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Cerebral resting state oscillations study with TD fNIRS

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ABSTRACT

This work aims to show the possibility to perform *in-vivo* acquisitions with high sampling rate (20 Hz) with Time Domain functional Near-Infrared Spectroscopy (TD fNIRS) for studying brain resting state oscillations. Based on numerical simulations, a protocol was designed for acquiring hemodynamics parameters on 13 healthy volunteers during normal and forced respiration. Both the experiments had a length of 15 minutes and during the forced respiration one, subjects were asked to breathe at 5 breaths per minute (0.083 Hz) following a metronome. Systemic (UP) and cortical (DW) oxy- (O₂Hb) and deoxy- (HHb) hemoglobin concentrations (absolute values) were successfully retrieved with a single measure on the frontal lobe. Temporal series and Power Spectral Density (PSD) were calculated for: physiological signals (electrocardiogram, breath signal, blood volume pulse, skin conductance and temperature), total counts at the two wavelengths (RED = 689.5±0.5 nm and IR=828.5±0.5 nm), counts in temporal gates for RED and IR, absolute values of O₂Hb_UP, O₂Hb_DW, HHb_UP and HHb_DW. Specific characteristic peaks were evaluated in the cardiac, respiratory, low, and very low frequency bands. The behavior among the subjects was uniform and differences between the two experiments were found.

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 oscillations¹. 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 applied². However, up to now, no sufficient Signal-to-noise Ratio (SNR) 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* measurements³, 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- (O₂Hb) 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 Physics Department, Politecnico di Milano³. 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 defined based on 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 on the frontal right lobe, 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 breathe at 5 breaths per minute (0.083 Hz modulated breath), following a metronome.
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Electrocardiogram (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) O₂Hb and HHb concentrations⁴. 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 O₂Hb_UP, O₂Hb_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.

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 O₂Hb and HHb are characterized by lower variance. A periodicity due to the cardiac activity is visible for the UP parameters, while for O₂Hb_DW and HHb_DW was not so well defined. In Figure 1, the PSD for O₂Hb_UP, O₂Hb_DW (a), HHb_UP and HHb_DW (b) are shown. The total power for the HHb after the detrending phase was lower than O₂Hb (see inset in panel (b)), according to their absolute values. The average hemodynamics absolute values were, in fact, O₂Hb_UP= 50.4±5.944 μM, O₂Hb_DW: 51.4±6.9 μM, HHb_UP: 25.8±3.0 μM and HHb_DW: 26.6±3.7 μM 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 and 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 O₂Hb_UP, O₂Hb_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 O₂Hb 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 O₂Hb_DW signal.

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 O₂Hb 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 PaCO₂, which is well known to induce a remarkable hemodynamic response in the brain tissue, as we found in our signal.

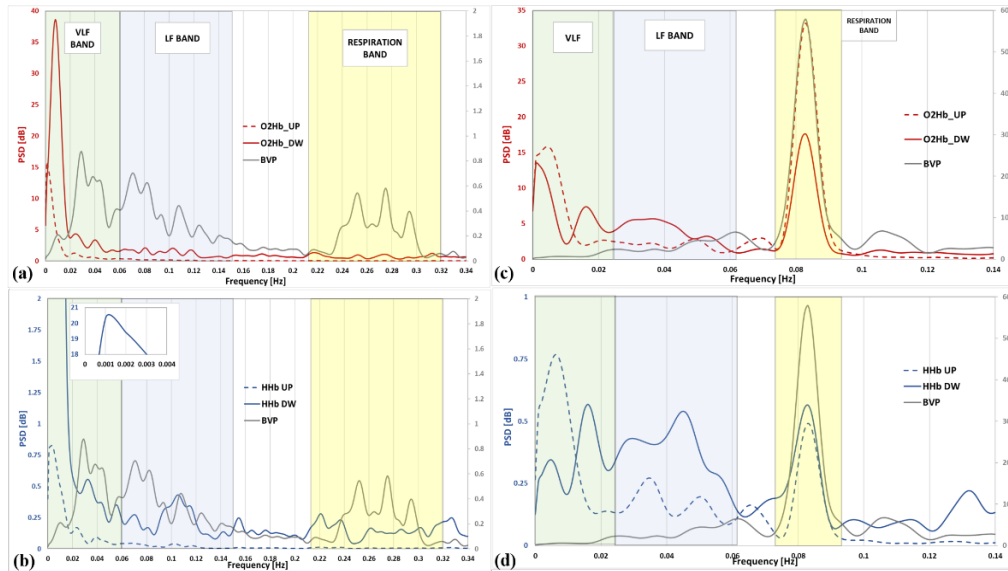


Figure 1. PSD for the hemodynamics parameters during normal (a, b) and forced breath (c, d) for a representative subject. UP: upper layer, i.e. systemic components; DW: deeper layer, i.e. cerebral components. In the inset in panel b, the detail of the peak for the HHb_DW in the VLF is presented.

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