

# nirsLAB: A Problem-Solving Environment for fNIRS Neuroimaging Data Analysis



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## Introduction

Access to well configured computing environments is a key factor necessary to accelerate application development derived from data intensive sensing platforms. In the field of neuroimaging, already well developed are publicly available resources that support processing of EEG [1], MEG [2] and fMRI [3] measures, among other types of data intensive platforms. In recent years commercial devices supporting high density NIRS data have become available, but lagging has been development of well-configured computing environments that support data processing by non-domain experts. Several publicly available platforms have been developed, including Homer 2 [4], NIRS-SPM [5], NAP [6], NILAB and NAVI [7], each having their strengths and weaknesses. Motivating the configuration of resources available in nirsLAB is consideration of the need for improved resources to facilitate data and event editing, capacity to process more expansive wavelength vectors, improved visualization tools, and access to additional utilities supportive of application development.

Key functionalities include: sensor registration for arbitrary arrays, data and event editing tools, artifact correction, parameter estimation from up to 8 wavelengths of input (instantaneous, canonical event-related responses), display resources onto planar, scalp and cortical surfaces including block averaging and movies, anatomical structure identification, Level 1 and Level 2 GLM based SMP analysis, data export utilities, recording of history and batch processing, and intersubject comparisons for hyperscanning studies. Also available are utilities to reformat data in support of inter-platform compatibility and to perform batch processing for group subjects. Parameter specification can be made through keyboard entry or graphically. Access to other utilities for use of machine learning algorithms [8] and 3D image recovery are in progress.

## Home Page

The nirsLAB environment features processing portals segmented in accordance with principal elements of a pipeline approach. Briefly, this comprises: (1) registration of optode layout and merging of event protocol; (2) artifact correction and filtering as needed; (3) computation of hemoglobin states; (4) data plotting, editing and topographic viewing; (5) Level 1, 2 GLM-based SPM computation; (6) data export and other utilities. The homepage and some sub-GUIs are shown in Figure 1.

## Processing Portals

**Data Loading:** Data loading is immediately accomplished using metadata produced by the NIRx line of imagers. Data from other system types can also be processed but require an initial transformation of formats. Also initially loaded are a predefined arbitrary optode layout and a protocol-based event table. The former can be generated using supplied graphical tools or by loading data from a digitizer. Editing tools are supplied for editing of the event file as needed.

**Data Preprocessing:** This module is intended to correct for the presence of artifacts, allow deletion of undesired time segments, and perform frequency filtering as needed. Spikes and mean shifts can occur due to changes in optode contact. Disturbances in the channel data can be selected either graphically or using a variance dependent threshold. Data merging following deletion is accomplished by resetting the mean value post-artifact to that seen pre-artifact. Correction for mean shifts without deletions is accomplished similarly. Elimination of spikes is accomplished by either substituting affected time intervals with the mean of the nearest neighbor values observed during the same period, or with assigned random values having a similar variance.

**Hemodynamic States:** Computation of relative values of hemodynamic states (oxyhemoglobin, deoxyhemoglobin, total hemoglobin and hemoglobin oxygen saturation) is accomplished using a modified Beer-Lambert method corrected for the wavelength-dependent differential pathlength factor, and estimated values of mixed venous oxygenation and tissue hemoglobin concentration. Up to eight different wavelengths can be considered ranging from 650-950 nm. Selection of these can be made graphically, as shown in Figure 2, or by entry in a data field. When more than two wavelengths are specified, hemoglobin computation is made based on solving an over-determined system of equations by a least-squares method. Also available are options to compute hemoglobin values based on user-selected pairs of wavelengths.

**Data Viewing:** This portal supports viewing of raw and processed data either as an amplitude-dependent time series or as a composite spatial map viewed in various 2D, scalp or cortical viewing options. To facilitate anatomical views, additional overlays involving sensor positions and EEG landmarks are also available. Shown in Figure 3 is an example of various topographical maps revealing computed hemoglobin values projected onto the MNI atlas registered within a defined head space. Also seen is a scalp view with additional specification of EEG locations in accordance to the International 10-10 system. Mapping of instantaneous hemoglobin values, movies of selected time segments or movies of block averaged events are available. Figure 4 shows an example of block-averaged hemoglobin values. Also accessible is determination of anatomical features as revealed from registration of the automated anatomical labeling atlas available from SPM [3].

**GLM-based Data Analysis:** This module is fashioned after the tools originally provided by SPM8 [3]. The drop-down menus provided enable the user to: 1) specify a hemodynamic state for analysis; 2) choose the mathematical form for estimating the hemodynamic response function, and modify the chosen function's parameters; 3) select time series (e.g., stimulus timing records) to use as the primary models in the GLM design matrix; 4) if desired, include additional design-matrix models (e.g., via a discrete cosine transform) to account for hemodynamic fluctuations unrelated to the experimental protocol; 5) implement pre-coloring and/or pre-whitening procedures to account for serial correlations that may be present in the hemodynamic time series.

**Connectivity Measures:** We have adapted the Dynamic Causal Modeling module of SPM [3] for evaluation of causally directed brain connectivity measures. The module operates on two or more selected ROIs and applies the DCM inverse operation as a basis for model selection.

