Correction for time-varying signal power in fNIRS connectivity analyses

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Introduction: Functional Near-Infrared Spectroscopy (fNIRS) signals are contaminated by various sources of noise, including physiological noise and motion artefacts, both of which can change over time. We empirically establish the non-stationarity of fNIRS signals, identifying the distribution of the time-varying signal power. Non-stationarity of fNIRS signals violates the stationarity assumption imposed by resting-state functional connectivity (RSFC) measures, invalidating statistical significance tests. We propose a simple correction for the time-varying signal power of fNIRS signals that restores the integrity of RSFC analyses. The correction is drawn from a similar method proposed for non-stationary functional Magnetic Resonance Imaging (fMRI) data, that was analytically established to restore the voracity of RSFC tests [1].

Methods: Neurovascular effects can affect both neuronal and physiological components of fNIRS signals. While filtering can remove additive noise, changes in signal power can be multiplicative. This can be modelled using the signal model $y_t = \sqrt{p_t} \cdot y_{s,t}$, where y_t and $y_{s,t}$ denote the observed non-stationary fNIRS signal and the underlying stationary signal, respectively, and p_t denotes the time-varying signal power. It's assumed that non-stationary signal power affected all channels, and can be estimated using signal ensemble variance, denoted $\hat{p}_t$. The corrected signal, a scaled estimate of the underlying stationary signal, $y_{c,t}$, can be obtained by $y_{c,t} = y_t/\hat{p}_t$. The impact of time-varying power on correlation was assessed using simulation data. White Gaussian signal pairs with a true correlation of 0.2 were scaled by non-stationary power, generated from an Inverse Gamma distribution. Experimental fNIRS data was obtained from an open-access dataset [2]. RSFC estimates were calculated before and after correction using Fisher's z-scores, adjusted for non-white frequency spectra [3].

Results and Conclusion: Using simulation data we demonstrate that non-stationary signal power increased the variance of z-score distribution (Fig.1A, Fig.1B). After applying the correction the distribution is restored to that of stationary timeseries (Fig.1C, Fig.1D). For experimental signals, the time-varying variance and signal intensities are optimally fit using an Inverse Gamma distribution (Fig.2A) and a Student's *t*-distribution (Fig.2B), respectively. The decreases in z-scores in connectivity results (Fig.2C - Fig.2F) show the ability for the correction method to correct for the connectivity induced by time-varying signal power. In conclusion, the non-stationarity of fNIRS signals needs to be corrected in connectivity analyses.

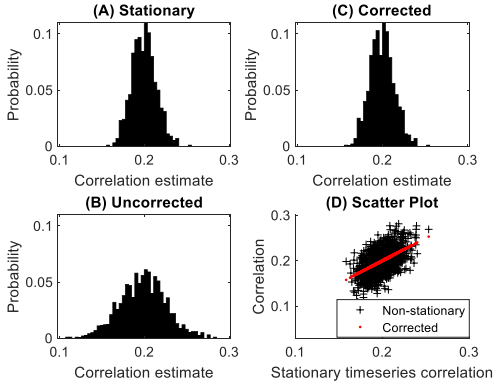

Fig. 1. Simulation results

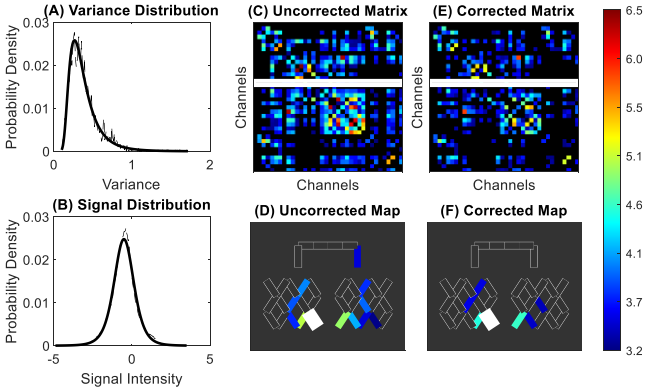

Fig. 2. Experimental results

References

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[3] Wang, M., Davey, C. E., & Johnston, L. A. (2021). Correction of induced functional connectivity in filtered resting state fNIRS data. In *25th Annual Meeting of the Organization for Human Brain Mapping (OHBM)*.