Spatial filter vs short channel regression for removing global component of fNIRS

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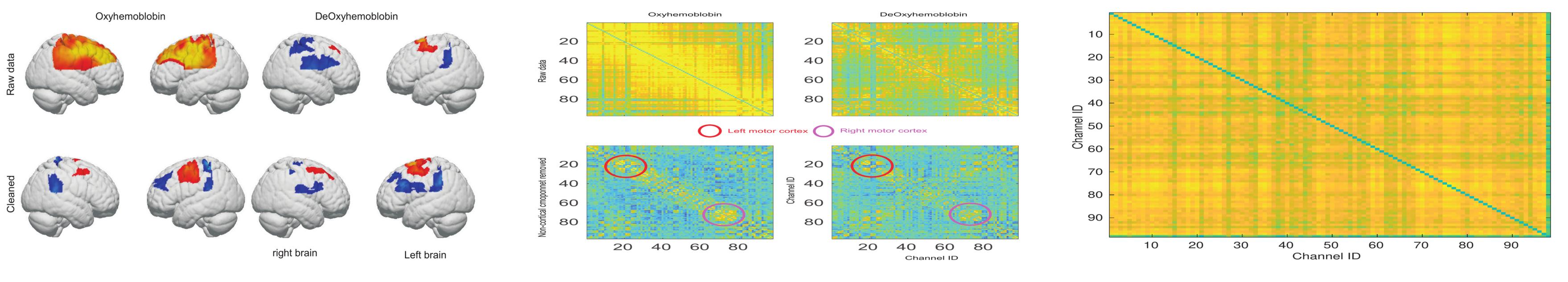
Abstract

In fNIRS, non-cortical components are related to blood pressure and respiratory activities
Two methods: global component removal and short channel removal are presented and compared using fnirs data during fingertapping task

Non-cortical component in fNIRS



(a) fNIRS activity (b) fNIRS correlation (c) fMRI, correlation

(a,b), upper panels are raw fNIRS data, lower panels are global component removed data, (b) the red circles shows either contralateral or ispylateral mortor cortex where the correlation should be high. (c) the voxels of the fMRI image near the fNIRS channels. (b,c) X Y axes are channel IDs.

Non-cortical components [1] can manifest as global activity, especially in the oxyhemoglobin signal [2], and as global connectivity, in both the oxy and deoxy hemoglobin signals. They may also reduce the activity in the deoxyhemoglobin signal in cases of blood volume increasing. They are also prevalent in fMRI [3] so that the first principle component is known to be non-cortical.

Short Channel regression (SCR)

Short channel data (S) contains non-cortical components from the scalp and little task-related components [4, 5]. Using linear regression, the non-cortical component in fNIRS data (Y) can be estimated and removed. However, to our best effort, the SNR of the short channel is smaller than 1.

$$Y = Y^{task} + Y^{non-cortical} + \epsilon;\ and\ S = S^{non-cortical} + S^{noise}$$

$$Y \approx Y^{task} + \beta\, S^{non-cortical} + \epsilon\ |_{S^{noise} \approx 0}$$

$$\hat{\beta} \approx \frac{\beta}{1 + SNR^{-1}}\Big|_{SNR\, =\, rms(S^{non-cortical})/rms(S^{noise})}$$

Global component removal (GCR)

