NeuroImage 141 (2016) 120–132

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Reduction of global interference of scalp-hemodynamics in functional near-infrared spectroscopy using short distance probes

Takanori Sato [a,b,1], Isao Nambu [a,*,1], Kotaro Takeda [b,c], Takatsugu Aihara [d], Okito Yamashita [d], Yuko Isogaya [b], Yoshihiro Inoue [e], Yohei Otaka [b,f,g], Yasuhiro Wada [a], Mitsuo Kawato [b], Masa-aki Sato [d], Rieko Osu [b,**]

[a] Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan
[b] ATR Brain Information Communication Research Lab. Group, 2-2-2 Hikaridai, Keihanna Science City, Kyoto 619-0288, Japan
[c] Fujita Memorial Nanakuri Institute, Fujita Health University, 423 Oodori-cho, Tsu, Mie 514-1296, Japan
[d] ATR Neural Information Analysis Laboratories, 2-2-2 Hikaridai, Keihanna Science City, Kyoto, 619-0288, Japan
[e] Research and Development Department, Medical Systems Division, Shimadzu Corporation, 1 Nishinokyo-Kuwabaracho, Nakagyo-ku, Kyoto 604-8511, Japan
[f] Tokyo Bay Rehabilitation Hospital, 4-1-1 Yatsu, Narashino, Chiba 275-0026, Japan
[g] Keio University School of Medicine, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan

ARTICLE INFO

Article history:
Received 29 March 2016
Accepted 28 June 2016
Available online 30 June 2016

Keywords:
Functional near-infrared spectroscopy
General linear model
Multidistance probe arrangement
Principal component analysis
Scalp blood flow

ABSTRACT

Functional near-infrared spectroscopy (fNIRS) is used to measure cerebral activity because it is simple and portable. However, scalp-hemodynamics often contaminates fNIRS signals, leading to detection of cortical activity in regions that are actually inactive. Methods for removing these artifacts using standard source–detector distance channels (Long-channel) tend to over-estimate the artifacts, while methods using additional short source–detector distance channels (Short-channel) require numerous probes to cover broad cortical areas, which leads to a high cost and prolonged experimental time. Here, we propose a new method that effectively combines the existing techniques, preserving the accuracy of estimating cerebral activity and avoiding the disadvantages inherent when applying the techniques individually. Our new method accomplishes this by estimating a global scalp-hemodynamic component from a small number of Short-channels, and removing its influence from the Long-channels using a general linear model (GLM). To demonstrate the feasibility of this method, we collected fNIRS and functional magnetic resonance imaging (fMRI) measurements during a motor task. First, we measured changes in oxygenated hemoglobin concentration (ΔOxy-Hb) from 18 Short-channels placed over motor-related areas, and confirmed that the majority of scalp-hemodynamics was globally consistent and could be estimated from as few as four Short-channels using principal component analysis. We then measured ΔOxy-Hb from 4 Short- and 43 Long-channels. The GLM identified cerebral activity comparable to that measured separately by fMRI, even when scalp-hemodynamics exhibited substantial task-related modulation. These results suggest that combining measurements from four Short-channels with a GLM provides robust estimation of cerebral activity at a low cost.

© 2016 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Introduction

Functional near-infrared spectroscopy (fNIRS) is a noninvasive functional neuroimaging technique that can measure concentration changes in oxygenated and deoxygenated hemoglobin (ΔOxy- and ΔDeoxy-Hb) in the cerebral cortex. It has advantages of portability, fewer physical constraints on the participant, and simplicity of use. Therefore, although measurements are limited to the cortical surface, it has been adopted widely in clinical practices and daily life situations (Fujimoto et al., 2014; Hoshi, 2005; Kato et al., 2002; Obrig, 2014; Piper et al., 2014; Takeda et al., 2007; Vernieri et al., 2006).