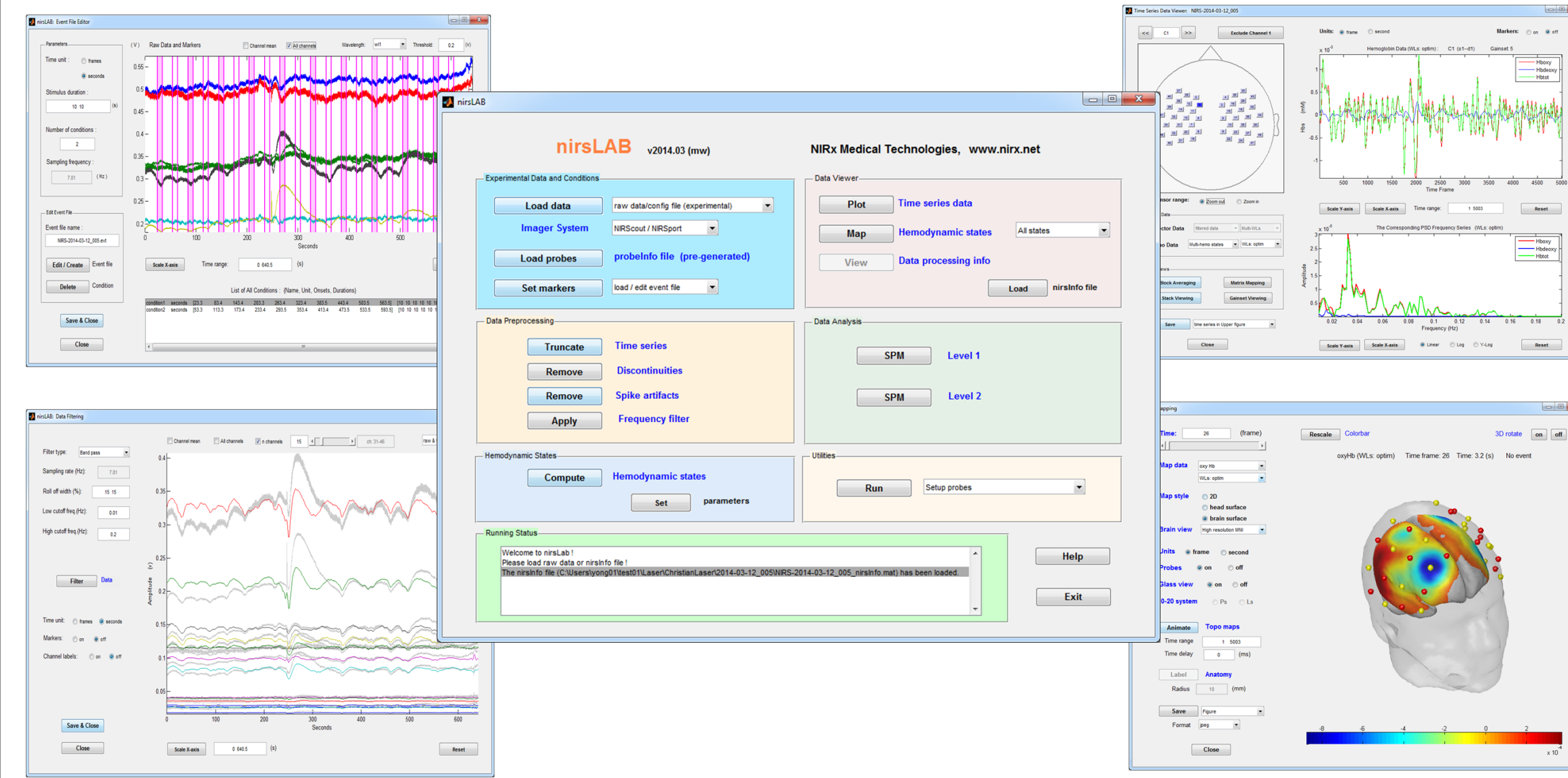


Figure 1. nirsLAB homepage and some sub-GUIs

**Hyperscanning:** This module supports the loading of data files obtained from two or more subjects engaged in a common task and computes various time-dependent metrics based on selected seed vectors. Measures of temporal coherence, cross correlation, and cross-spectral density, among others, are available. An experimental hyperscanning result is presented in the last section.

**NIRS Signal Classifying:** This module provides users with a GUI that supports access to the TU-BCI toolbox developed by Müller and co-workers [8]. The main functions are: (1) Loading hemodynamic states from nirsInfo file of nirsLAB and converting the NIRS signals into TU-BCI format; (2) Graphically editing NIRS channels for signal classification; (3) Classifying the NIRS signal based on spatial, temporal, and spatio-temporal features; (4) Continuously applying the classifier in offline and online modules. An experimental result of NIRS signal classifying is presented in last section.

## Utilities

In this portal, the sensor registration tools and nirsLAB-based data output tool are provided. Figure 5 shows some GUIs of these tools. Under development are GUIs that support access to 3D FEM based tomographic imaging resources.

