

# Cerebral resting state oscillations study with TD fNIRS

Re, R.; Contini, L.; Contini, D.; Orihuela-Espina, F.; Torricelli, A.; Spinelli, L.

DOI:

[10.1117/12.2668895](https://doi.org/10.1117/12.2668895)

License:

Other (please specify with Rights Statement)

*Document Version*

Peer reviewed version

*Citation for published version (Harvard):*

Re, R, Contini, L, Contini, D, Orihuela-Espina, F, Torricelli, A & Spinelli, L 2023, Cerebral resting state oscillations study with TD fNIRS. in D Contini, Y Hoshi & TD O'Sullivan (eds), *Diffuse Optical Spectroscopy and Imaging IX.*, 126280I, Proceedings of SPIE - The International Society for Optical Engineering, vol. 12628, SPIE, Diffuse Optical Spectroscopy and Imaging IX 2023, Munich, Germany, 25/06/23.  
<https://doi.org/10.1117/12.2668895>

[Link to publication on Research at Birmingham portal](#)

## **Publisher Rights Statement:**

Copyright 2023 Society of PhotoOptical Instrumentation Engineers (SPIE). One print or electronic copy may be made for personal use only. Systematic reproduction and distribution, duplication of any material in this publication for a fee or for commercial purposes, and modification of the contents of the publication are prohibited.

## **General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

## **Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.

# Cerebral resting state oscillations study with TD fNIRS

R. Re<sup>\*a,b</sup>, L. Contini<sup>a</sup>, D. Contini<sup>a</sup>, F. Orihuela-Espina<sup>c</sup>, Torricelli<sup>a,b</sup> and L. Spinelli<sup>b</sup>.

<sup>a</sup>Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, Italy;

<sup>b</sup>Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche, Piazza Leonardo da Vinci 32, 20133 Milan, Italy; School of Computer Science, <sup>c</sup>University of Birmingham, Birmingham, United Kingdom

## ABSTRACT

A TD fNIRS device allowing measurements with an acquisition rate of 20 Hz was employed during an *in-vivo* measurement campaign on 13 volunteers. The power spectral density (PSD) for systemic and cortical O<sub>2</sub>Hb and HHb concentrations were retrieved with a single non-invasive measure. Specific characteristic peaks were evaluated in the cardiac, respiratory, low, and very low frequency bands.

**Keywords:** Time domain near infrared spectroscopy, brain, resting state oscillations

## 1. INTRODUCTION

It is well known that well structured patterns of oscillations exist in brain cortex also in absence of specific stimuli. These fluctuations are present also in the hemodynamic signal and can be investigated with functional near infrared spectroscopy (fNIRS). The typical devices employed were based on continuous wave (CW) or frequency domain (FD) modality, which allow to reach proper acquisition rates (at least 10 Hz) for studying brain oscillations<sup>1</sup>. The main limitation of these modalities is the limited depth sensitivity with a single acquisition channel. This implies the contamination of the cerebral signal with the confounding effect of the more superficial blood fluctuations (due to the scalp and skull contributions). To overcome these problems, the time domain (TD) approach can be applied<sup>2</sup>. However, up to now, no sufficient SNR level has been reached to increase the measurement acquisition rate up to 10 Hz or more. Recently the same authors, developed an instrument able to reach 20 Hz of acquisition rate during *in-vivo* measurements<sup>3</sup>, opening the investigation of resting state oscillations also with TD fNIRS. The purpose of this work is to show the results of an *in-vivo* measurement campaign on 13 healthy volunteers to study resting state oscillations during normal and modulated breath, by presenting the power spectrum density (PSD) of the superficial signal (systemic contributions) and of the brain cortex for oxy- (O<sub>2</sub>Hb) and deoxy- (HHb) hemoglobin, obtained with a single acquisition channel.

