NIRS-ICA Manual

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1. Introduction

NIRS-ICA is a cross-platform MATLAB toolbox for applying independent component analysis (ICA) in fNIRS studies. It integrates commonly used ICA algorithms for source separation and provides user-friendly GUIs which can be used for both noise reduction and extracting Sources of Interest (SOI). In addition, NIRS-ICA also incorporates quantitative evaluation metrics to evaluate the separated sources. Therefore, users can speed up the procedure of source selection by ranking the sources based on the value of the metrics. The options used in the processing can also be output as a report easily, which facilitates reproducing the ICA method in another study.

1.1 The data format of NIRS-ICA

NIRS-ICA The input data format supported by NIRS-ICA currently is the format converted using NIRS-KIT, which is a MATLAB toolbox for conducting conventional data analysis for fNIRS data developed by our group[Hou et al., 2021]. IRS-KIT provides a data conversion module for converting data recorded from various fNIRS devices. The output structure is named as nirsdata，which contains the following fields：

Table 1 Fields in the nirsdata structure.

Fields	**Meaning**	**Type**	**Example**
oxyData	Oxygenated hemoglobin concentration	array	[6000 x 44 double]
dxyData	deoxygenated hemoglobin concentration	array	[6000 x 44 double]
totalData	Total hemoglobin concentration	array	[6000 x 44 double]
T	Sampling period	number	10
nch	Number of channels	number	44
exception_channel	Bad channels	array	[1 x 44 double]
subject	Subject ID (or name)	string	‘Zhao’
system	fNIRS recording system	string	'HITACHI ETG4000'
probe2d	2D probe montage	cell	“{}，{}”
probe3d	3D coordinates in brain space	array	[3 x 44 double]

1.2 Software Requirements

1. MATLAB software (Tested on 2019a, 2020b)

1.3 Hardware Requirements

NIRS-ICA is developed and tested using a computer with Intel(R) Core (TM) i7-2600 CPU @ 3.40GHz 4.00GB RAM

1.4 Software updates

If you find any bug, don’t hesitate to send emails to zhaoyang@mail.bnu.edu.cn.

1.5 Software download

https://www.nitrc.org/projects/nirskit/

1.6 Sample data

The sample data can be found in the root directory of the NIRS-ICA package. To get the information of the sample data, one can refer to Zhao et al., 2021.

Installation

To use NIRS-ICA, users need first install the MATLAB and add the NIRS-KIT folder to the search path, then tap “NIRS_KIT” in the MATLAB command line to open the main interface. To use NIRS-ICA for noise reduction, users can click Task fNIRS-> Preprocessing->NIRS-ICA-Denoiser to open the main interface of NIRS-ICA (Figure 1). To use NIRS-ICA for extracting sources of interest, users can click Task fNIRS-> Individual-level Analysis->NIRS-ICA-Explorer to open the main interface of NIRS-ICA (Figure 2).