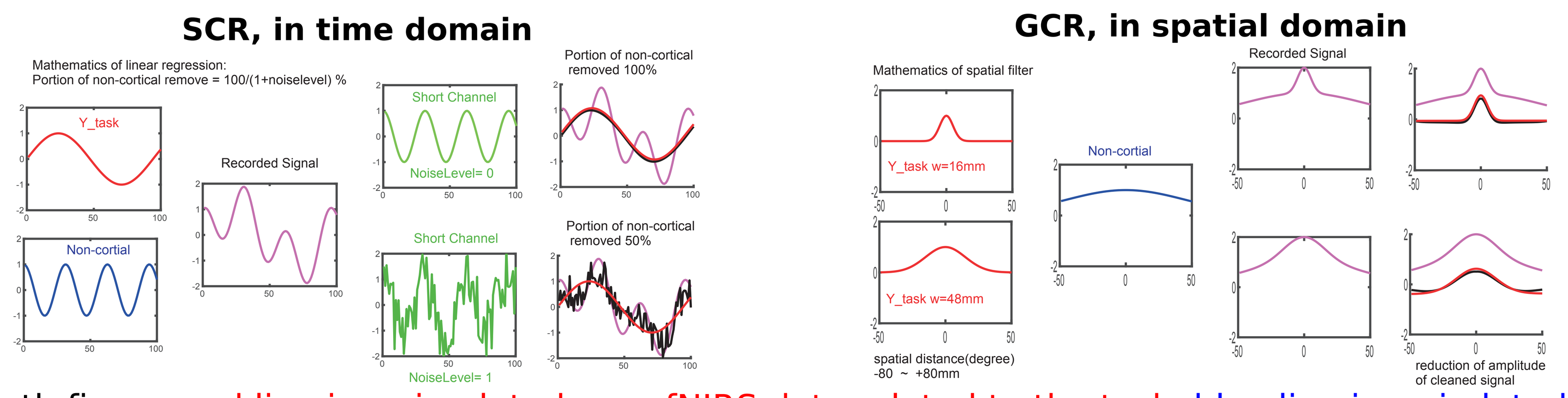
Task-related activity Y^{task} has limited spatial extent, while the non-cortical components are global. Using a Gussian spatial smooth with a kernel radius of $\sigma = 46^{\circ}$, the non-cortical component can be separated [2]. d is the sphere surface distance between the center and a surrounding location. (QR code for MATLAB code in github)

$$global = Y^{task} \circledast e^{\frac{-d^2}{2\sigma^2}} + Y^{non-cortical} \circledast e^{\frac{-d^2}{2\sigma^2}} + \epsilon \circledast e^{\frac{-d^2}{2\sigma^2}}$$

$$\approx 0 + Y^{non-cortical} + 0\ |_{\ the\ size\ of\ Y^{task} >> \sigma}$$

$$\approx \alpha\, Y^{task} + Y^{non-cortical} + 0\ |_{\ \alpha > 0;\ if\ Y^{task}\ size\ is\ similar\ to\ \sigma}$$

Limitations



In both figure, red line is a simulated pure fNIRS data related to the task. blue line is a simlated pure non-cortical component and the the purple line is the simulated recorded data the sum of the red and blue trace.The black trace are the cleaned data after processing. For SCR the green lines simulate two types of recorded short channel data For GCR the red lines simulate two spatial extents of the fNIRS activity related to task