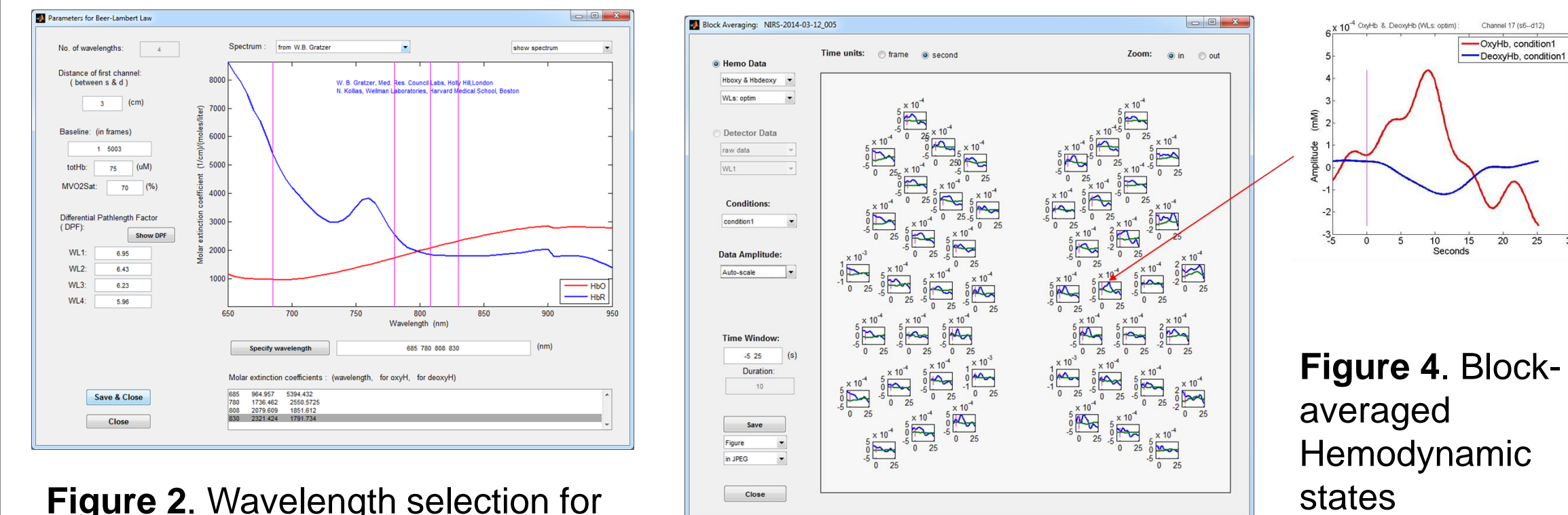


Figure 2. Wavelength selection for computing Hb states

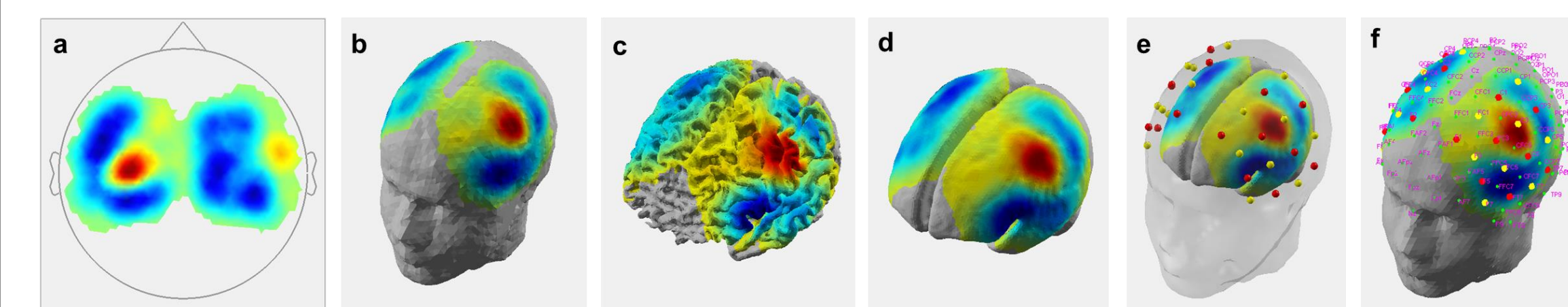


Figure 3. Topographic maps of Hb state: a) 2D scalp; b) 3D scalp; c) cortical viewing (NIRx atlas); d) cortical viewing (MNI atlas); e) glass viewing with probes; f) 3D scalp viewing with EEG 10-20 system locations and probes.

