CEREBROVASCULAR CHANGES DURING THE VALSALVA MANEUVER MEASURED WITH VASO

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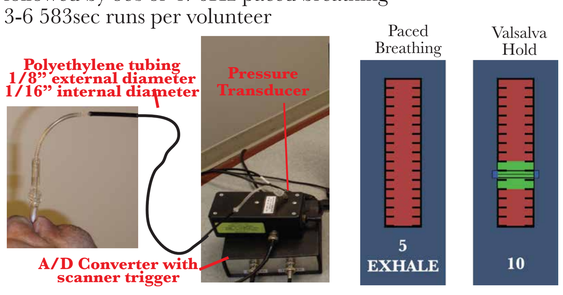
INTRODUCTION

The Valsalva Maneuver involves an increase in chest pressure during a breath hold that alters blood pressure and heart rate (Dawson 1999). For a constant breath hold duration, the fMRI BOLD-weighted response scales with chest pressure magnitude. Both the undershoot during the breath hold and the signal peak after the hold ends increases with increasing pressure (Wu 2015). This parametric modulation of cerebrovascular reactivity by pressure has the potential to be used as a relatively simple cerebrovascular reactivity probe, but the mechanisms underlying the fMRI signal changes aren't fully understood. In this study, we use Vascular Space Occupancy (VASO) (Lu 2003) to measure BOLD-weighted and blood volume-weighted signal changes during Valsalva challenges with the goal of better understanding how the Valsalva Maneuver affects MRI signal changes.

VALSALVA TASK

Task Design

10 cycles of 15s Valsalva Maneuver (28-35mmHg pressure target) followed by 39s of 1/6Hz paced breathing
3-6 583sec runs per volunteer



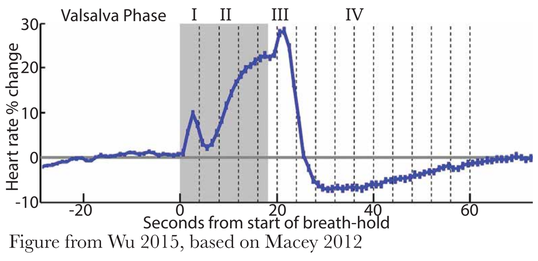


Figure from Wu 2015, based on Macey 2012

The Valsalva Maneuver has a distinct pattern of heart rate, cerebral blood flow, and cerebral blood pressure changes during and after the breath hold

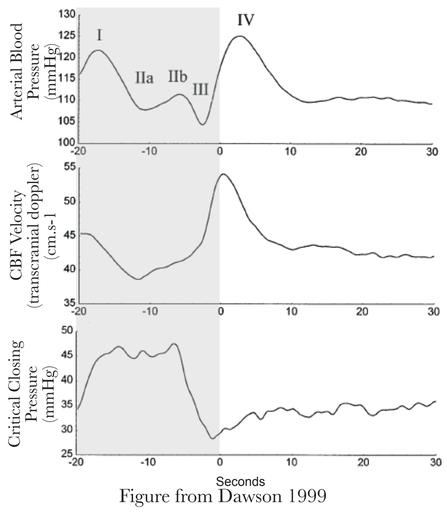
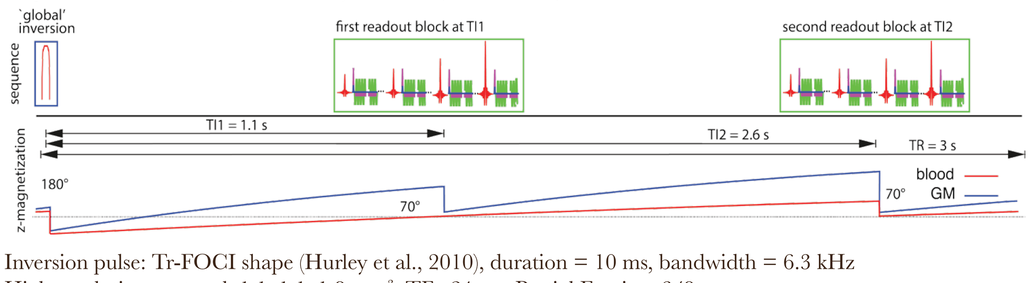


