On the removal of physiological artifacts from fNIRS

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Abstract. In the present study we report on the reduction of physiological rhythms in hemodynamic signals recorded with functional near-infrared spectroscopy (fNIRS). We investigated the use of two different signal processing approaches (independent component analysis [ICA] and transfer function models [TFs]) to reduce the influence of respiratory and blood pressure rhythms (Mayer waves) on the hemodynamic responses. The results show that both approaches reduce the artifactual influences equivalently well. However, TFs do so with significantly lower impact ($p < 0.01$) on none artifactual signal components then ICA.

Keywords: Functional near infrared spectroscopy, artifact removal, transfer function, independent component analysis

1. Introduction

Functional near-infrared spectroscopy (fNIRS) is a noninvasive optical technique that can be used for neuroscientific studies and optical brain–computer interfaces (oBCIs) systems [Coyle et al., 2004]. With fNIRS characteristic cerebral hemodynamic responses (changes in oxy- (oxy-Hb) and deoxyhemoglobin (deoxy-Hb) concentration) during different types of tasks can be measured. A common challenge, not only for oBCIs, is stable and reliable investigation and classification of spatio-temporal patterns. For this it is essential to reduce the influence of physiological noise. A spectral analysis of the optical signal reveals various quasi-periodic physiological rhythms, such as cardiovascular, vascular, respiratory and 3rd order blood pressure (BP) rhythms (Mayer waves; [Koepchen, 1991]), which may influence the recorded signals [Coyle et al., 2004; Elwell et al., 1991] and superimpose the changes caused by cerebral activation. The aim of this work is to investigate and compare two signal processing approaches (independent component analysis (ICA) and transfer function (TF) models) which reduce the systemic influences (respiration and Mayer waves) in the recorded fNIRS signals.

2. Material and Methods

2.1. Subjects, experimental design and data aquisition

The investigations were carried out on a group of 10 subjects (6 female, aged 24.2 ± 4.2 years) who participated in an fNIRS study on the cortical effects of BCI training [Bauernfeind et al., 2011]. In the framework of this study the subjects performed three sessions of cue-guided right hand or feet motor imagery. For fNIRS recordings a 52-channel continuous wave system (ETG-4000, Hitachi Medical Co.) measuring changes of oxy-Hb and deoxy-Hb in the cortex was used. Only channels covering the motor cortex (34 channels) were used for further analysis. Additionally, in two of the three sessions (2 and 3) the continuous BP signal (CNAP™ Monitor 500, CNSystems Medizintechnik AG) and the respiration (resp) were recorded and used in the present study. From the BP signal the diastolic BP (BPdia) was extracted. These two signals (BPdia and resp) were band-pass filtered between 0.07-0.13 Hz and 0.2-0.4 Hz, respectively, and used in the following approaches to reduce the systemic influences in the recorded oxy-Hb signal.

2.2. Signal processing and analysis

ICA approach: The oxy-Hb signal is decomposed into independent components (ICs) via SOBI ICA [Belouchrani et. al., 1997]. The coherence between each IC and the BPdia and resp signals is then calculated. ICs for which the coherence with one of the artifact signals is higher than the mean of all the coherence scores with that artifact signal plus 1 standard deviation are flagged for removal. The choice of this threshold is based upon a compromise between removal of the components with the largest coherence with artifact signals and the desire to retain components with small or zero artifact contamination. The remaining ICs not flagged for removal are used to reconstruct the cleaned signals.

TF approach: By using the BPdia and resp signals, TF models were applied to remove the related influences. These models are of the form of $N[n] = X[n] - \sum_{u=0}^{m} g_u Y[n-u]$ where $X[n]$ (n=1,2,3,…) denotes the time series of the recorded signal, g_u (u=1,2,..,m) the model parameters, Y the systemic influence and N the signal without the influence. For further information see [Florian et al., 1998].

Comparison: To compare both approaches the oxy-Hb power reduction (averaged over the used channels) in the frequency bands between 0.07 and 0.13 Hz, for BP influence, and 0.2 and 0.4 Hz, for the respiration, were calculated (Figure 1A). Additionally, the power reduction in the non-influenced bands (0 - 0.06, 0.14 - 0.19 and 0.41 - 0.8 Hz), denoted as stability, was investigated. Good artifact removal will reduce the power in the BP and respiration bands while making no significant changes to the power in the rest of the spectrum. Hence, the lower the stability measure the more accurate the removal of artifacts.

3. Results

Combining both sessions, with TFs a mean reduction of 54% (BP influence) and 28% (respiration influence) was possible. No significant difference (for details see Figure 1B) was found between TF and ICA (43% (BP influence), 16% (respiration influence)). Comparing the stability a significant difference ($p < 0.001$) between ICA (25%) and TFs (3%) can be found.

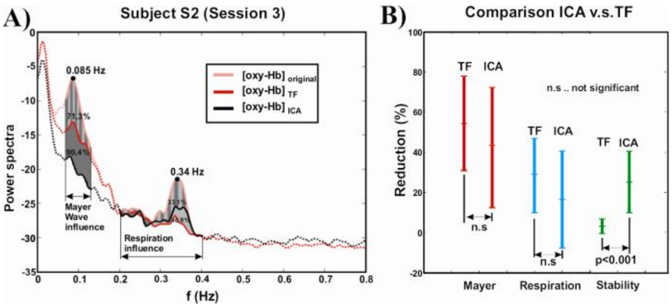

Figure 1. *A) Example power spectrum (averaged over all channels) illustrating percentage reduction in Mayer wave and respiratory rhythms via ICA and TFs. B) General comparison between ICA and TF.*

4. Discussion

Both, ICA and TFs, are seen to produce large reductions in Mayer wave and respiration influences on the oxy-Hb signals. However, while TFs induce only small changes in none-artifactual signal components ICA induces much larger changes. This suggests that TFs are the most suitable choice for artifact reduction.

TFs require a large amount (~60s) of data with which to estimate the coefficients before they can begin to be applied. By contrast ICA does not require any previous measures of the signal. Hence, while TFs are more suitable for offline analysis in neuroscientific studies ICA is potentially much more suitable for online artifact removal and use in an oBCI. Finally, the influence on classification performance of both methods remains to be investigated.

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