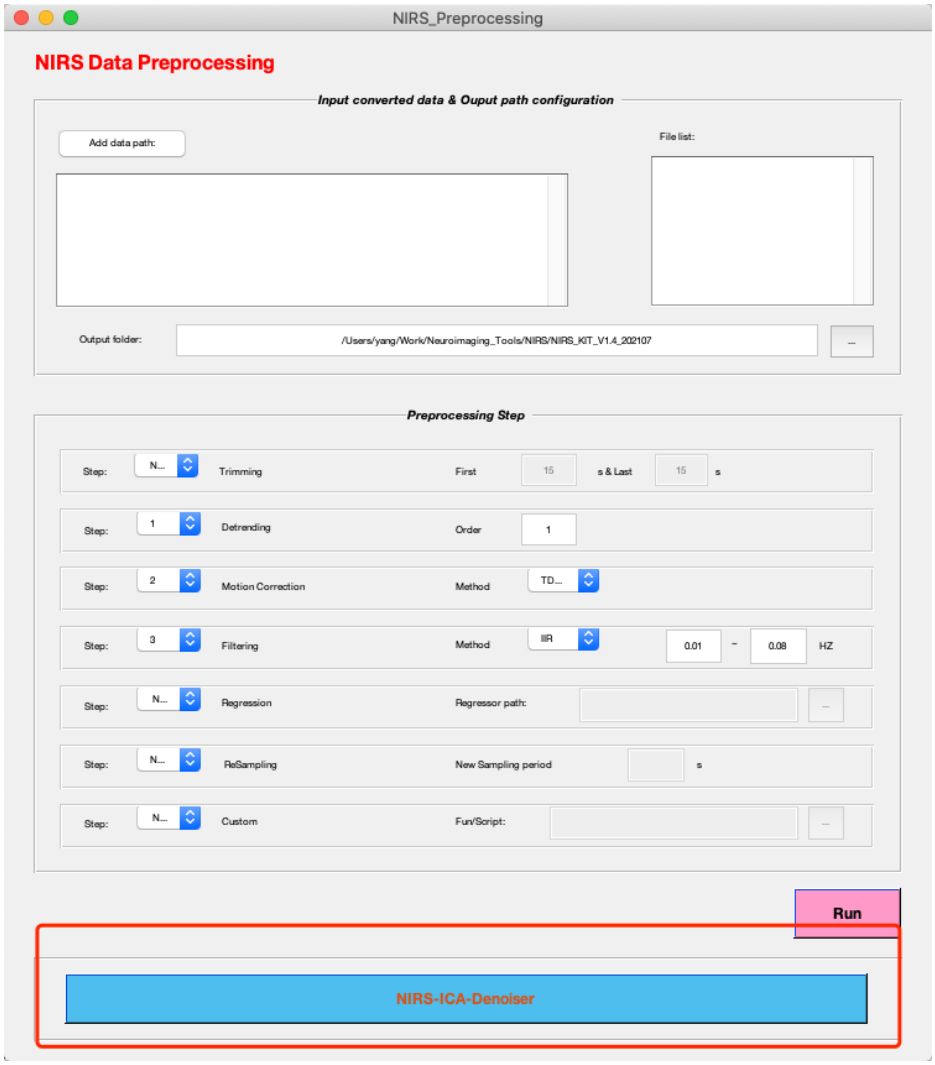


Figure 1. To use NIRS-ICA for noise reduction, users can click the NIRS-ICA-Denoiser button in the preprocessing module of NIRS-KIT.

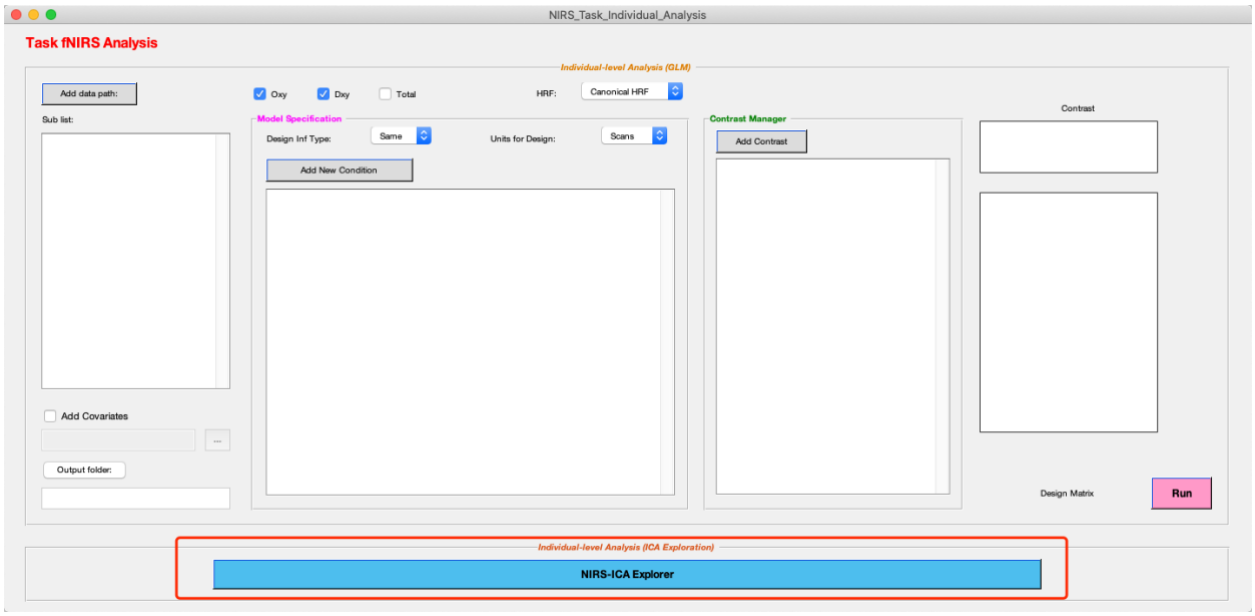


Figure 2. To use NIRS-ICA for extracting sources of interest, users can click the NIRS-ICA explorer button in the Individual analysis module of NIRS-KIT.

2. Input fNIRS data

Users can click the  button to input the directory of data files. It is suggested that users name the data files with the subject ID (Figure 3).