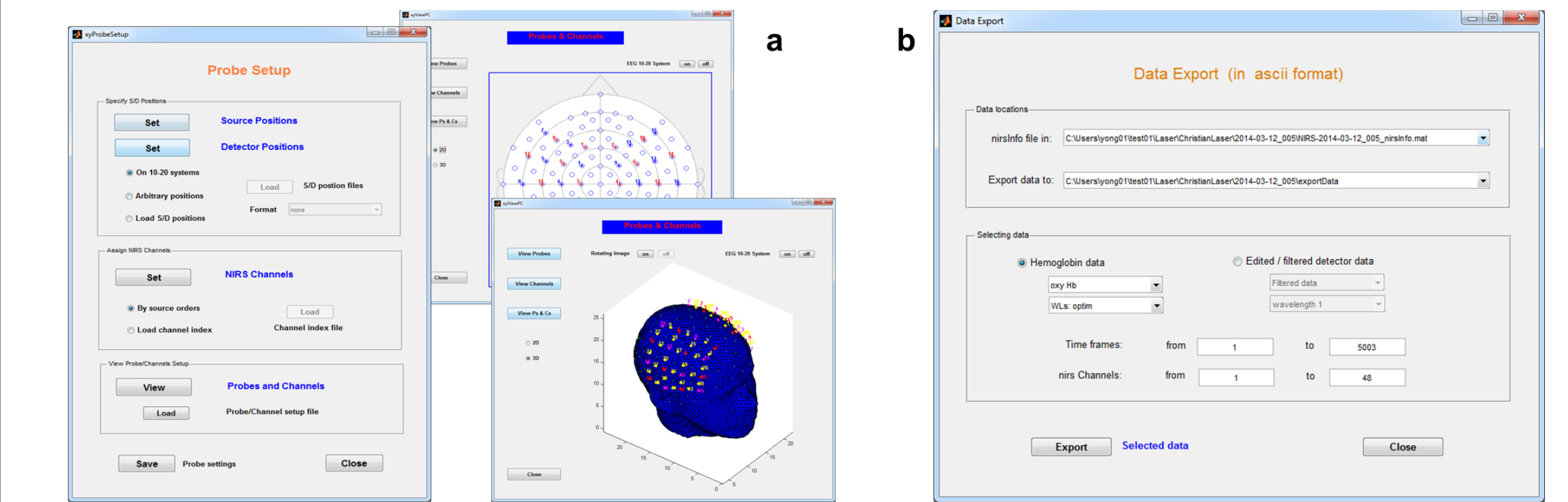


Figure 5. (a) Sensor registration tool and (b) nirsLAB-based data-output tool.

## Experimental examples

Examples of nirsLAB applications: Results from four experimental studies are presented.

**Comparison of optical sources:** Experiment: left- and right-hand finger tapping; Measurement: Laser NIRScout (780 and 830 nm) and LED NIRScout (760 and 850 nm).

