Assessment of longitudinal cerebrovascular reactivity measurements based on breath-hold and resting state BOLD multi-echo fMRI

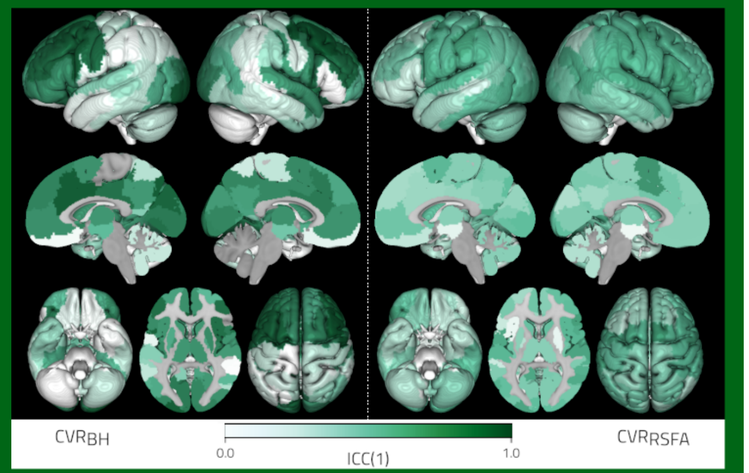
Stefano Moia[1], Rachael Stickland[2], Maite Termenon[1], Eneko Uruñuela[1], César Caballero-Gaudes[1], Molly Bright[2 3]

1. Basque Center on Cognition, Brain and Language, Donostia, Spain, 2. Physical Therapy and Human Movement Sciences, Feinberg School of Medicine, Northwestern University, Chicago, IL,
3. Biomedical Engineering, McCormick School of Engineering, Northwestern University, Evanston, IL

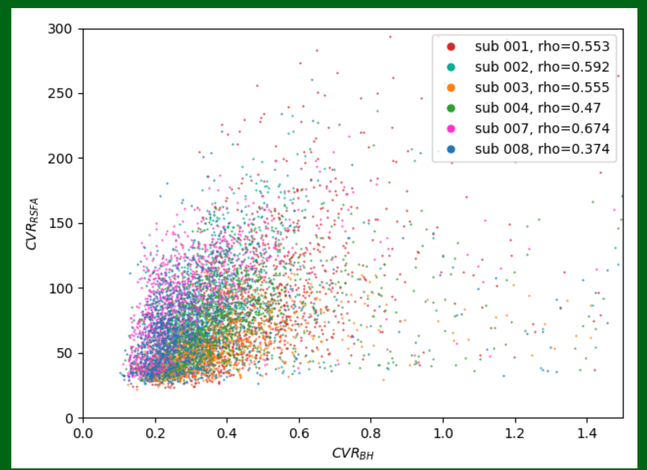
Email: **s.moia@bcbl.eu**

For more information, visit the website:
https://smoia.github.io/cvr-compare-bh-rs

CVR estimated from Breath-Hold fMRI is more reliable than CVR estimated from RSFA, but this effect shows substantial spatial variation.



Above: Figure 1. ICC(1) of CVR_{BH} and CVR_{RSFA}.
Below: Figure 2. CVR_{BH} vs CVR_{RSFA} for each subject.



Background

- Cerebrovascular Reactivity (CVR) can be measured with BOLD functional MRI and induced with Breath-Hold (BH) [1], but BH-derived CVR maps can be confounded by task-correlated movement, large vessel signals, and variability in task performance.
- Resting state (RS) fMRI data can be used to estimate CVR [2,3] with reduced concern over the aforementioned confounds.
- Resting State Fluctuation Amplitude (RSFA) is generally associated with physiological responses [4], however this surrogate metric may not map identical vascular parameters, and may not reflect the same underlying brain physiology compared to CVR.
- Parcellation is often adopted to reduce data dimensionality; when applied to CVR maps, reliability at the parcel level shows interesting spatial patterns [3].
- To our knowledge, no previous study has evaluated the reliability of CVR estimates beyond two scanning sessions.
- **Main aim**: Compare BH induced CVR and RSFA maps over ten sessions.

