Physiological origin of systemic artifacts in functional near infrared spectroscopy as revealed by fMRI

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INTRODUCTION Functional near-infrared spectroscopy (fNIRS) is a non-invasive technique for studying the functional organization of the human brain by measuring haemodynamic responses to stimuli in the cerebral cortex[1]. A major challenge of fNIRS is its high sensitivity to haemodynamic fluctuations in the scalp[2]. These superficial fluctuations contribute to the noise and can even mask actual brain activation producing false positive activation maps[3,4]. Several methods were proposed to separate cerebral and systemic driven extracranial signals including adaptive filtering, NIRS-tomography, independent component analysis and statistical parametric mapping. However, all of these methods make certain assumptions about the temporal or spatial characteristics of the extracranial NIRS signals and their application requires a thorough understanding of the physiology underlying superficial NIRS signals.

Here, we combined fNIRS, fMRI and peripheral physiological measurements (i.e. heart rate, blood pressure, skin conductance and skin blood flow) in order to explore the physiological origin of superficial signals in fNIRS and develop a method to separate them from cortical signals. Our results demonstrate that skin perfusion is strongly dependent on the cognitive and emotional state of the subject, thus challenging the standard assumption underlying many fNIRS studies. Using high resolution fMRI data, we show that the main origin of artifacts in fNIRS is task-evoked venous vasoconstriction in the scalp.

MATERIALS AND METHODS 15 healthy subjects (5 female/10 male, mean age/STD 34.9±7.2 years) participated in two separate fNIRS and fMRI experiments. We used a variation of the continuous performance task combined with a semantic categorization task in a blocked design. fMRI measurements were performed on a 3T (Siemens, Verio) scanner, equipped with a 32-channel coil. Gradient echo EPI (T_E/T_R/flip angle/bandwidth =30ms/2000ms/70°/1689Hz, GRAPPA factor 2) was used with whole brain coverage and 3x3x3 mm^3 resolution. In addition, a T_1 anatomical scan and phase-contrast angiography of the head vessels were acquired.

The optical measurements were performed using a time-resolved NIRS imaging setup[5] specifically adapted to the frontal measurement. Two light sources and four light detectors were fixed on the subject's foreheads (BA 10). The following systemic parameters have been recorded simultaneously with the fNIRS recording: heart rate (ECG), galvanic skin response (GSR), respiration, blood pressure, scalp blood flow measured with laser Doppler.
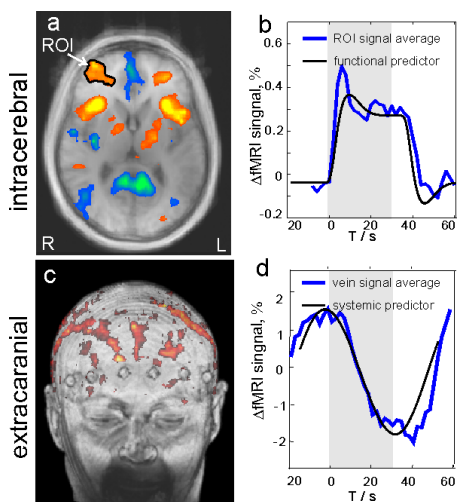

Fig. 1 (a) Results of the fMRI group analysis (b) ROI signal time course overlaid with the predictor used to model cerebral activation. (c) Activation pattern for the extracranial predictor overlaid on 3D reconstruction of the anatomical scan. The positions of NIRS sources and detectors are indicated by fiducial markers, (d) Block average of fMRI signal in extracranial vein overlaid with a sine function used to model the extracranial signal

Fig. 2 Hemoglobin concentrations changes (oxy/de-oxy, intra/extracranial) derived from GLM group analysis of fNIRS data overlaid on anatomical MR images. The color coded dots represent the group average concentration changes attributed to intra- (a-b) and extracranial (c-d) predictors for channels which show effect with a significance level corresponding to p<0.05. The regions probed by four fNIRS channels are indicated with numbers in (a)
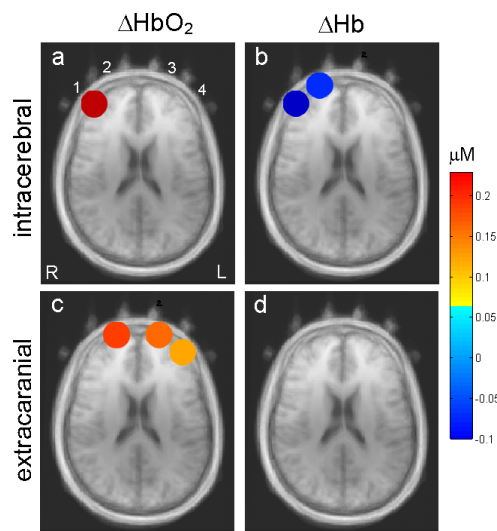
Fig.1

Fig.2

RESULTS AND DISCUSSION The activation map resulting from second level analysis of the fMRI data is shown in Fig. 1a. In addition to cerebral activation in BA10 (maximum at Talairach coordinates (32,48,11)), a strong task-evoked variation of the MR signal was observed for the series of voxels in the scalp co-localized with big veins (see Fig. 1c). The time course of intra- and extracranial fMRI signals is shown in Fig. 1b and 1d, respectively.

The obtained time course of the task-evoked intra- and extracranial signals were entered in a GLM analysis of fNIRS data. The results of the group analysis for two predictors and two hemoglobin species are presented in Fig 2. In agreement with our fMRI results, intracranial activation was found on fNIRS-channel 1 and 2. Clear extracranial signals were observed in the HbO_2, but not in the Hb.

Temporal correlation of the fNIRS and fMRI signals with peripheral physiological traces shows that vein constriction is most likely induced by increased sympathetic outflow during task performance. The cutaneous veins are known to be sympathetically innervated, and vein constriction in the skin is typically found in response to stress, mental effort, emotional stimuli and temperature changes[6].

CONCLUSION We have shown that scalp vessels induce artifacts in fNIRS, most likely due to task-evoked constriction of veins. We observe strong concentration changes in extracranial HbO_2 but not in Hb. Extra- and intracranial contributions to the fNIRS signal can be separated by means of regression analysis. We hypothesize that venous constriction is induced by increased sympathetic outflow during task performance. Since the changes in sympathetic outflow are concomitant with almost any cognitive and emotional process we expect similar scalp vessel artifacts as observed in our study to be present for a wide range of tasks used in neurocognitive research. This indicates that a number of experiments described in the literature on prefrontal cortical activation detected by fNIRS could be biased by systemic effects and caution should be used when interpreting these results.

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