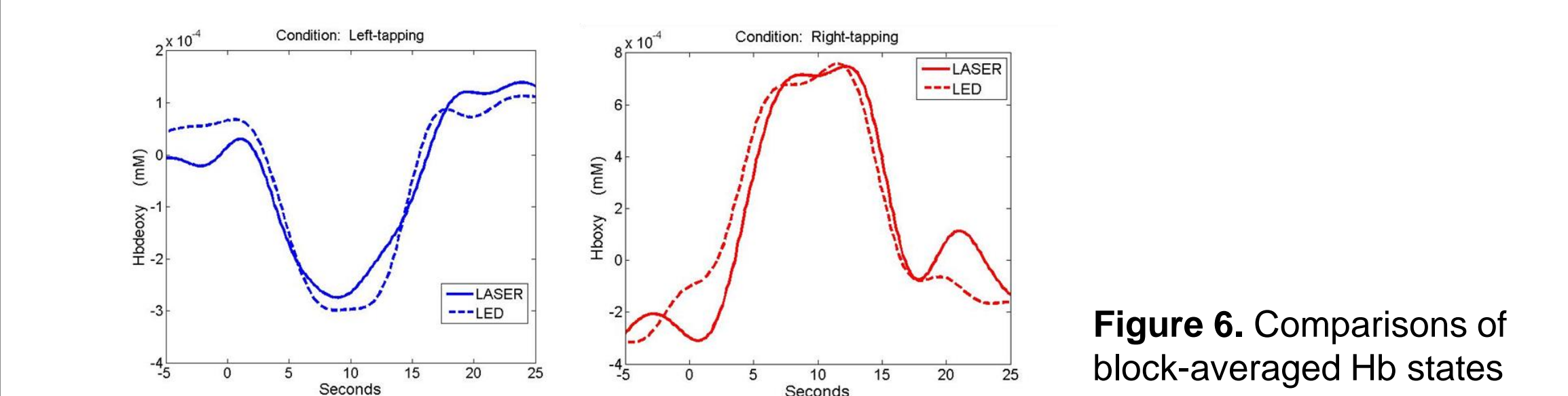


Figure 6. Comparisons of block-averaged Hb states

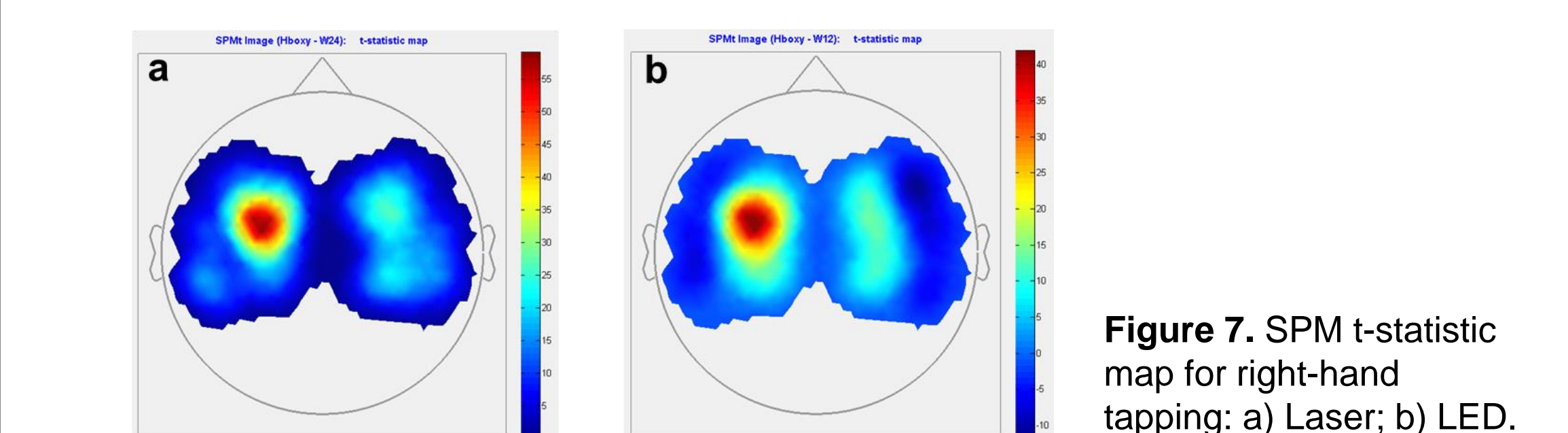


Figure 7. SPM t-statistic map for right-hand tapping: a) Laser; b) LED.

**Four wavelength measurements:** Experiment: left- and right-hand finger tapping; Measurement: Laser NIRScout (685,780, 808 and 830 nm).

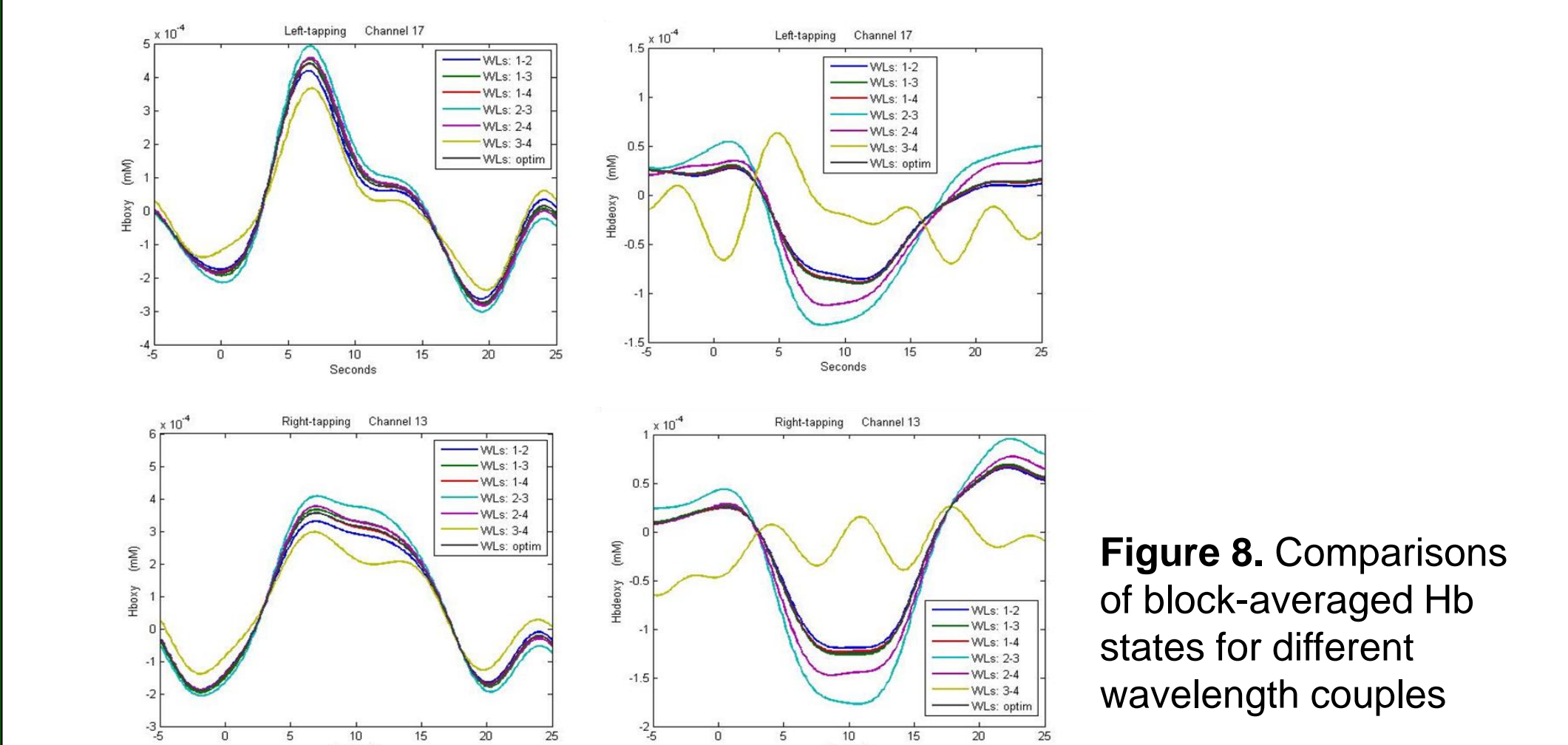


Figure 8. Comparisons of block-averaged Hb states for different wavelength couples

**Hyperscanning experiment:** The experiment setup is shown in Figure 9. The subjects perform left- and right-hand finger tapping.