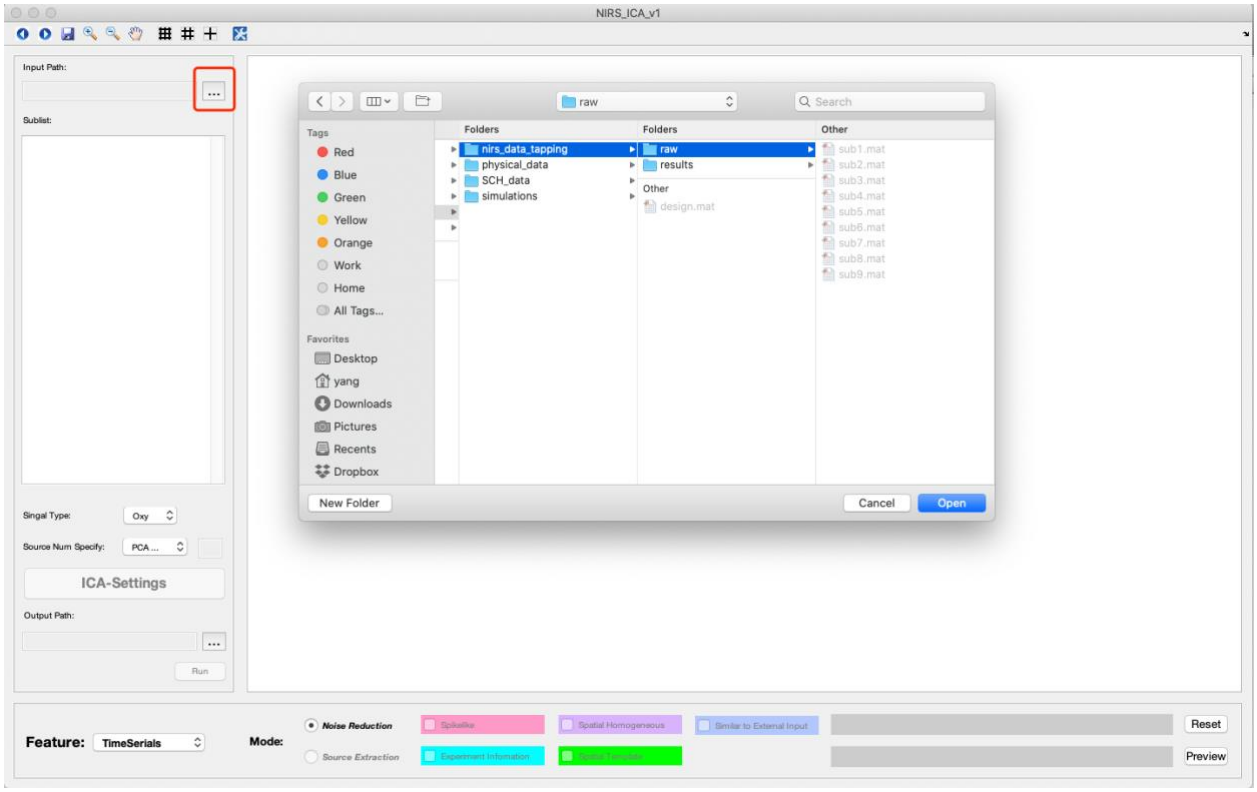


Figure 3. The main interface of NIRS-ICA. The red box indicates the button to input the directory of the fNIRS data file.

After users input the data directory, the directory is displayed in the textbox and the names of the data file are listed in the box below (Figure 4A, B). Users should also define the output directory to enable saving the noise-removed data or Sources of interest (Figure 4C). To run ICA for a specific subject, one can click the subject ID in the list (Figure 3B).

