Correction of induced functional connectivity in filtered resting state fNIRS data

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Introduction:

FNIRS is a non-invasive neuroimaging modality for monitoring brain oxygenation levels (Strangman et al., 2002). Resting-state functional connectivity (FC) methods applied to fNIRS data assume that the signals are white. If this assumption is violated, statistical tests are invalid and connectivity may be artificially recorded. Temporal filtering is known to cause a violation of the whiteness assumption, and corrections to statistical tests of connectivity have been proposed for fMRI data (Davey et al., 2013). However, such corrections assume that unfiltered signals are white. It is known that fNIRS signals are typically not white prior to preprocessing (Fernandez Rojas et al., 2017). We propose a correction to statistical tests of functional connectivity, that accounts for both non-white fNIRS data and the further effects of filtering.

Methods:

Theoretical: The impact of non-white fNIRS spectra on connectivity statistics, in conjunction with temporal filtering, was analytically established. A statistical correction was proposed to restore the validity of the connectivity estimates.
$\mathrm{corr}(x^f,y^f) \sim N(\rho,(1-\rho^2)^2/D)$
$D=(\Sigma k\ \sigma(k)^2 f(k)^2)^2/\Sigma k\ (\sigma(k)^2 f(k)^2)^2$
where x^f, y^f are filtered fNIRS signals with underlying correlation ρ. D is the corrected degrees of freedom. $\sigma(k)^2$ is the sample variance across channels for each frequency k. f(k) denotes the frequency response of the filter.
Simulations: White Gaussian noise, coloured noise using empirical fNIRS spectra and filtered coloured noise using a Butterworth bandpass filter were simulated. Null hypothesis distributions for Fisher's z-transformation and Student's t-statistic were generated. 95% confidence intervals using z- and t-statistics and our proposed correction were calculated.
Experiments: Two subjects resting state fNIRS data from (Jahani et al., 2018) were motion corrected (Wang & Seghouane, 2019) and filtered using a Butterworth bandpass filter. The sample variance across channels, standardised to cater for varying channel power, were used to characterise the fNIRS frequency spectra. A seed channel was selected in sensorimotor region (Mesquita et al., 2010). Correlation matrices and seed-based correlation maps derived from z-scores with 95% CIs (Bonferroni corrected) were compared between uncorrected and corrected data.

Results:

For simulated data, the variance of sample correlation for white signals (Fig.1A,E) is, as predicted by analysis, less than that of non-white fNIRS spectra (Fig.1B,F). This artificially induces correlation if the statistical tests are not modified appropriately. Filtering exacerbates the problem by further increasing the variance of sample correlation estimates (Fig.1C,G). After the proposed correction, the variance of sample correlation and appropriate CI have been restored, thereby avoiding artificially induced correlation (Fig.1D,H). Connectivity of unfiltered resting state fNIRS data, without correction to the statistical tests (Fig.2A,D,G,J) show remarkably high levels for both subjects. The filtered fNIRS data without correction (Fig.2B,E,H,K) show further increased connectivity, in agreement with our empirical results. Corrected estimates for filtered fNIRS data (Fig.2C,F,I,J) show substantially fewer significant correlation estimates, thereby providing more specific regional functional connectivity.