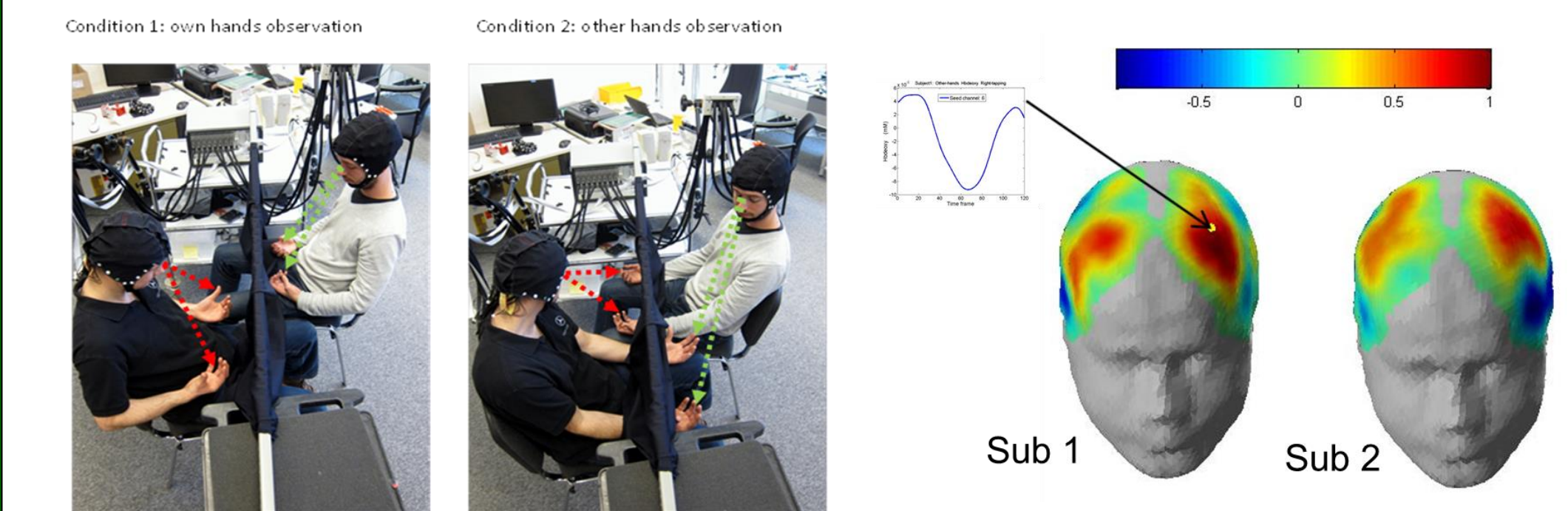


Figure 9. Experiment setup

Figure 11. 3D scalp map of fig 10(b)