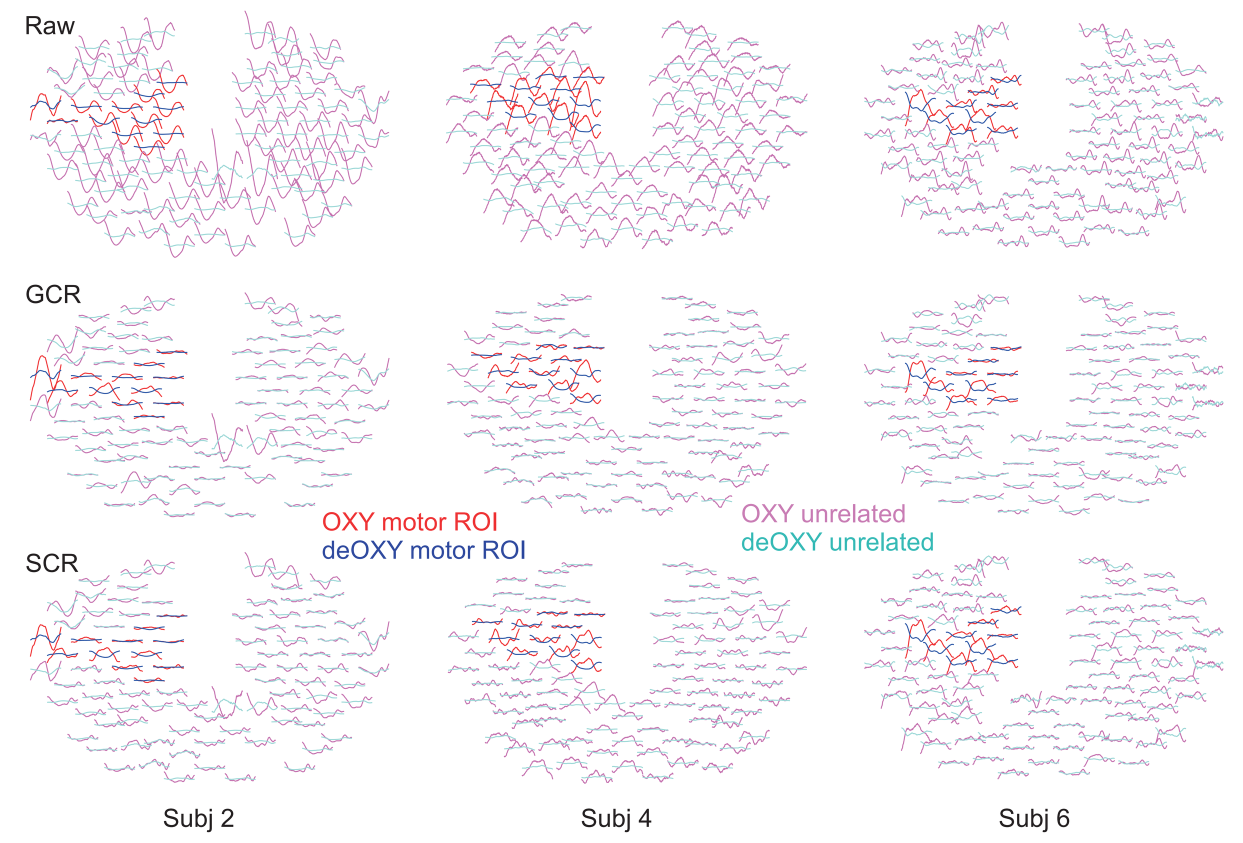
Both methods have limitation due to underlying mathematics.

- If signal-noise-ratio = one , 50% of non-cortical-components remain and extra noises are added into the SCR processed signal (black).
- Short channel does not contain the non-cortical component in the brain, as shown in fMRI data.
- When the size of the activity is either large or close to size of the optode coverage, the GCR processed activity (black) will be smaller than the actual one (red line).