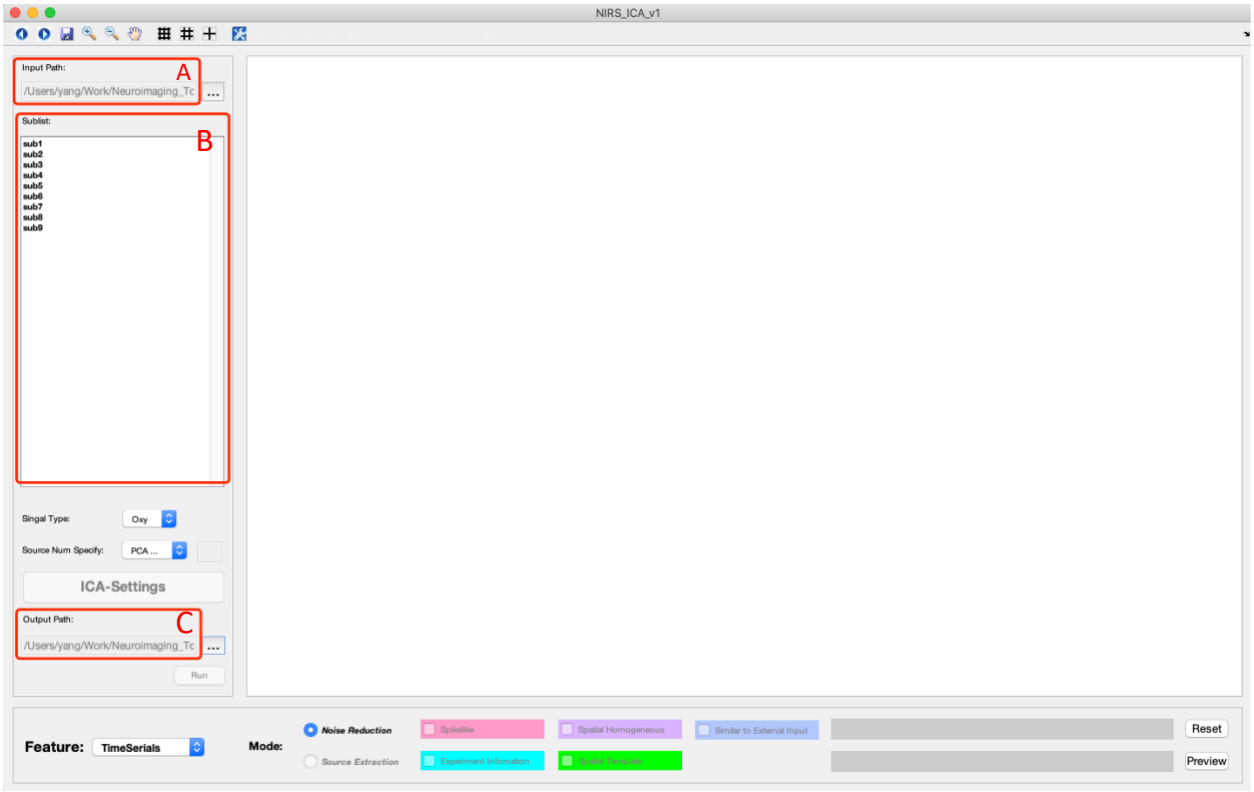


Figure 4. Displaying input and output directory and names of the fNIRS data file. （A）Input directory. (B) List of fNIRS data files in the input directory. (C) User-defined output directory.

3. Set processing options

Users can specify the options of ICA processing directly on the main interface of NIRS-ICA (red box in Figure 5). Users can specify the hemoglobin type to be processed and the number of sources to be retained.

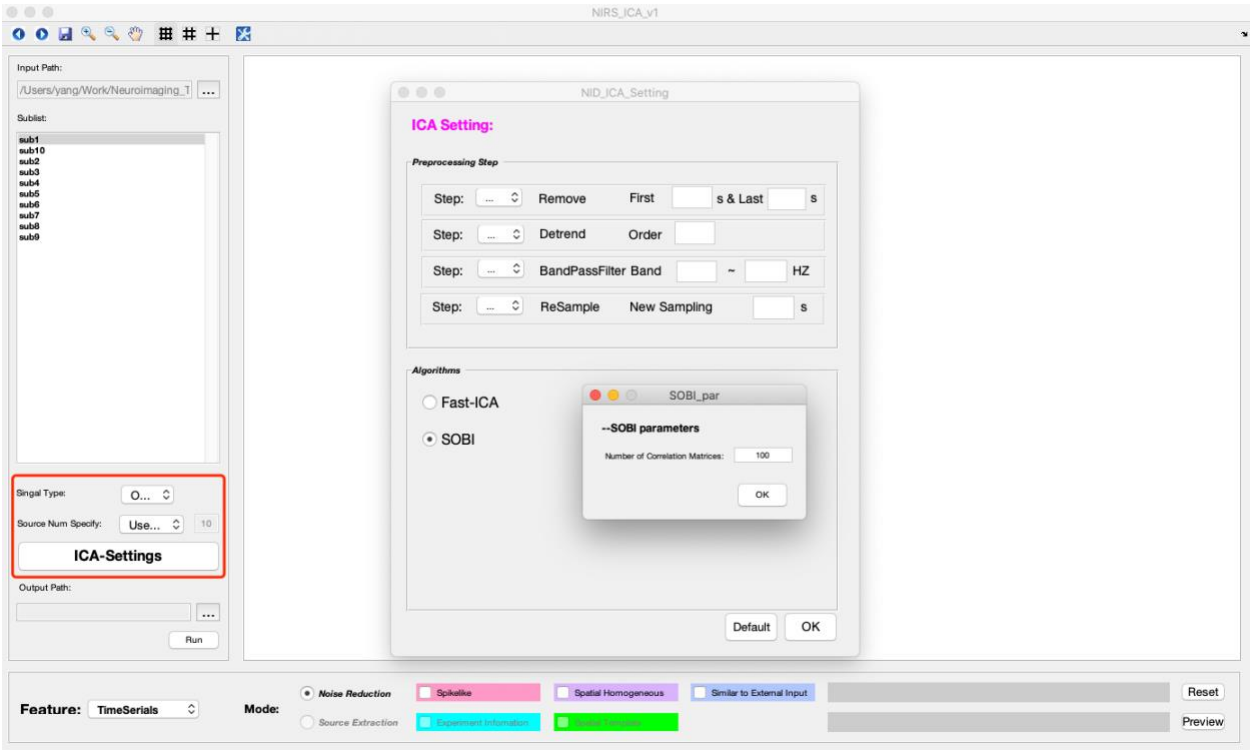


Figure 5. Set ICA parameters. Users can set the Hemoglobin type, Number of sources, and ICA algorithms (Red box). Users can also click the ICA-Settings button to set ICA parameters including preprocessing parameters and ICA algorithms. When users click a specific ICA algorithm (e.g., SOBI), NIRS-ICA opens a GUI to set the parameters of the current algorithm (e.g., number of the correlation matrix to be diagonalized). The parameters of decomposition algorithms implemented in NIRS-ICA are listed in Tables S1 and S2.

