Arterial Spin Labeling QUIPSS II (Wong et. al. 1998)
TI1 = 700ms, TI2 = 1500ms, tag size = 12cm,
Tag 1cm below bottom slice

For PASL, some scans were collected with no tagging pulse, but with keeping the QUIPSS II saturation pulses. This results in BOLD time series with no flow weighting. CBF responses were estimated in the same way as PASL with tagging. These data were used to identify task-related changes in the CBF estimates that aren't due to flow changes.

Valsalva Task: Volunteers received visual instructions to breathe in and out at 1/6Hz for 39s ending on an inhale followed by a 19 or 21s breath hold repeated for 5 or 6 cycles. During the breath holds, they were told to blow into a non-complaint tube that was attached to an air pressure transducer. They were given real-time feedback of the air pressure in the tube. Before each run, volunteers were given a target pressure of 10, 20, 30 or 40mmHg.

Paced Breathing: Volunteers received visual cues to breath in and out at 1/6Hz for 5 min.



Data were processed in AFNI (afni.nimh.nih.gov) and Matlab
Preprocessing: After motion correction, the alternating tag and control scans were interpolated to create both a tag and control volume at teach time point. These were averaged to create BOLD time series and subtracted to create the CBF time series.

Time series were averaged over a whole-brain mask that was the insection of several masks: Probable gray matter voxels from a T1 map (magnitudes between 1200 & 1600), voxels with a mean CBF in a rest or paced breathing scan greater tha 5, and voxels with a significant BOLD response to the Valsalva task (p<0.01 uncorrected)

REFERENCES

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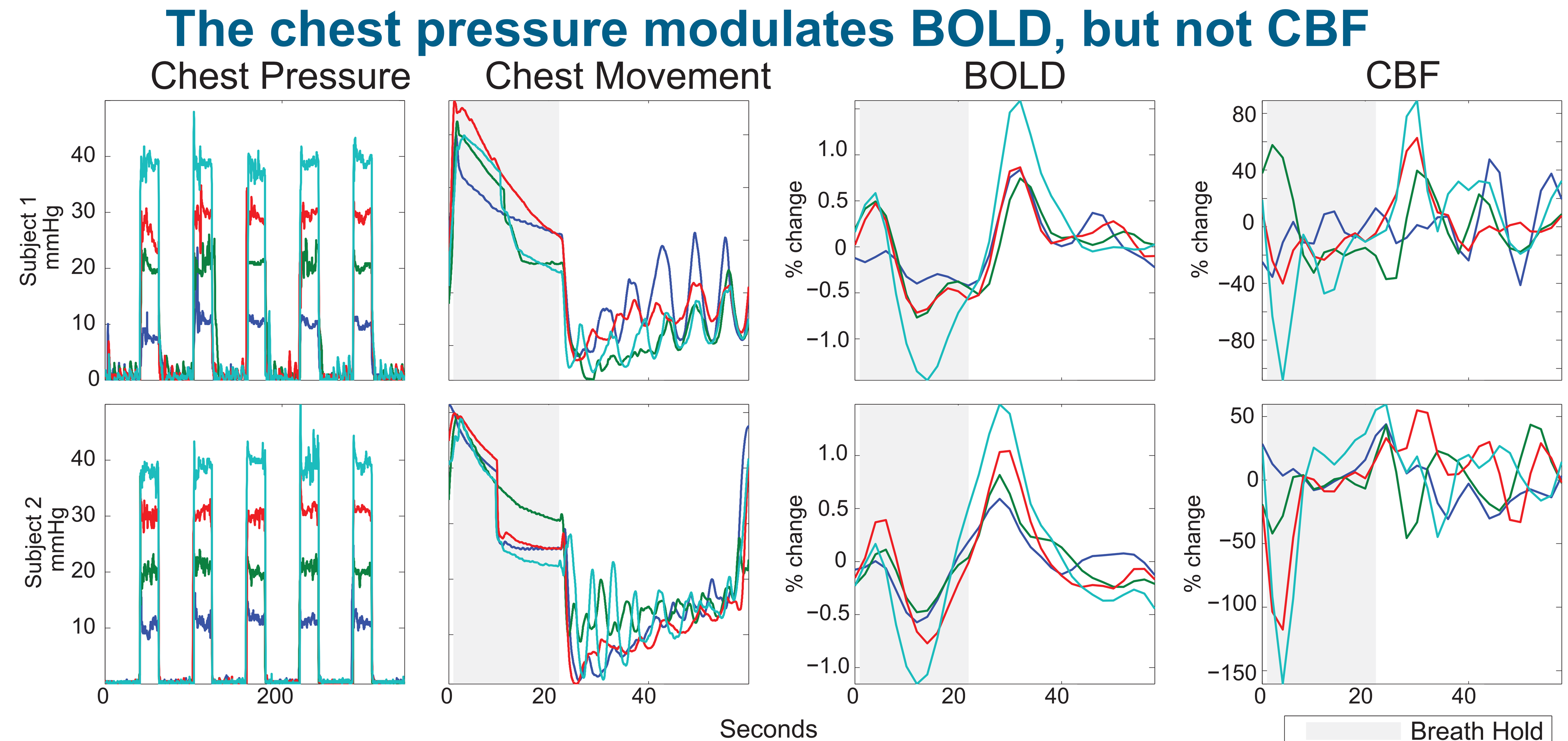
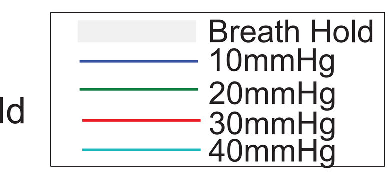
ACKNOWLEDGEMENTS