Figure from Dawson 1999

VASO

SIEMENS Magnetom 7T, 32 channel Nova coil
Sequence: SS-SI VASO (Huber 2014): TR = 3 s, TI1 = 1.2 s, TI2 = 2.7 s



Inversion pulse: Tr-FOCI shape (Hurley et al., 2010), duration = 10 ms, bandwidth = 6.3 kHz
High-resolution protocol: 1.1x1.1x1.8 mm^3, TE=24 ms, Partial Fourier=6/8
Low-resolution protocol: 2x2x2 mm^3, TE=22ms, Partial Fourier=off

VASO might be contaminated by inflow of fresh (non-inverted) blood (Donahue et al., 2006). This is particularly challanging in hyapercapnia related tasks because the arterial arrival time is reduced by up to 20% (Ho et al., 2011). These inflow effects are minimized here by the aplication of a custom designed inversion pulse with an adjustable inversion efficiency. (Here efficiency reduction = 7%.)
Readout: 3D EPI (Huber 2016b), GRAPPA = 2, Kernel size = 2 x 3, #reference lines = 24, ACS lines = FLASH (Talagala et al., 2016), phase correction = local,
Slab parameters: Slab excitation pulse duration 5 ms, variable flip angle 11°-90° to minimize across-segment smoothing, 10 slices/segments per slab.
To ensure proper spin inversion performance despite SAR and field inhomogeniety constraints at 7T, a MAFI B1+ map (Boulant, 2009) was acquired for every participant.

Data processing

Data were preprocessed using AFNI. Volumes were motion corrected wtihin subject. The BOLD time series are the volumes without blood nulling. The VASO time series are the ratio of the nulled volume over the average of the flanking non-nulled volumes. Statistical significance maps ($p<0.001$ uncorrected) were separately caculated for BOLD and VASO data using a finite impulse response model. Since, SS-SI VASO data contain two different T1 weightings, a MP2RAGE-like Block model could be used to obtain quantitative T1-maps in functional EPI space (Huber, 2016a). Voxels with T1 values less than 4900ms that were significant in both BOLD and VASO were included in the clustering analyses. The average trial response for BOLD and VASO (18 volumes each) were separately scaled to mean 0 and standard deviation of 1. Ward's Heirchical Clustering was run on these 36 volume vectors to identify clusters of voxels with similar BOLD and VASO response models.

Response Predictions

	Microvasculature BOLD	Microvasculature VASO	Large veins BOLD	Large veins VASO
[DeoxyHb] ↑	↓	—	↓	—
CBF ↑	↑	↓	↑	↓
CBV ↑	↓	↓	↓	↓

An increase in blood pressure could potentially increase CBV and CSF volume

Since the relationship between deoxyhemoglobin concentration, blood flow (CBF), and blood volume (CBV) might vary, one cannot predict the VASO response from BOLD. For example, during a breath hold, there is an initial decrease in CBF and an increase in [DeoxyHb] which results in a BOLD decrease. In VASO, the larger vasoconstriction in microvasculature would cause a VASO increase while the increase in blood pressure might passively expand large veins and cause a VASO decrease