Table 2. Parameter of SOBI.

Parameter	Description	Value (Default)
Number of sample-delayed correlation matrices	Number of sample-delayed correlation matrices for joint diagonalization	100

Source: Implementation from EEGLAB: https://sccn.ucsd.edu/eeglab/download.php

Table 3. Parameters of FastICA.

Parameter	Description	Value (Default)
TICA or SICA	Perform temporal ICA or spatial ICA	TICA
Demixing approach	Estimate components sequentially (defl) or in parallel (symm)	symm
g	The nonlinearity used in the objective function	tanh
Maximum number of iterations	The optimization stops when it does not converge in the maximum number of iterations	10000
Stop criterion	The algorithm converges when the difference of the value of the objective function between two iterations is smaller than this value	0.00001

Other parameters of FastICA are set as the default value, see the source code for more information. Source: http://www.cis.hut.fi/projects/ica/fastica

Users can specify the number of sources using the pop-up menu. The default method of determining the number of sources is via retaining 99% of the data variance using the PCA method. Users can also change the percentage of variance by clicking the PCA method in the pop-up menu (Figure 6). Other methods to determine the number of sources include AIC, BIC, and manual input.

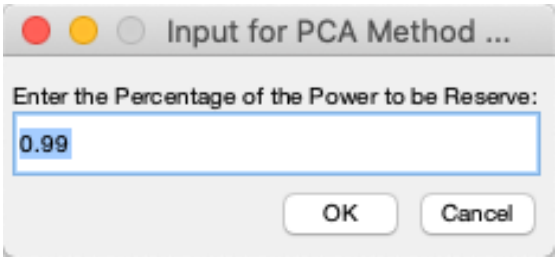


Figure 6. Input the percentage of variance to be retained using the PCA method.

4. ICA decomposition

After setting ICA parameters, users can click the 

button to run ICA decomposition. After a few moments of ICA decomposition (the running time depends on the algorithms used for the decomposition), the results of the decomposition will be output in the right hand of the main interface (Figure 7).

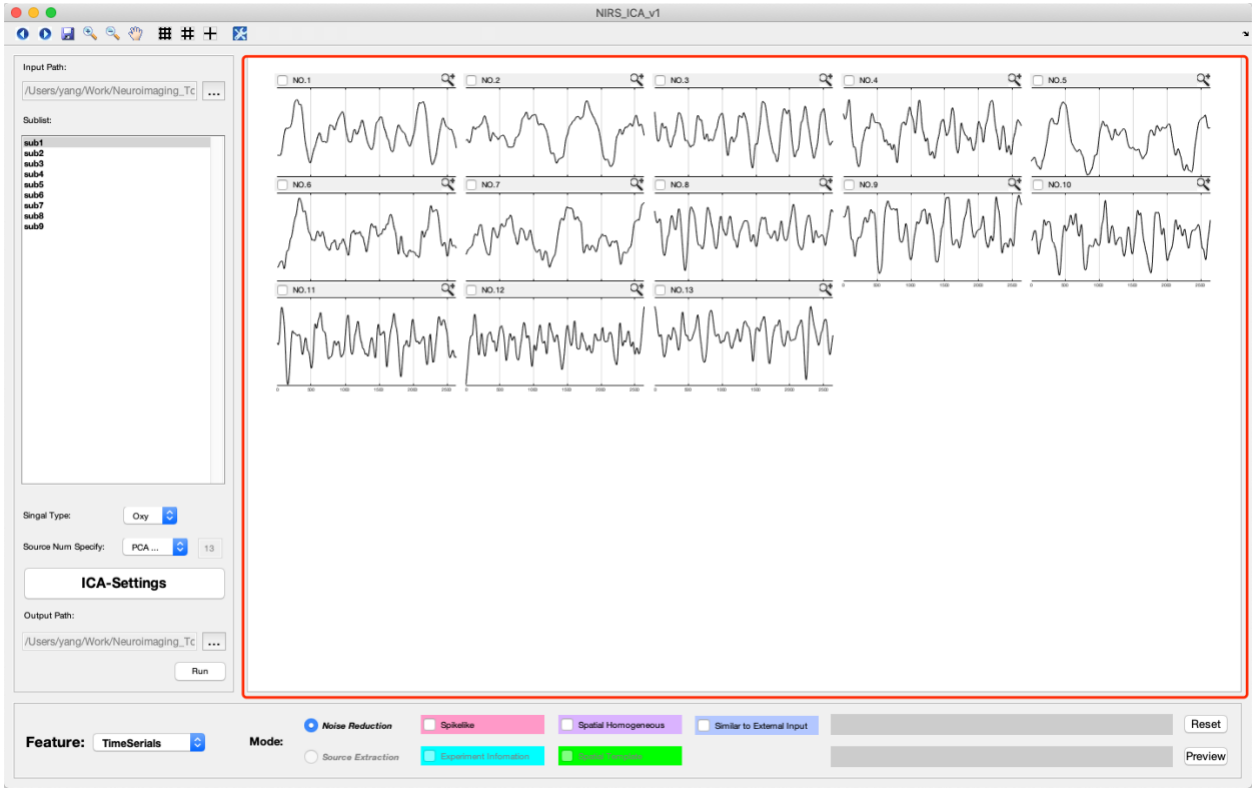


Figure 7. Results output after running ICA. The results displaying panel is highlighted using the red box.