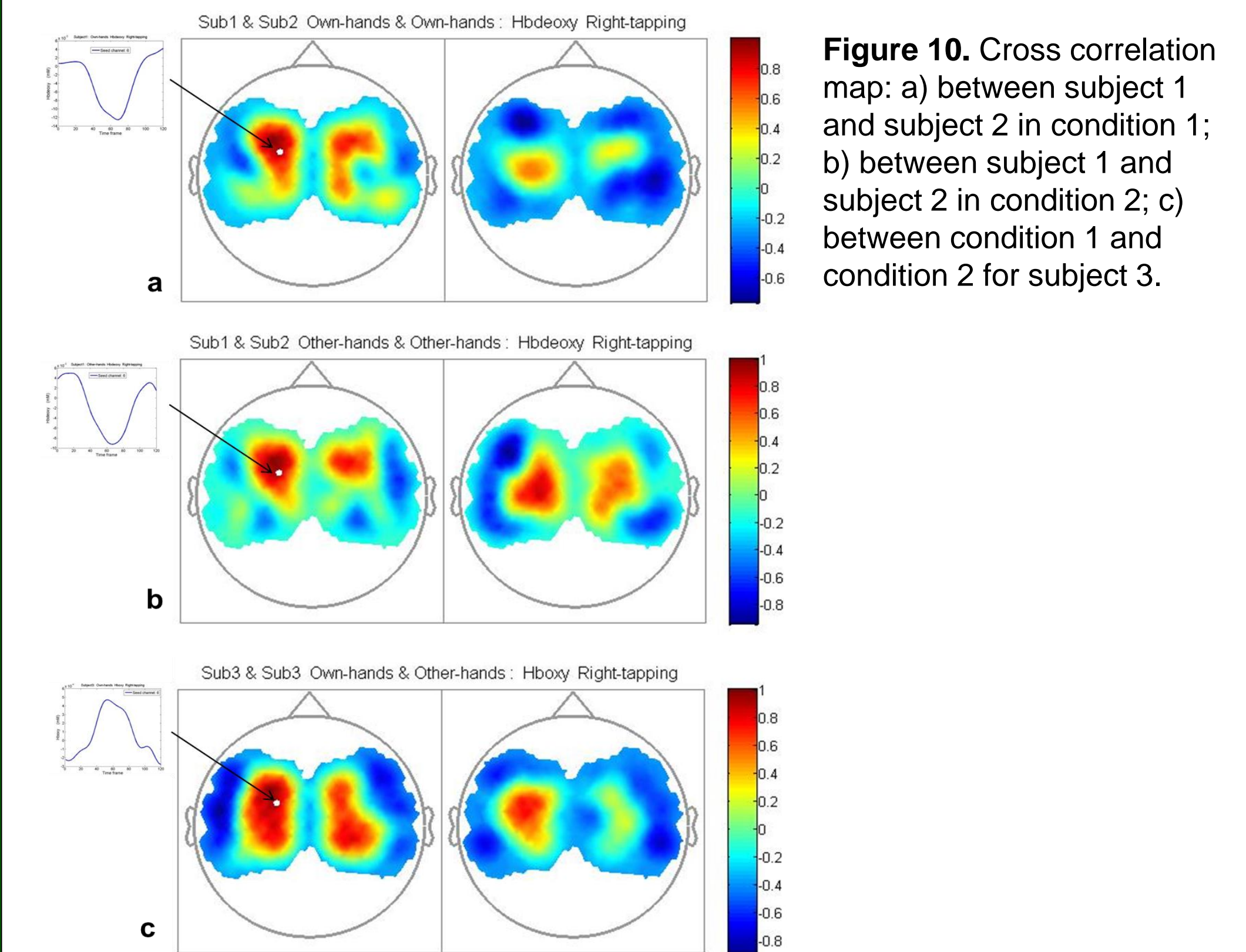


Figure 10. Cross correlation map: a) between subject 1 and subject 2 in condition 1; b) between subject 1 and subject 2 in condition 2; c) between condition 1 and condition 2 for subject 3.

**NIRS signal classification:** In this example, NIRS signals from actual and imagined left/right-hand finger tapping experiments are classified by use of regularized linear discriminant analysis (RLDA) algorithm [8].