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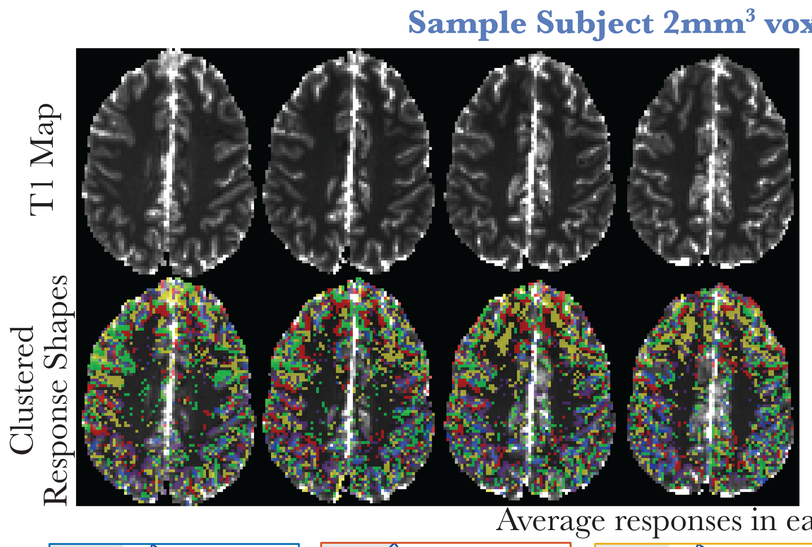
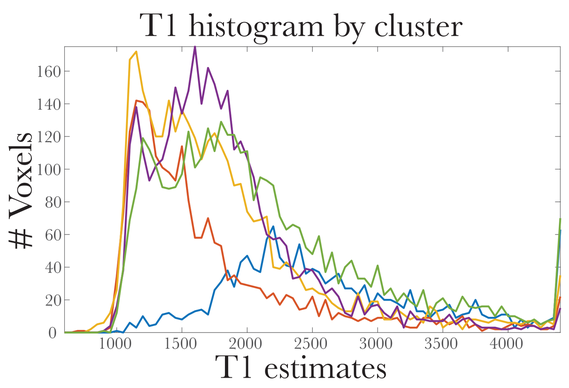
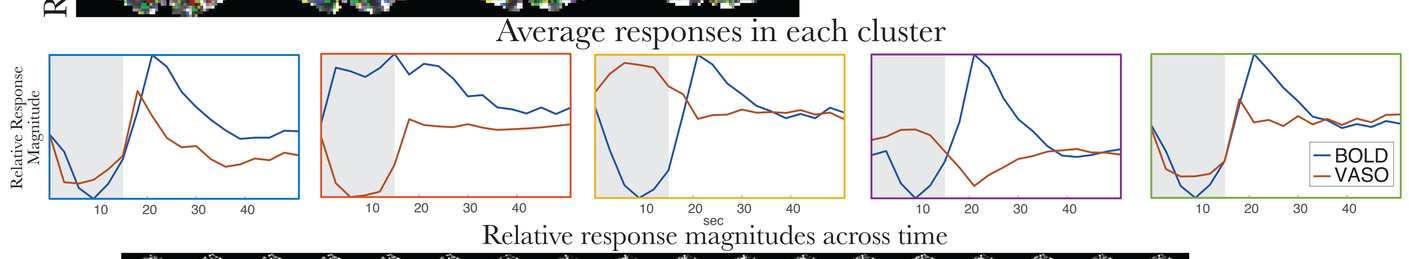
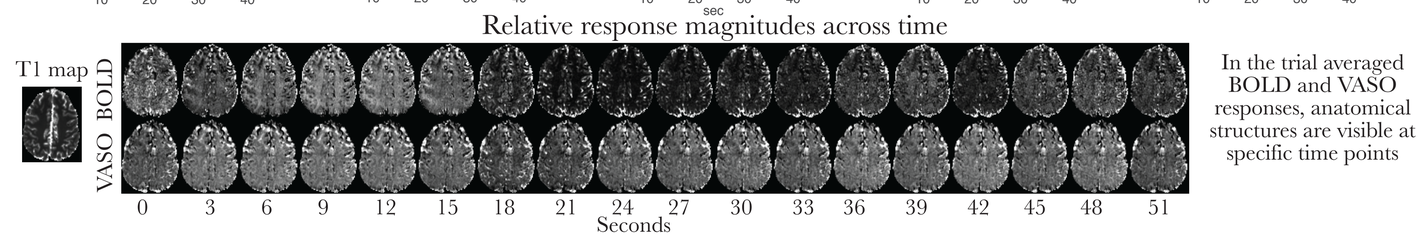
RESPONSE SHAPE PATTERNS

Sample Subject 2mm³ voxels (30 trials)