5. Source selection

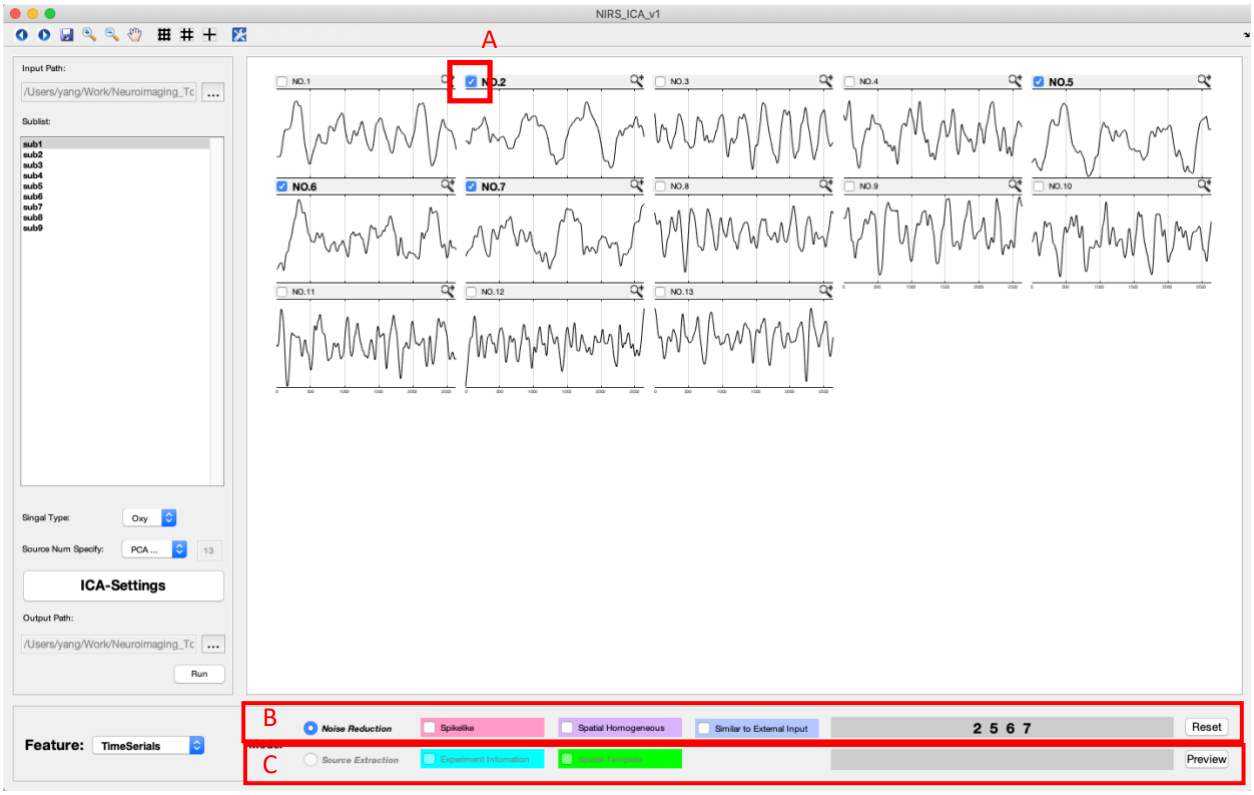


Figure 8. Source selection via visual inspection or quantitative evaluation metrics. (A) Labeling the noise source or source of interest by clicking the checkbox. (B) Select quantitative metrics to evaluate and order the sources for noise reduction. (C) Select quantitative metrics to evaluate and order the sources for extracting sources of interest.

Users can manually select noise sources or sources of interest based on their spatial and temporal features. Besides the time courses, the spatial maps or the frequency spectrums of the separated sources can also be displayed by clicking the pop-up menu at bottom of the main interface (Figure 9). NIRS-ICA also provides several quantitative metrics to rank the separated sources, which can facilitate the manual source selection procedure.