However, undesirable artifacts such as head motion and scalp-hemodynamics often contaminate fNIRS signals, and obscure task-related cerebral-hemodynamics (for review, Scholkmann et al., 2014). In particular, scalp-hemodynamics, which is systemic changes of blood flows in the scalp layer, cannot be prevented experimentally because they are affected by systemic physiological changes resulting from activation of the autonomic nervous system or by changes in blood pressure accompanied by actions (Bauer et al., 2006; Lee et al., 2002; Scremin and Kenney, 2004). Indeed, both scalp- and cerebral-hemodynamics increase in a task-related manner. This is especially true for ΔOxy-Hb, which is more widely used as an indicator of cerebral activity than ΔDeoxy-Hb because of its higher signal-to-noise ratio. For example, a majority of task-related changes in ΔOxy-Hb during a verbal

* Correspondence to: I. Nambu, Graduate School of Engineering, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan.
** Corresponding author.
E-mail addresses: inambu@vos.nagaokaut.ac.jp (I. Nambu), osu@atr.jp (R. Osu).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.neuroimage.2016.06.054
1053-8119/© 2016 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

fluency task was reported to originate from the scalp rather than the cortex (Takahashi et al., 2011). Furthermore, Minati et al. (2011) reported that rapid arm-raising movement during visual stimulus presentation generated transient increases in systemic blood pressure, and that ΔOxy-Hb in the visual cortex was coupled with this change in blood pressure, rather than with visual stimulation. Given that scalp- and cerebral-hemodynamics in ΔOxy-Hb have similar temporal profiles, removing the scalp-hemodynamic artifacts by conventional temporal filtering or block averaging is difficult.

Assuming that changes in scalp-hemodynamics are more global than changes in cerebral-hemodynamics, several analytical techniques have been proposed that estimate scalp-hemodynamic artifacts from spatially uniform components of ΔOxy-Hb that are measured by a standard source–detector distance of 30 mm (Long-channels). Using principal component analysis (PCA), Zhang et al. (2005) proposed an eigenvector-based spatial filter from data obtained during rest periods (baseline), which assumes that the effects of systemic hemodynamics is dominant in baseline data. This method has been further extended by applying Gaussian spatial filtering (Zhang et al., 2016). Furthermore, using independent component analysis (ICA), Kohno et al. (2007) extracted the most spatially uniform component of ΔOxy-Hb and showed that it was highly correlated with scalp blood flow that was simultaneously measured by laser-Doppler tissue blood-flow. By removing these spatially uniform ΔOxy-Hb components, both methods identified task-related cerebral-hemodynamics in more spatially localized regions, suggesting that global scalp-hemodynamics is a major source of artifacts that decrease the signal-to-noise ratio in fNIRS measurements. Because the ΔOxy-Hb recorded by Long-channels is a summation of scalp- and cerebral-hemodynamics, these techniques can lead to over-estimation of scalp-hemodynamic artifacts and underestimation of cerebral activity if the two spatially overlap or are highly correlated with each other. Therefore, independent measurement of scalp and cerebral hemodynamics-related ΔOxy-Hb is preferable. Moreover, few studies have experimentally supported the assumed homogeneity of scalp-hemodynamics.

Recent studies have proposed removal of local scalp-hemodynamic artifacts using direct measurements from source–detector distances that are shorter than the standard Long-channels (these are the Short-channels) (Funane et al., 2014; Gagnon et al., 2011, 2012a, 2014; Gregg et al., 2010; Saager et al., 2011; Yamada et al., 2009; Zhang et al., 2009, 2011) (Fig. 1A). For example, Yamada et al. (2009) added a Short-channel detector with a 20-mm distance to each of four Long-channel probe pairs during a finger-tapping task, and subtracted the Short-channel signal from the corresponding Long-channel signal. They confirmed that the activation area that remained after artifact subtraction was comparable with that measured by functional magnetic resonance imaging (fMRI). Although this is a powerful and accurate technique, numerous probes are necessary to cover broad cortical areas because the same number of Long- and Short-channels is required. Dense and broad fNIRS probe arrangements are expensive, heavy, and time consuming, and therefore not practical or feasible, especially for clinical applications.