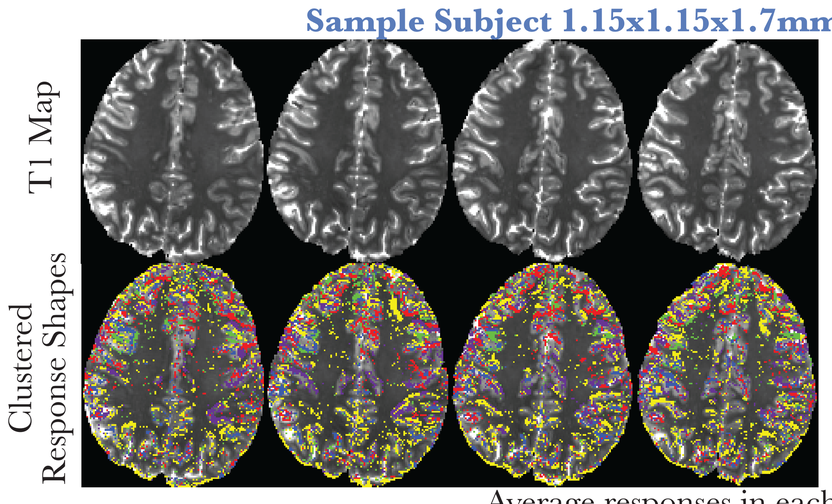


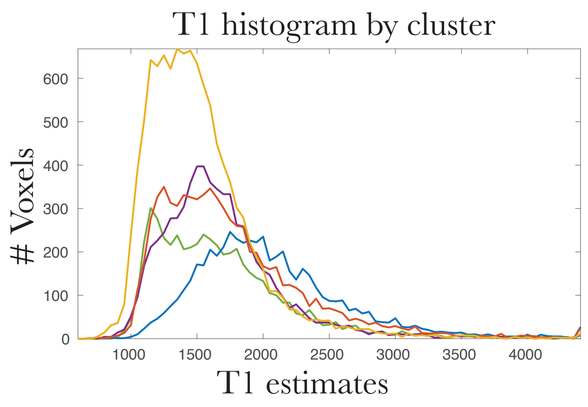


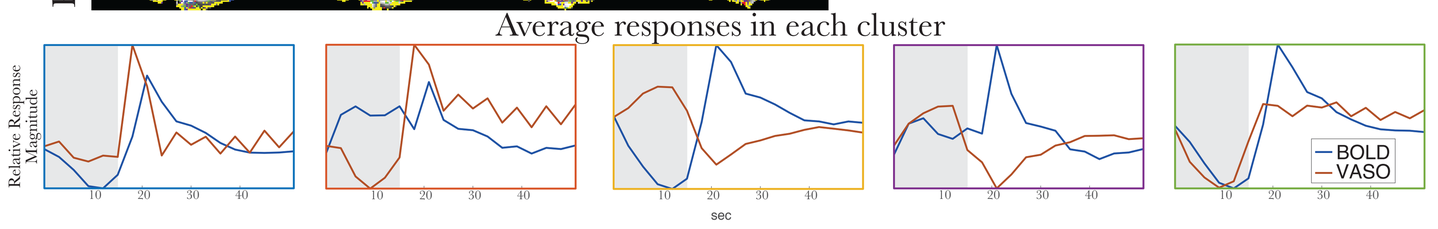


In the trial averaged BOLD and VASO responses, anatomical structures are visible at specific time points