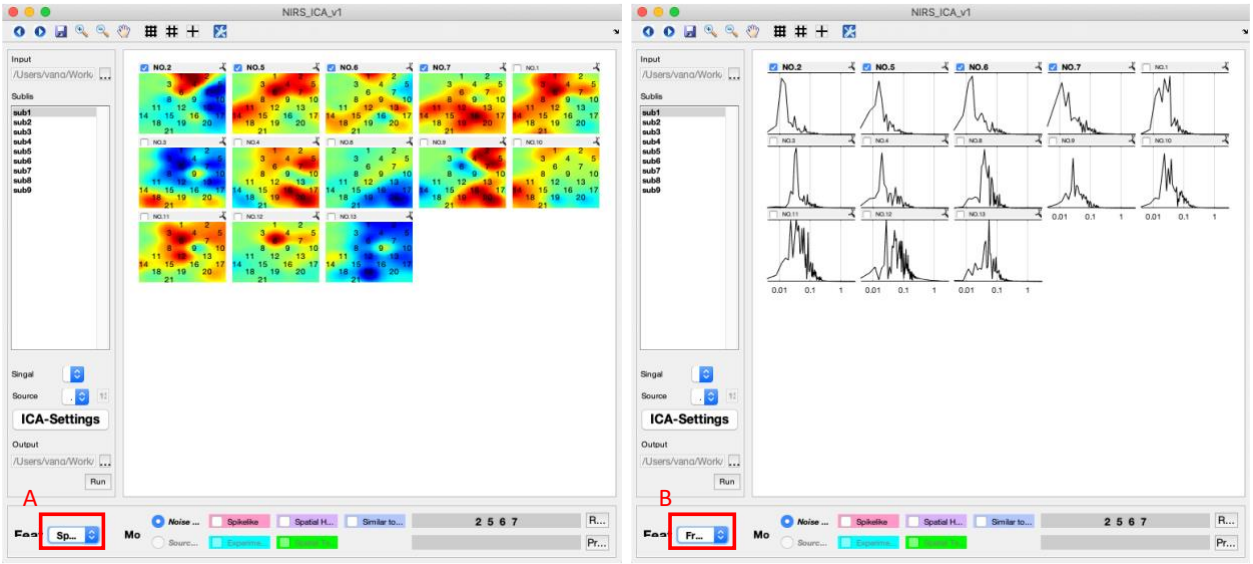


Figure 9. Specifying the features to be displayed in the results panel. (A) displaying spatial maps of the sources. (B) displaying the frequency spectrums of the time course of sources.

1.7 Select noise-related sources

Three metrics are implemented to facilitate identifying noise-related sources. The spike-shaped metric evaluates sources' time course for identifying motion artifacts based on Scholkmann et al. (2010).

Spike-shaped metric

Users can click the spikelike checkbox to open the GUI of parameter settings for spike-shaped sources detection (Figure 10). The functionalities of the parameters are listed in Table 4.