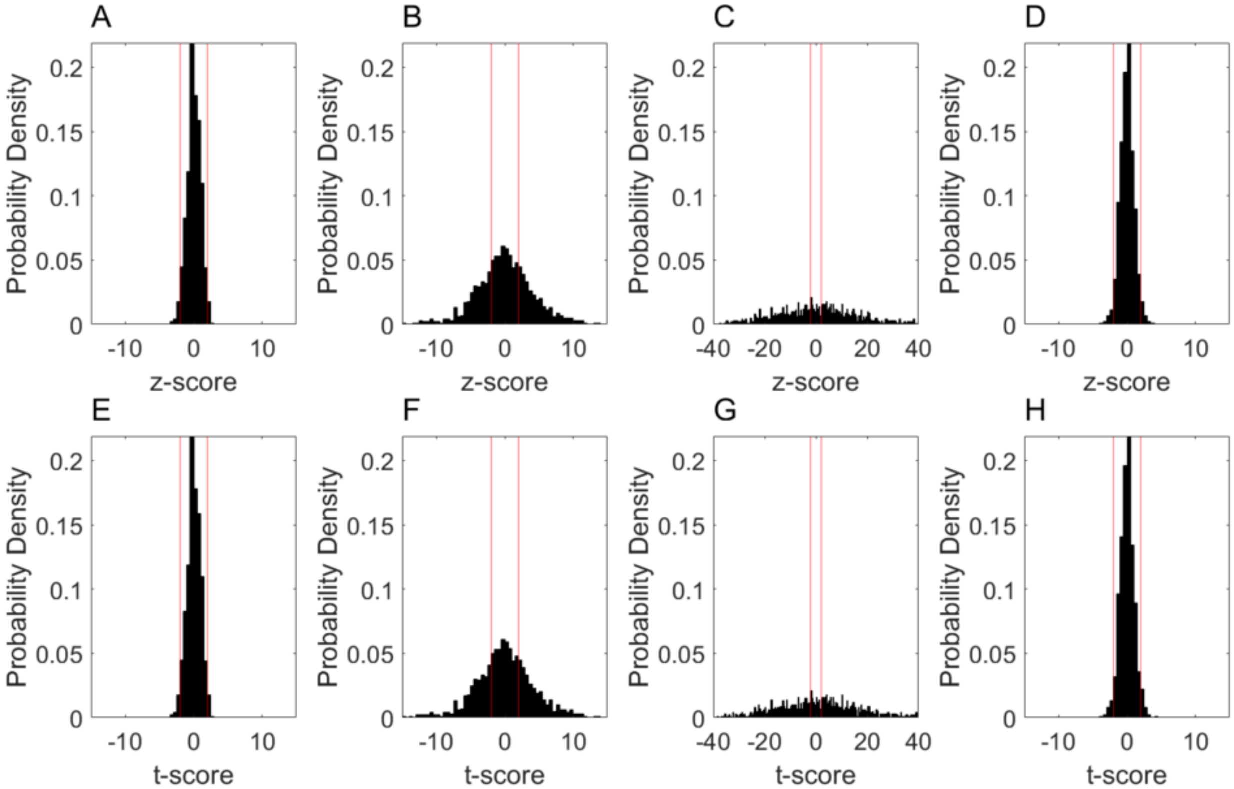

Figure 1: Empirical distributions of Fisher's-z and Student's-t, correlation test variates for signals with different underlying frequency spectra, showing confidence intervals derived for the standard assumption of white input signals. True underlying correlation was $\rho_{x,y}= 0$, T=9000, for all signals. A 3rd-order Butterworth band-pass filter (0.01-0.1Hz) was applied. Note the changes in z-score/t-score range in panel C and G, resulting from significant changes in sample correlation variance. **A:** z-scores for white Gaussian noise. **B:** uncorrected z-scores for coloured noise with empirical fNIRS spectra. **C:** uncorrected z-scores for filtered coloured noise with fNIRS spectra. **D:** corrected z-scores for filtered coloured noise with fNIRS spectra. **E:** t-scores for white Gaussian noise. **F:** uncorrected t-scores for coloured noise with empirical fNIRS spectra. **G:** uncorrected t-scores for filtered coloured noise with fNIRS spectra. **H:** corrected t-scores for filtered coloured noise with fNIRS spectra. Red lines: the lower/upper limit of the 95% confidence interval.

(https://files.aievolution.com/prd/hbm2101/abstracts/abs_1171/fig1.png)

