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Cerebral resting state oscillations study with TD fNIRS

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ABSTRACT

A TD fNIRS device allowing measurements with an acquisition rate of 20 Hz was employed during an *in-vivo* measurement campaign on 13volunteers. The power spectral density (PSD) for systemic and cortical O_2Hb 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[1]. 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[2]. 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[3], 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_2Hb) 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[3]. 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_2Hb and HHb concentrations[4]. 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_2Hb_UP, O_2Hb_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.

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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±5.944 μM, O_2H_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 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.

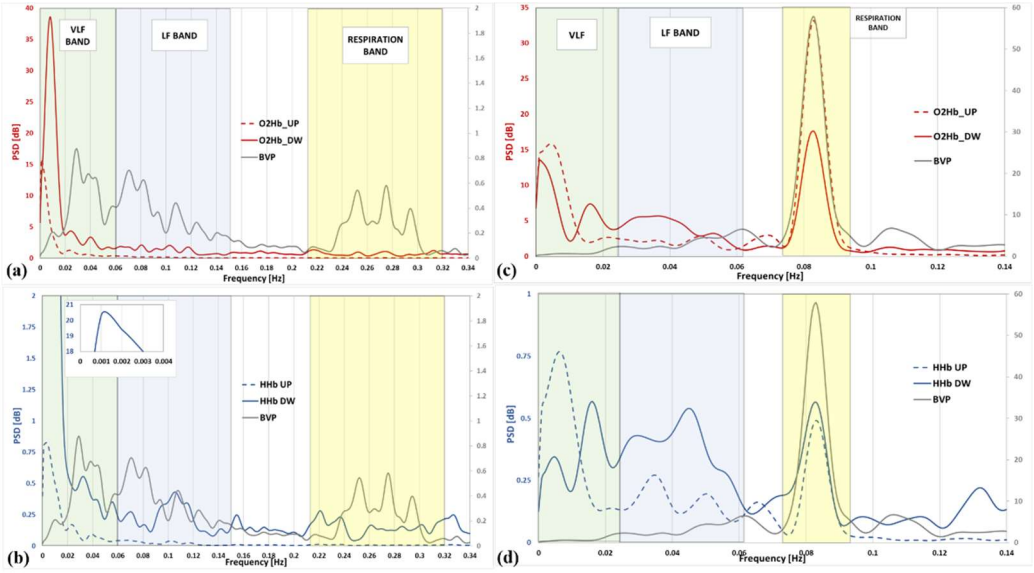

Figure 1. PSD for the hemodynamics parameters during normal (a, b) and forced breath (c, d) for a representative subject. UP: upper layer, i.e. systemic components; DW: deeper layer, i.e. cerebral components. In the inset in panel b, the detail of the peak for the HHb_DW in the VLF is presented.

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_2Hb 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 $PaCO_2$, which is well known to induce a remarkable hemodynamic response in the brain tissue, as we found in our signal.

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