Paul Guillod wrote the stimulus presentation & pressure recording script in Presentation. Ronald Harper, George Dold and Thomas Talbot helped with the pressure recording sytem setup. Javier Gonzalez-Castillo and Vinai Roopchansignh helped and advised with data analysis and presentation

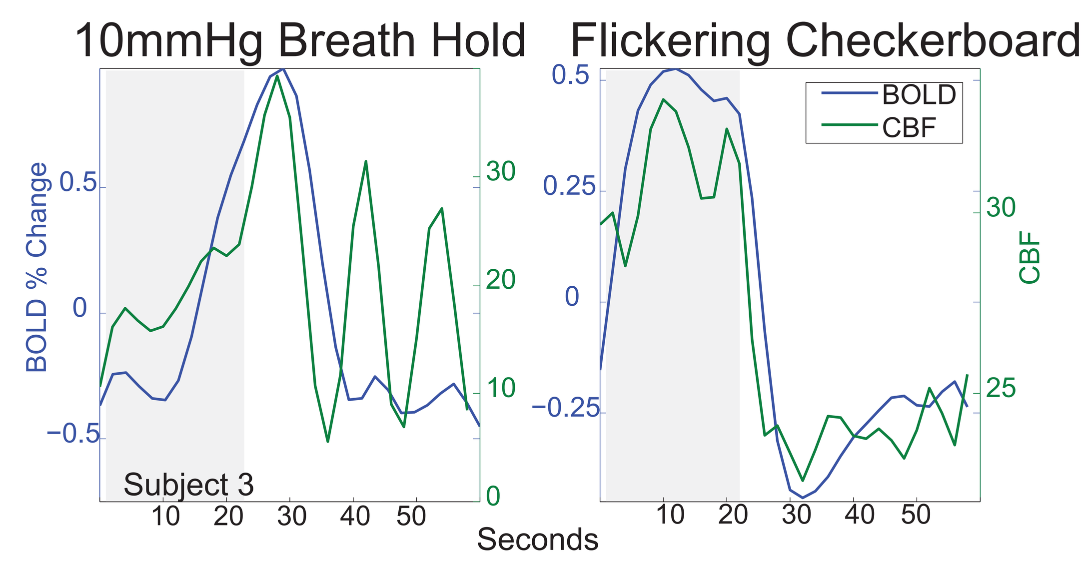
Supported by the NIMH Intramural Research Program