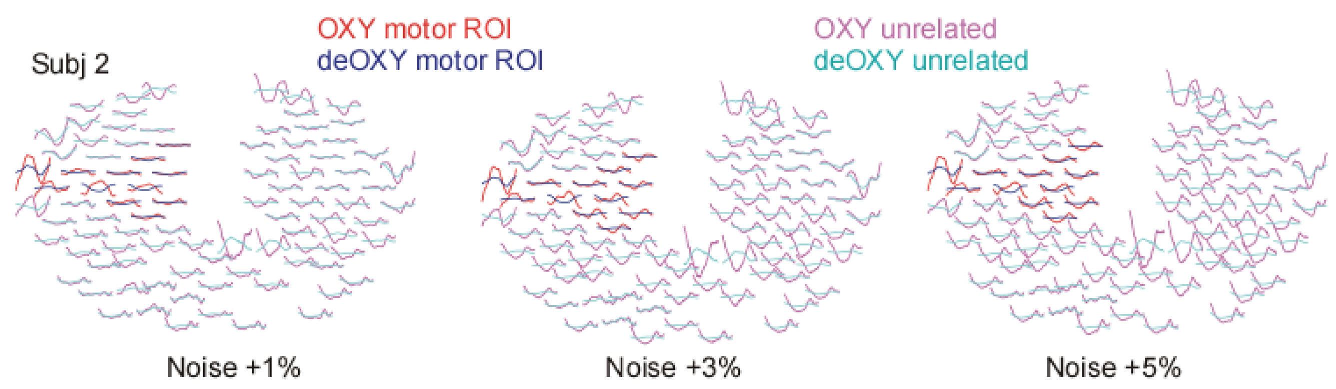
Result

SCR and GCR target the same underlying physiological phenomenon. As expected, our previous study [6] showed that they perform similarly. However, another study [7], which have similar data and analysis showed significantly difference.

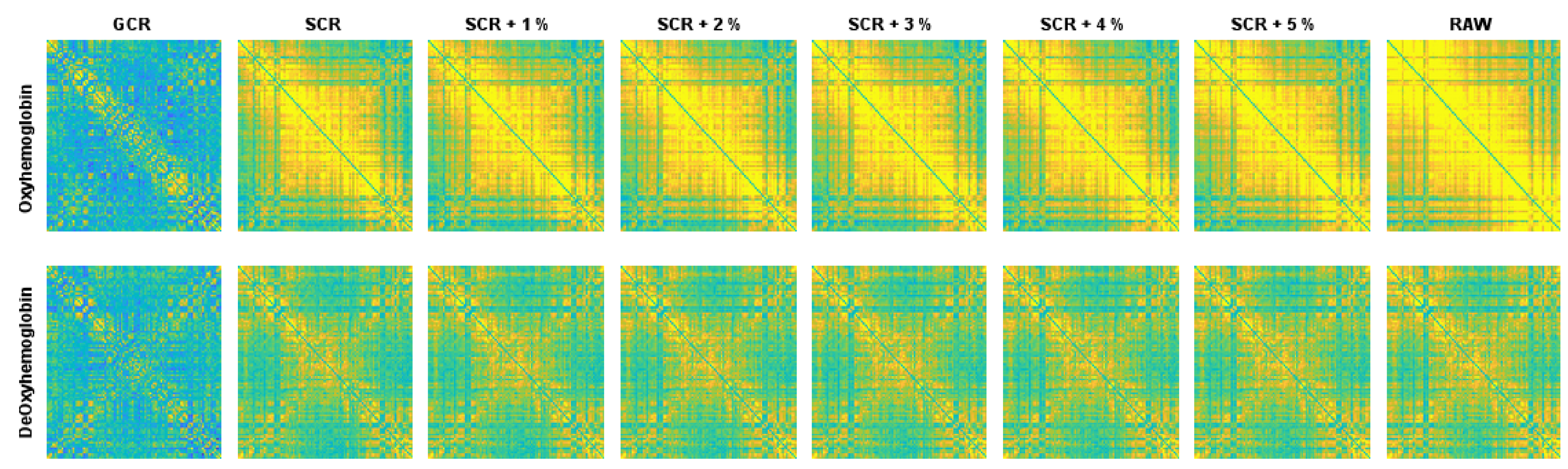
Similarity between GCR and SCR



Adding random noise in short channel



Data from one subject demonstrate that, by adding noise into our short channel data, more and more non-cortical components remain not removed.



The effect of adding random noise on the cross-channel correlation. The average of the correlation among channels for 8 subjects: The SCR method is not effective in removing the cross channel correlation induced by non-cortical components (such as Mayer waves).

Conclusion

fNIRS signal contains global components. Some of them are task related, probably due to fixed respiratory pattern related to the timing of the task. Other components mainly contribute to to cross channel correlation and will affect the results of connectivity or cross brain synchrony analyses. SCR and GCR both have strength and limitation and should be applied appropriately. In paticular, the short channel data should be acquired with high signal to noise ratio. Global components are signal for the short channel.

Reference

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