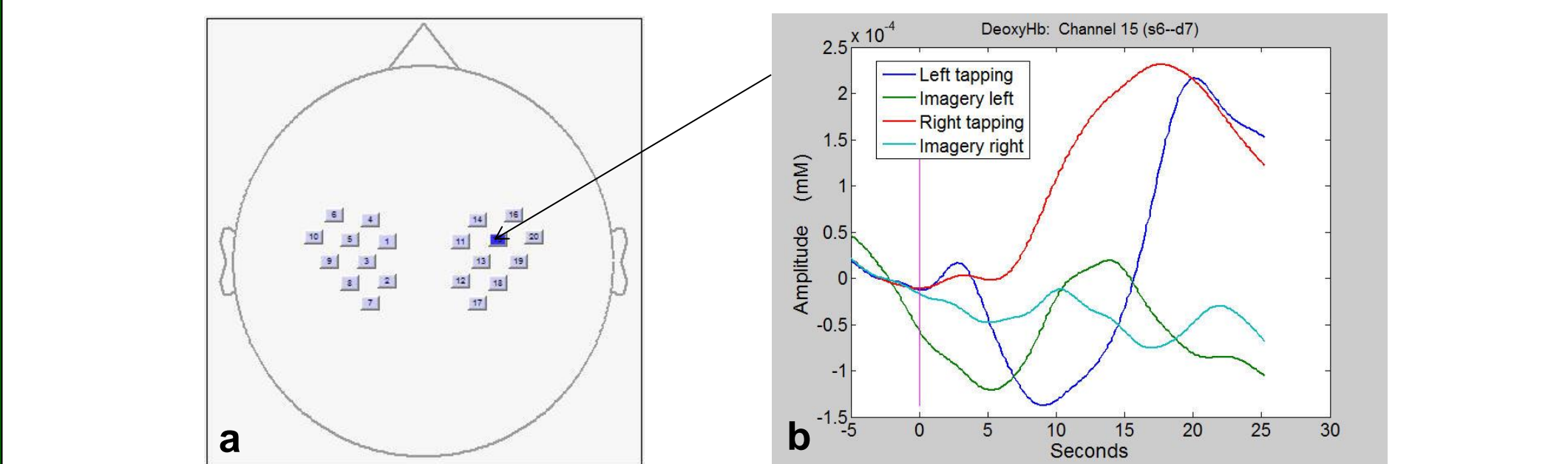


Figure 12. (a) NIRS channel positions; (b) NIRS signals (deoxyHb) comparison

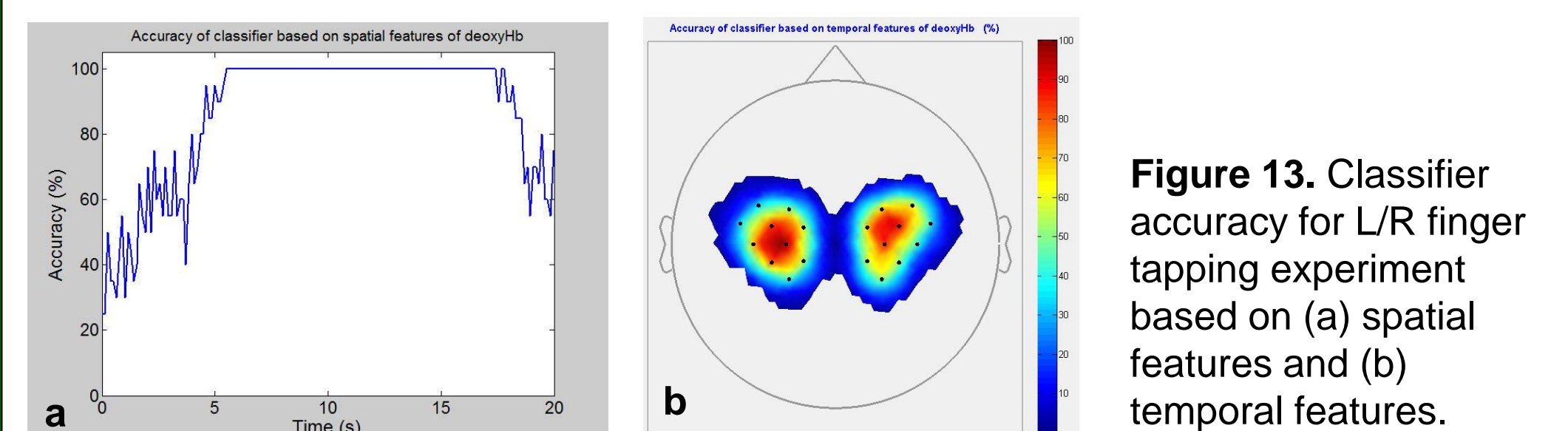


Figure 13. Classifier accuracy for L/R finger tapping experiment based on (a) spatial features and (b) temporal features.

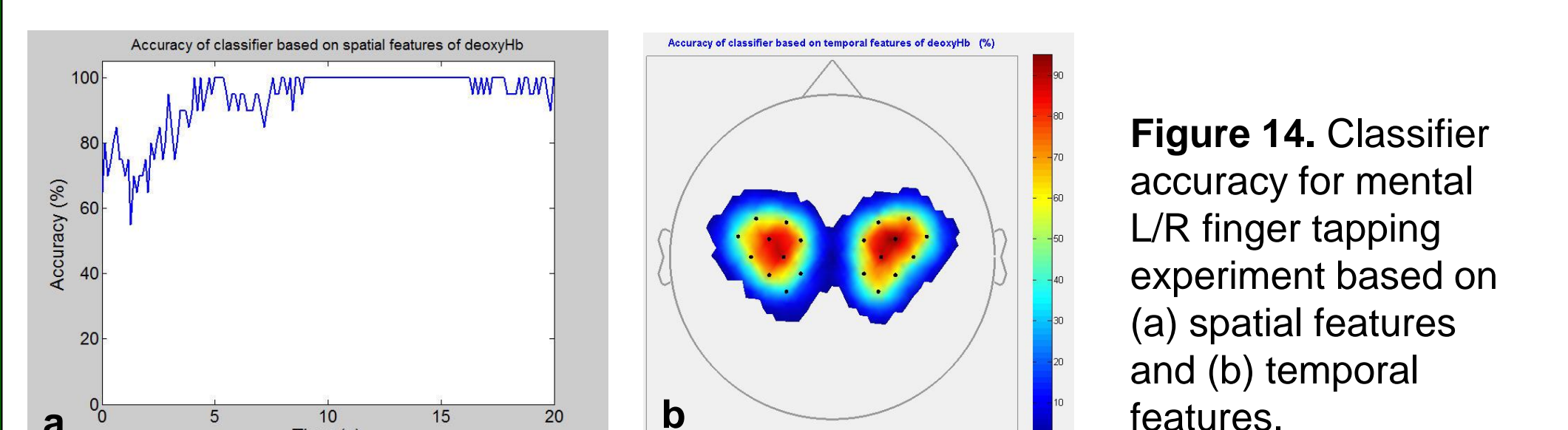


Figure 14. Classifier accuracy for mental L/R finger tapping experiment based on (a) spatial features and (b) temporal features.

## References

- [1] <http://scn.ucsd.edu/eeglab/>
- [2] <http://www.sourcesignal.com/>
- [3] <http://www.fil.ion.ucl.ac.uk/spm/>
- [4] <http://www.nmr.mgh.harvard.edu/PMI/resources/homer2/home.htm>
- [5] <http://bisp.kaist.ac.kr/NIRS-SPM.html>
- [6] <http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0024322>
- [7] [http://www.nitrc.org/projects/nirs\\_downstate](http://www.nitrc.org/projects/nirs_downstate)
- [8] <http://bbci.de/toolbox/>

## Acknowledgements

This research was supported by the NIH grant R21NS067278, DARPA project N66001-10-C-2008, the New York State Department of Health (Empire Clinical Research Investigator Program) and NIRx Medical Technologies.