The chest pressure modulates BOLD, but not CBF





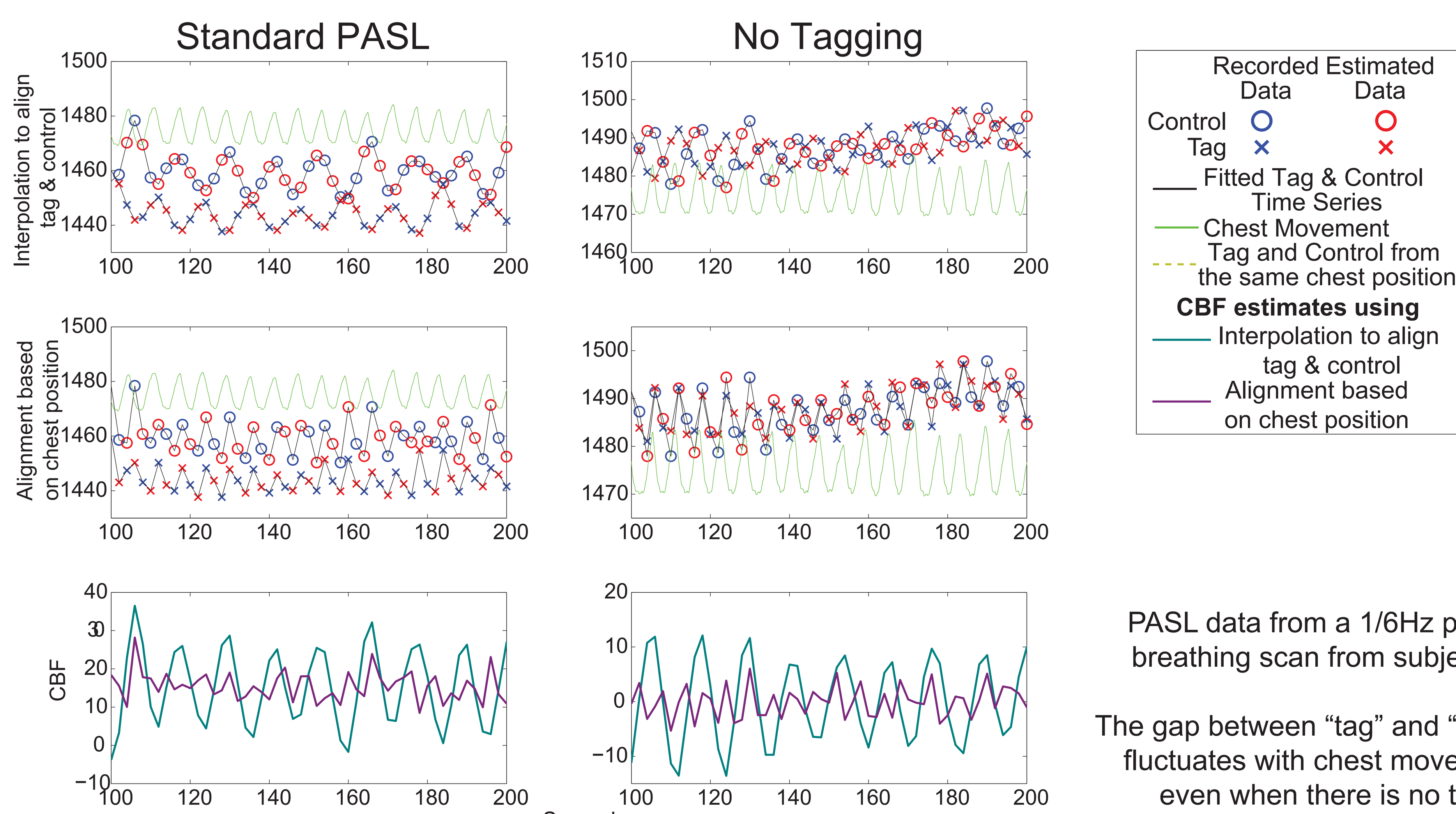
PCASL data averaged across gray matter voxels. 21s breath hold repeated 5 times
Task compliance is high, but CBF noise is bigger than the flow increase during the breath hold