To take advantage of its simplicity of use and the ability to measure activity from broad cortical regions, a simple method that can remove fNIRS artifacts from broad measurement areas is required. To meet this requirement, here we first tested whether it is possible to estimate scalp-hemodynamic artifacts with a reduced number of Short-channels. Above-mentioned previous methods using Short-channels used multiple Long- and Short-channel pairs because scalp-hemodynamics was considered to vary at different locations (channels) on the head. However, if scalp-hemodynamics is globally uniform as has been assumed in previous studies (Kohno et al., 2007; Zhang et al., 2005,

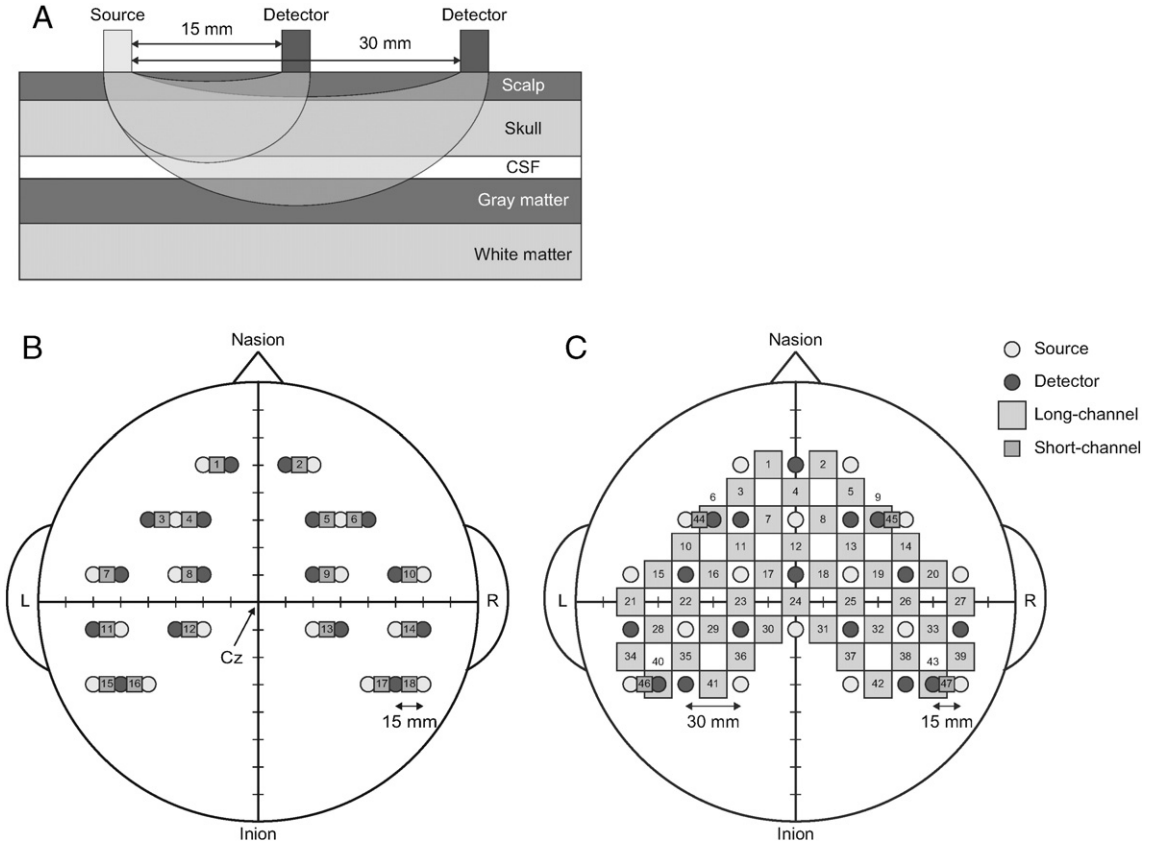

Fig. 1. fNIRS probe arrangements. (A) Schematic illustration of depth sensitivity corresponding to source–detector distance. (B) Probe arrangement for the scalp-hemodynamics measurement in Experiment 1A. Eighteen Short-channels were arranged so that they covered the motor-related areas of both hemispheres. (C) Probe arrangement for evaluation in Experiment 2. Forty-three Long-channels and four Short-channels were arranged to cover the same areas as in (B).

Download English Version:

https://daneshyari.com/en/article/6023100

Download Persian Version:

https://daneshyari.com/article/6023100

Daneshyari.com