## 2. MATERIAL AND METHODS

TD fNIRS acquisitions were performed on the frontal cortex of 13 healthy volunteers (28.5±4.1 years) by means of a device previously developed at the Department of Physics, Politecnico di Milano<sup>3</sup>. The study was approved by the Ethical Committee of Politecnico di Milano and was conducted in compliance with the Declaration of Helsinki. All subjects gave their written informed consent to participate to the study. The best protocol in terms of length, acquisition rate and number of counts was decided on the basis of numerical simulations performed with a custom-made software. The acquisition rate was set at 20 Hz and the interfiber distance at 4 cm. During a first acquisition, the subjects laid supine for 15 minutes with a backrest tilted at 30 degrees and breathing at their normal rate. During a second acquisition, the subjects were instructed to breath at 5 breaths per minute (0.083 Hz modulated breath), following a metronome. ECG, breath signal, blood volume pulse, skin conductance and temperature were also monitored. The photon mean pathlengths in a two-layer medium were calculated and used to estimate the absolute values for the systemic (UP) and cortical (DW) O<sub>2</sub>Hb and HHb concentrations<sup>4</sup>. Time courses for: physiological signals, total counts ( $N_{tot}$ ) at the two wavelengths (RED = 689.5±0.5 nm and IR=828.5±0.5 nm), counts in temporal gates ( $N_g$ ) for RED and IR, absolute values of O<sub>2</sub>Hb\_UP, O<sub>2</sub>Hb\_DW, HHb\_UP and HHb\_DW were retrieved. After a third order polynomial detrending of the time courses, the PSD of the same parameters were calculated with a Matlab script based on the Welch algorithm, using Hamming windows of 3 min length and an overlapping factor of 0.5.

\* rebecca.re@polimi.it

### 3. RESULTS

In the following, we will describe the typical behavior of a representing subject, considering that all the described features are present in the whole population. The TD fNIRS signal was compared only with respiration and BVP signals, while the other physiological sensors were employed to verify that the subjects remained in a real rest condition. The frequency ranges considered in the PSD were: very low frequencies (VLF<0.06 Hz), low frequencies (0.06<LF<0.15), respiration (around 0.3 Hz in the normal breath and 0.08 Hz in the modulated one) and cardiac band (around 1 Hz).

**Normal Breath.**  $N_{tot}$  time course at IR presents clear fluctuations at 1 s periodicity (cardiac fluctuations) superimposed to slower oscillations (respiratory activity), while for  $N_{tot}$  at RED, the sinusoidal component around the heartbeat frequency is visible but much less noticeable. The above effect generates high-power Fourier components in the PSD of  $N_{tot}$ . In addition, other significant Fourier components are present at lower frequency values (LF and VLF). Since the number of early photons is much higher than the late ones, the UP layer concentrations time series for  $O_2Hb$  and  $HHb$  are characterized by lower variance. A periodicity due to the cardiac activity is visible for the UP parameters, while for  $O_2Hb_{DW}$  and  $HHb_{DW}$  was not so well defined. In Figure 1, the PSD for  $O_2Hb_{UP}$ ,  $O_2Hb_{DW}$  (a),  $HHb_{UP}$  and  $HHb_{DW}$  (b) are shown. The total power for the  $HHb$  after the detrending phase was lower than  $O_2Hb$  (see inset in panel (b)), according to their absolute values. The average hemodynamics absolute values were, in fact,  $O_2H_{UP}= 50.4\pm 5.944 \mu M$ ,  $O_2H_{DW}: 51.4\pm 6.9 \mu M$ ,  $HHb_{UP}: 25.8\pm 3.0 \mu M$  and  $HHb_{DW} : 26.6\pm 3.7 \mu M$  respectively. No significant peaks are present in correspondence of the respiratory rate (yellow band) in any signals. An interesting modulation is also present in the VLF (green area) and LF (light blue area) bands, more related with the myogenic ad neurogenic activity.

**Modulated Breath:** All the consideration done for the cardiac peak in the previous experiment can be replicated for this one. When the subject is forced to breath at a very low rate, an oscillation around the corresponding forced breath frequency (0.083Hz) is clearly visible in the  $N_{tot}$  at both the wavelengths. A peak at this frequency is also clearly visible in the PSD for  $O_2Hb_{UP}$ ,  $O_2Hb_{DW}$  (Fig. 1(c)),  $HHb_{UP}$  and  $HHb_{DW}$  (Fig.1 (d)) and for the BVP signal (grey); but the power is always higher for the  $O_2Hb$  with respect to  $HHb$  in both the UP and DW signals. It is also interesting the presence of distinct peaks in the VLF bands for the  $HHb_{DW}$ , which are not present in the  $O_2Hb_{DW}$  signal.