To test whether the lack of CBF response was due to CBF having more noise than BOLD, we collected 20 trials of 10mmHg breath hold data and a flickering checkerboard task with the same timing. The data are averaged over voxels significant to both tasks

While there is a now a clear rise in CBF during the breath hold, there are also large CBF fluctuations during the paced breathing. BOLD and CBF responses have similar response shapes for the checkerboard task

Chest movement affects CBF calculations

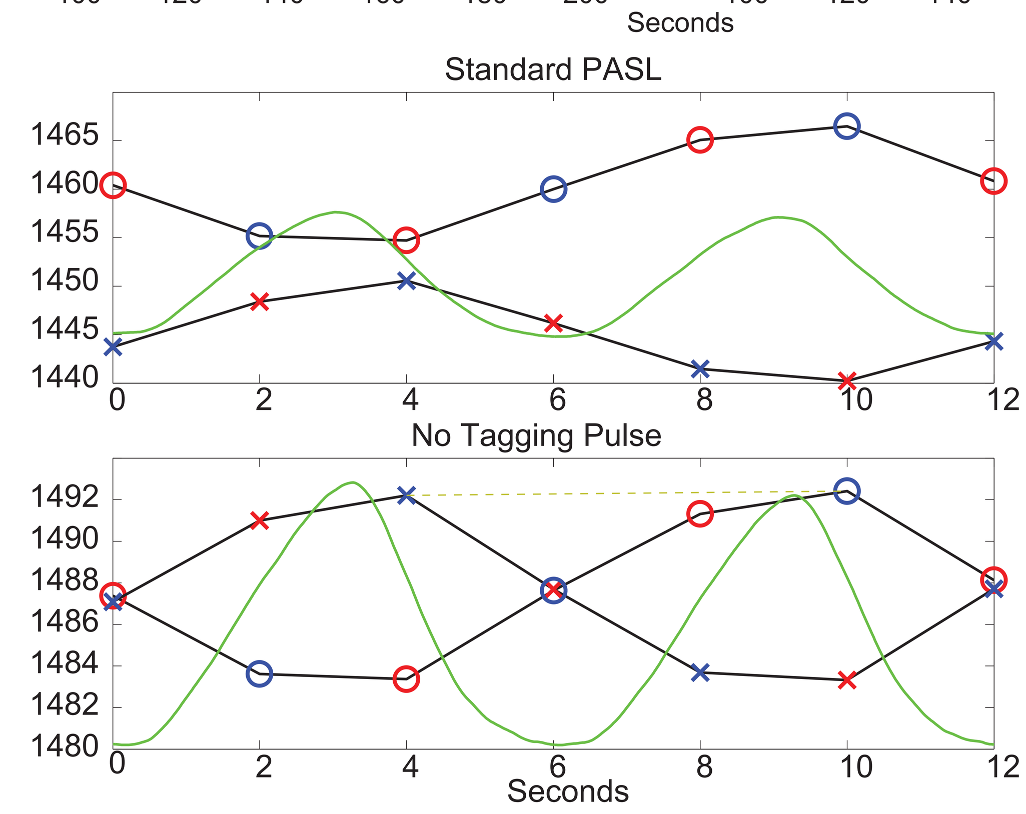


PASL data from a 1/6Hz paced breathing scan from subject 7.