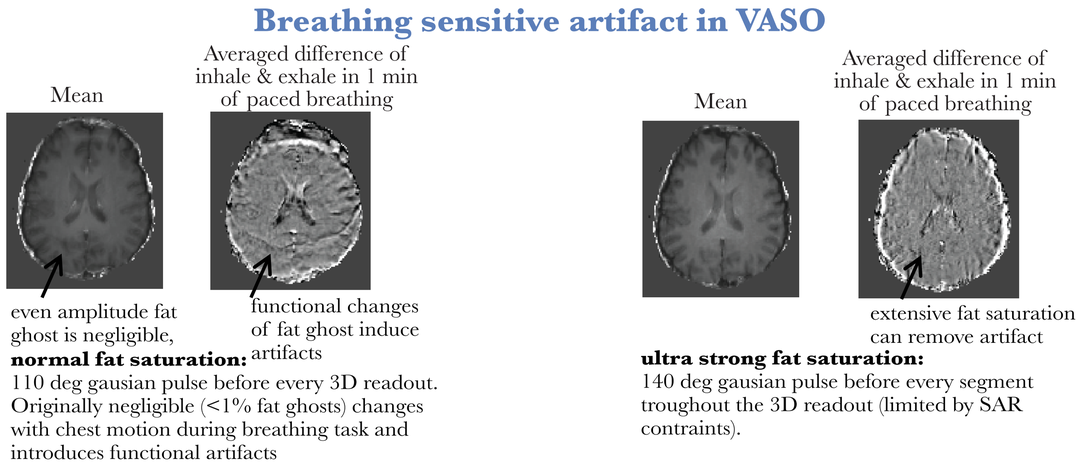
Sample Subject 1.15x1.15x1.7mm³ voxels (60 trials)







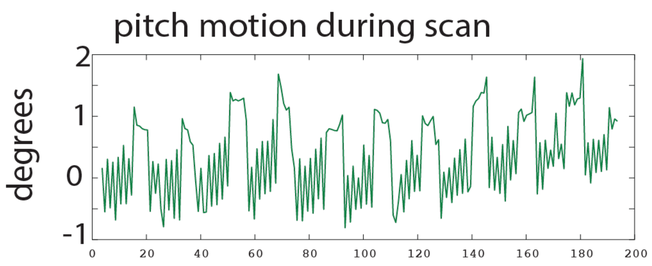
Breathing sensitive artifact in VASO



normal fat saturation:
110 deg gausian pulse before every 3D readout. Originally negligible (<1% fat ghosts) changes with chest motion during breathing task and introduces functional artifacts

ultra strong fat saturation:
140 deg gausian pulse before every segment troughout the 3D readout (limited by SAR contraints).

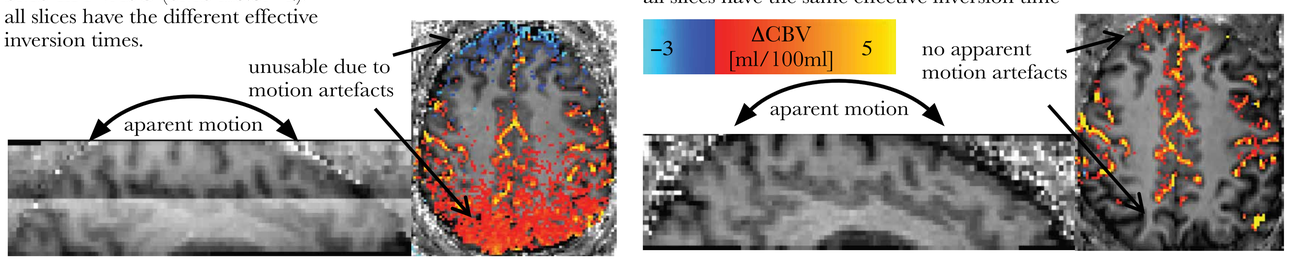
Motion artifact for SMS-EPI vs. 3D-EPI VASO



Valsalva can be contaminated with task-correlated field variations, manifesting as apparent motion.

SMS-EPI VASO (SMS factor=2):
all slices have the different effective inversion times.

3D-EPI VASO (z-GRAPPA=2):
all slices have the same effective inversion time



CONCLUSIONS

As seen in Wu et al 2015, the BOLD reseponse usually decreases during the Valsalva breath hold and increases afterwards before returning to baseline
For voxels with similar BOLD responses, the VASO response varies more. For voxels in clusters with T1 values that are closer to gray matter, the VASO response also seems to decrease during the hold implying a gray-matter CBV increase.
With higher resolution voxels, we sometimes see a response spike in BOLD and VASO after the hold
Since this task has large, global blood flow changes and task-correlated chest movements, it has proven useful for highlighting and addressing artifacts that are hidden in more subtle studies.

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