Results

- Fig. 1: At the parcel level, the reliability of positive CVR_{BH} is generally high, especially in frontal, occipital, and subcortical areas, but it shows extremely high spatial variability; CVR_{RSFA} has low reliability that is spatially more homogeneous. With the exception of few areas, both ICC(1) maps appear to be fairly symmetrical across hemispheres.
- Fig. 2: In most subjects, positive CVR_{BH} and CVR_{RSFA} show a moderate spatial correlation, that varies greatly depending on the subject.
- Fig. 3: At the voxel level, the reliability of positive CVR_{BH} is systematically higher than that of CVR_{RSFA}.

More results in the companion website.

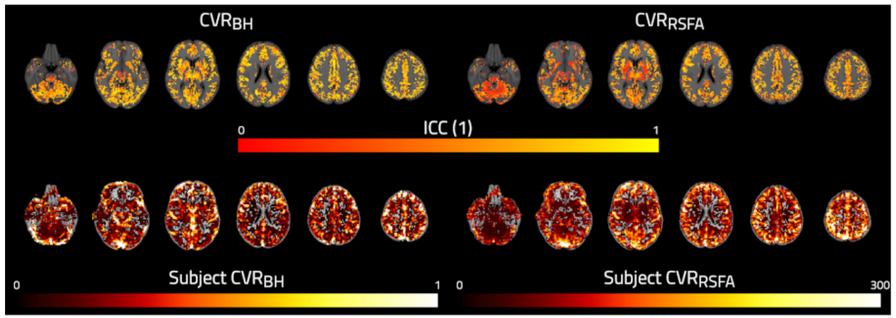


Figure 3. Above: Voxelwise ICC of CVR_{BH} (left) and CVR_{RSFA} (right); Below: maps of a session of a representative subject.

Methods

- Six healthy volunteers underwent 10 MRI sessions in a 3T Siemens PrismaFit scanner, spaced 1-week apart at the same time of day.
- A RS and a BH task adapted from [5] were administered at each session while collecting ME-fMRI data. CO_2 levels were measured using a nasal cannula with gas analyzer (ADInstruments) and BIOPAC MP150 system. A T1-w image was collected during each session. The parameters can be found in the website version.
- To obtain CVR maps from the BH fMRI data, data preprocessing and analysis followed the steps described in [6] (CVR_{BH}).
- CVR maps based on RS fluctuation amplitude (CVR_{RSFA}) were computed using AFNI's 3dRSFC [7], after applying the same preprocessing described in [6] on RS data.
- Both CVR_{BH} and CVR_{RSFA} maps were normalised to the MNI152 template, then the average value of 118 parcels were obtained using the Schaefer 2018 atlas [8] (100 regions) with the cerebellum and subcortical parcellation of the Destrieux 2010 atlas [9] (18 subcortical and cerebellar regions).
- Due to the physiological difference between positive and negative CVR_{BH}, voxels with positive CVR_{BH} were analysed separately from voxels with negative CVR_{BH}. Only those voxels that were always positive for all sessions and all subjects were considered for further analysis.
  The results of the analysis on negative CVR_{BH} voxels is on the companion website.
- ICC(1) [10] was computed for each parcel (figure 1) and for each voxel (figure 3) adopting subjects as objects of measurements and sessions as observations.
- Spearman's rho between CVR_{BH} and CVR_{RSFA} was computed for each subject across all parcels and sessions.

Bibliography

1. Kastrup A et al (2001), MRI; 2. Liu P et al (2017), Neuroimage; 3. Lipp I et al (2015), Neuroimage;
4. Kannurpatti SS & Biswal BB (2008), Neuroimage; 5. Bright MG & Murphy K (2013), Neuroimage;
6. Moia S, Stickland R et al (2020), accepted in Proceedings of the 42nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Montreal, Canada; 7. Taylor PA & Saad ZS (2013), Brain Connect.;
8. Schaefer A (2018), Cerebral Cortex; 9. Destrieux C et al (2010), Neuroimage;
10. McGraw K & Wong S (1996), Psychological Bulletin.

Acknowledgements

Research supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under award number K12HD073945, the European Union's Horizon 2020 research and innovation program (Marie Skłodowska-Curie grant agreement No. 713673), a fellowship from La Caixa Foundation (ID 100010434, fellowship code LCF/BQ/IN17/11620063), the Spanish Ministry of Economy and Competitiveness (Ramon y Cajal Fellowship, RYC-2017- 21845), the Spanish State Research Agency (BCBL "Severo Ochoa" excellence accreditation, SEV- 2015-490), the Basque Government (BERC 2018-2021 and PIBA_2019_104), the Spanish Ministry of Science, Innovation and Universities (MICINN; FJCI-2017-31814)