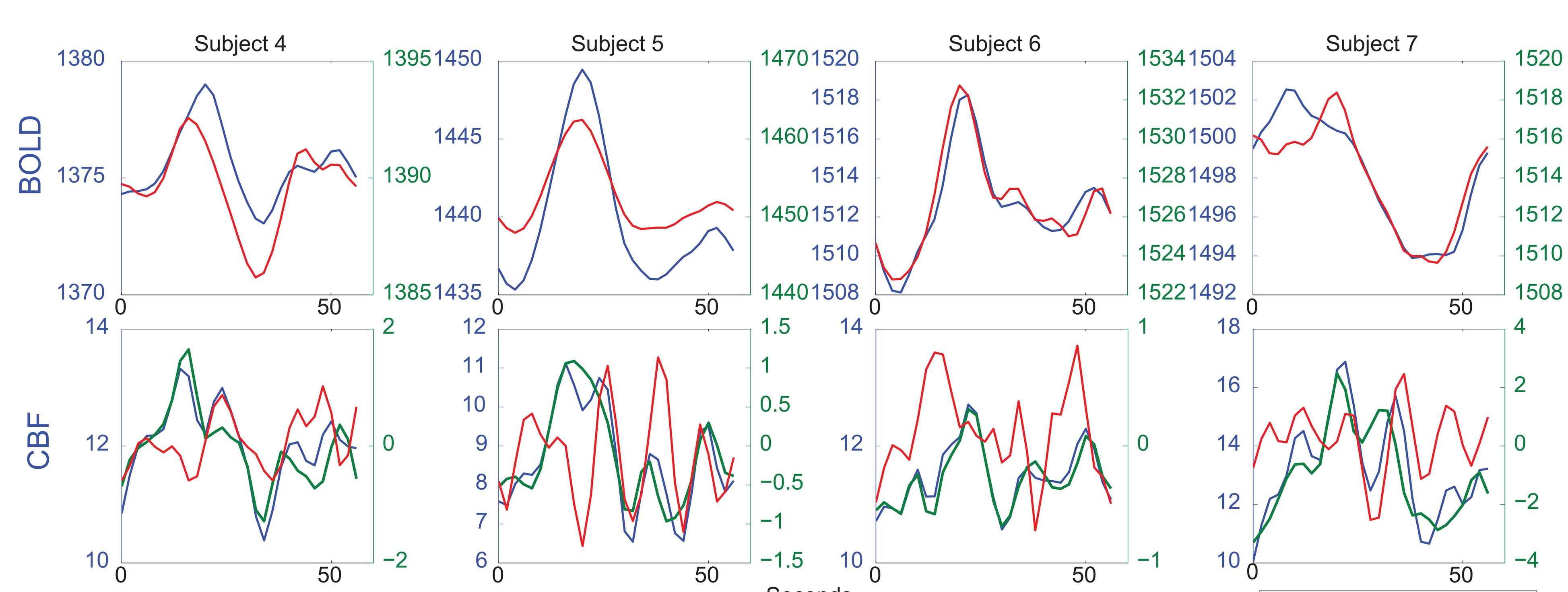
The gap between "tag" and "control" fluctuates with chest movement even when there is no tag (both are controls).

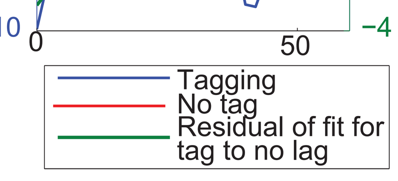
This causes a periodic CBF fluctuation at half the rate of chest movement since each tag occurs at the same chest movement position as 12 s earlier (4 s from tag-to-tag with 6 s chest movement cycles)

Instead of interpolation, shifting the time series by 3 volumes and causes the paired tags and controls to occur at the same chest positions. This removes the chest movement induced fluctuations in the CBF calculations



ASL analyses on tagged and untagged data help identify and slightly decrease the artifact during the Valsalva task





PASL data with 18-24 10mmHg breath holding for data with and without tagging
Regressing out the fluctuations from the no tag runs slightly reduces the paced breathing artifacts in the tagged runs

CONCLUSIONS

Cerebral blood flow estimates are very sensitive to chest movement for multiple ASL sequences

By having volunteers breath at a constant rate, we were able to identify and characterize the effects of chest position

Accounting for chest movement might help reduce a major source of temporal noise in CBF estimates that is usually overlooked when subjects breath freely

Contact: handwerkerd@mail.nih.gov