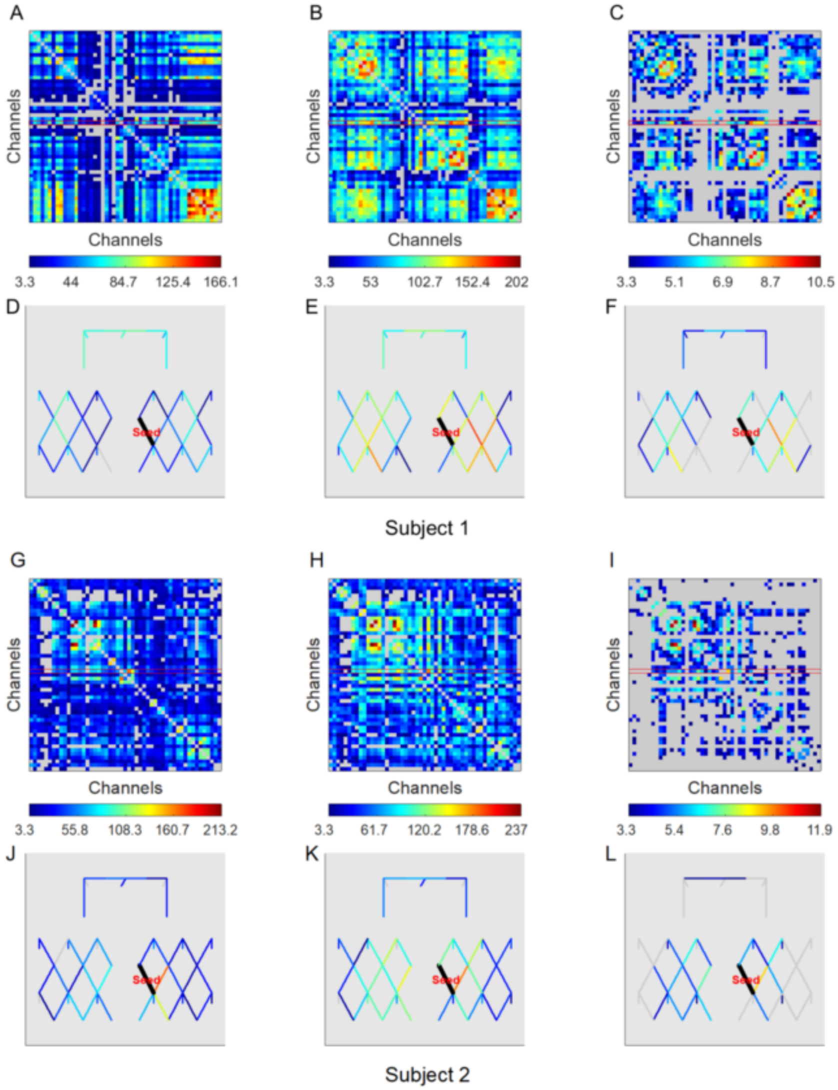

Figure 2: Correlation matrices and seed-based connectivity maps derived from sample correlation values for unfiltered, filtered experimental fNIRS signals, significant test using Fisher's z-transformation, threshold at *p*<0.05 (Bonferroni corrected). A 3rd-order Butterworth band-pass filter (0.01-0.1Hz) was applied. Subject 1: subplots A-F. Subject 2: subplots G-L. **A, G:** uncorrected z-scores matrix for unfiltered fNIRS signals. **B,H:** uncorrected z-scores matrix for filtered fNIRS signals. C, I: Corrected z-scores matrix for filtered fNIRS signals. **D, J:** uncorrected seed-based z-score map for unfiltered fNIRS signals. **E, K:** uncorrected seed-based z-score map for filtered fNIRS signals. **F, L:** corrected seed-based z-score map for filtered fNIRS signals. Grey: insignificant correlation. Red rectangle: seed channel in the correlation matrix. The thicker line and red text in the seed-based spatial map: seed channel.

(https://files.aievolution.com/prd/hbm2101/abstracts/abs_1171/fig2.png)

Conclusions:

The variance of sample correlation and associated test variates is higher for fNIRS data with coloured frequency spectra, than white. We have proposed a method to correct the induced correlation by modelling the coloured spectra. Simulation results show successful restoration of the correlation induced by coloured spectra and temporal filtering. Experimental results demonstrate the ability of the correction technique to return more specific connectivity maps and accord with published fNIRS connectivity results.

Modeling and Analysis Methods:

Connectivity (eg. functional, effective, structural) [2]
Task-Independent and Resting-State Analysis

Novel Imaging Acquisition Methods:

NIRS [1]

Keywords:

Modeling
Near Infra-Red Spectroscopy (NIRS)
Statistical Methods
Other - functional connectivity

[1|2]Indicates the priority used for review

My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Resting state

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Not applicable

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Other, Please specify - functional Near-Infrared Spectroscopy

Provide references using author date format

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