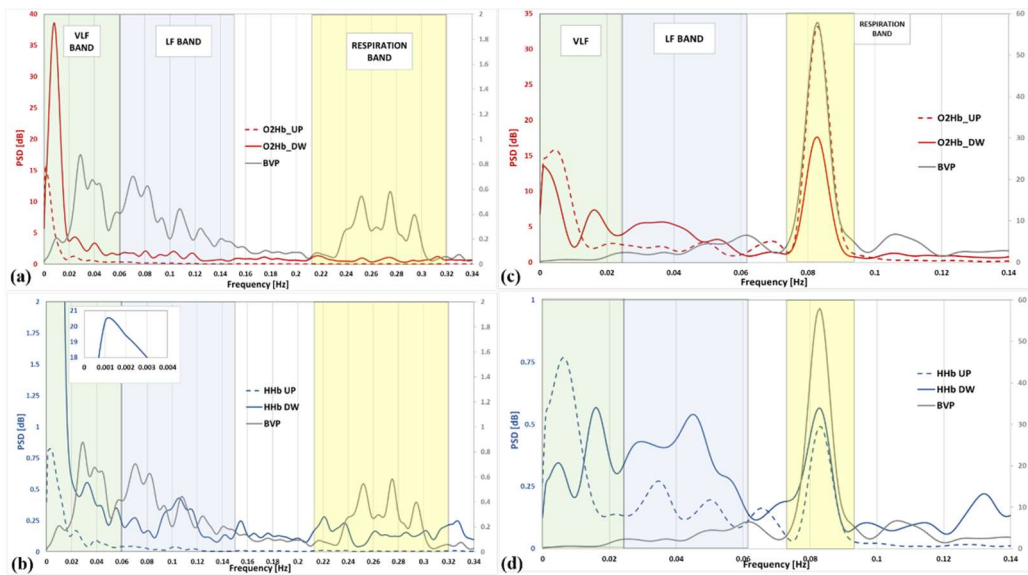


Figure 1. PSD for the hemodynamics parameters during normal (a, b) and forced breath (c, d) for a representative subject. UP: upper layer, i.e. systemic components; DW: deeper layer, i.e. cerebral components. In the inset in panel b, the detail of the peak for the  $HHb_{DW}$  in the VLF is presented.

## 4. CONCLUSION

In this work, we demonstrated the possibility to performed brain resting state oscillation studies on healthy volunteers with TD fNIRS. The protocols and analysis methods were defined based on numerical simulations previously performed (presented in another contribution). The homogeneity of the results obtained among the subjects during this first measurement campaign suggests that the methodology is robust and reliable. Specifically, we compared the PSD of both the O<sub>2</sub>Hb and HHb for both the systemic and cerebral compartments during a resting state and a modulated breathing experiment. In particular, the latter task was previously used in other studies to induce a variation in the blood PaCO<sub>2</sub>, which is well known to induce a remarkable hemodynamic response in the brain tissue, as we found in our signal.

## ACKNOWLEDGMENT

This work was supported by the Laserlab-Europe EU-H2020 871124 project.

## REFERENCES

- [1] Obrig, H.; Neufang, M.; Wenzel, R.; Kohl, M.; Steinbrink, J.; Einhupl, K.; Villringer, "A. Spontaneous Low Frequency Oscillations of Cerebral Hemodynamics and Metabolism in Human Adults," *Neuroimage*, 12, 623–639 (2000).
- [2] Yamada, Y.; Suzuki, H.; Yamashita, Y. "Time-Domain Near-Infrared Spectroscopy and Imaging: A Review," *Appl. Sci.*, 505(9), 1127 (2019).
- [3] Re, R.; Pirovano, I.; Contini, D.; Amendola, C.; Contini, L.; Frabasile, L.; Levoni, P.; Torricelli, A.; Spinelli, L. "Reliable Fast (20 Hz) Acquisition Rate by a TD fNIRS Device: Brain Resting-State Oscillation Studies," *Sensors*, 23, 196 (2023).
- [4] Zucchelli, L.; Contini, D.; Re, R.; Torricelli, A.; Spinelli, L. "Method for the discrimination of superficial and deep absorption variations by time domain fNIRS," *Biomed. Opt. Express*, 4, 2893 (2013).