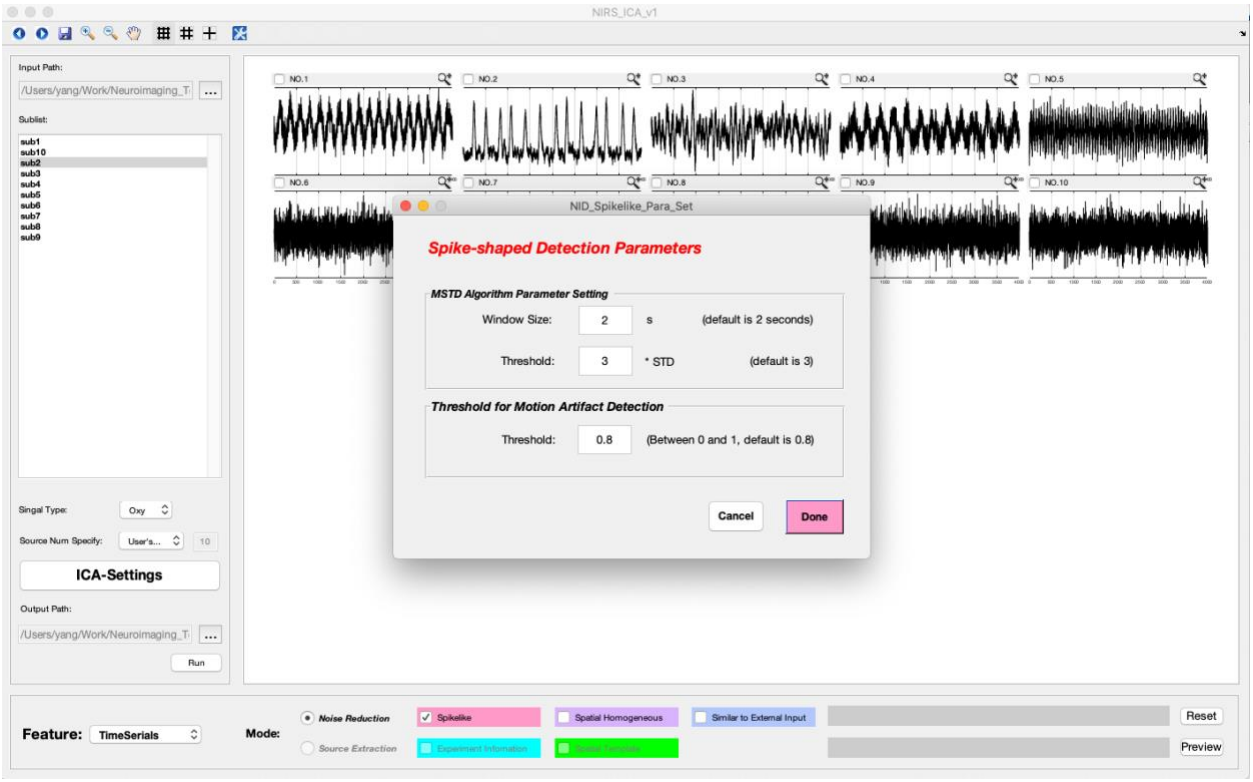


Figure 10. The interface of specifying the parameters of spike-shaped source detection.

Table 4. Parameters of the spike-shaped sources detection algorithm

Name	Appearance	Functionality
Window size	Window Size: 2 s	Should be similar to the period of spikes.
Threshold for determining the noise period	Threshold: 3 * STD	When the MSD of a time point exceeds this threshold, it is determined as noise period.
Threshold for motion artifact detection	Threshold: 0.8	The threshold of determine a source as source of motion artifact.
Cancel	Cancel	Quit the GUI.
Save the parameters	Done	Save the input parameters.

Spatial homogeneity metric

The spatial homogenous metric quantifies the spatial map of sources, which is evaluated based on the coefficient of spatial uniformity (CSU). Users can click the spatial homogeneity to

set the threshold of the CSU value.

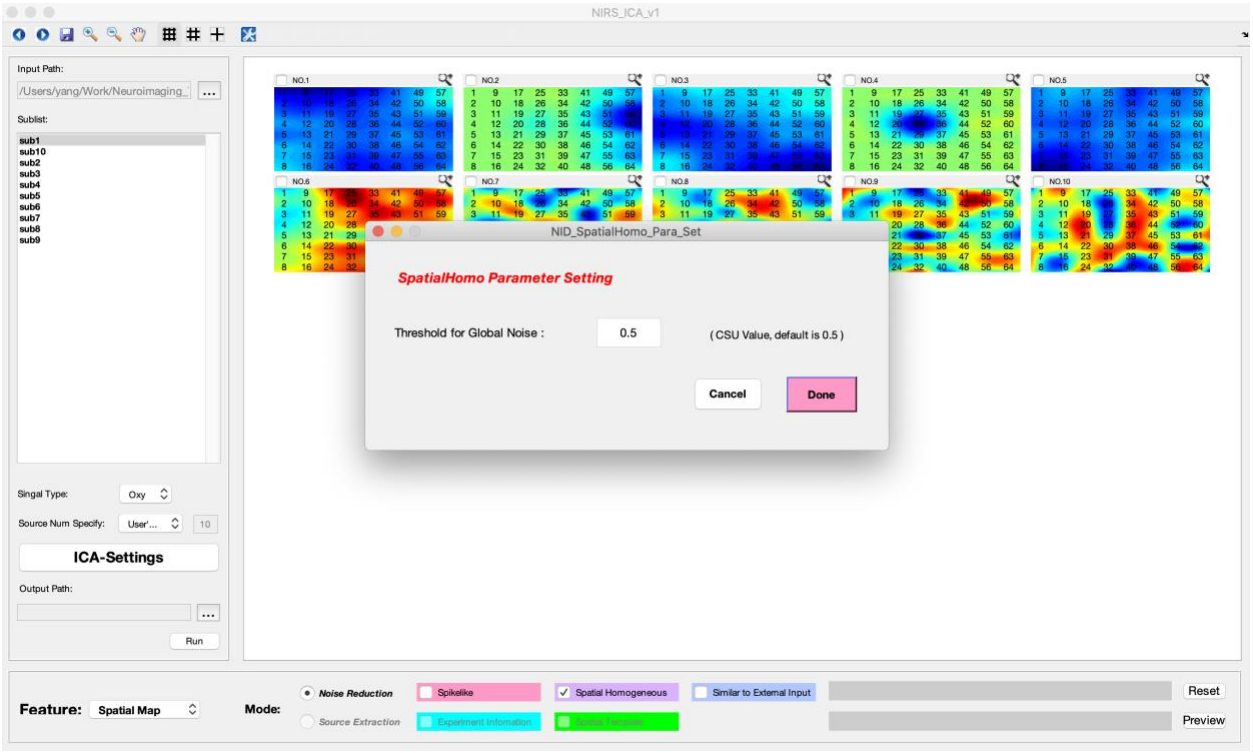


Figure 11. Evaluation separated sources using spatial homogeneity of their spatial map.

Correlation with external input metric

Users can click similar to external input checkbox to input external recordings such as physiological instruments, short channels (Figure 12). NIRS-ICA then computed the correlation between the time course of external inputs and the separated sources and order the sources using the resultant correlation values.

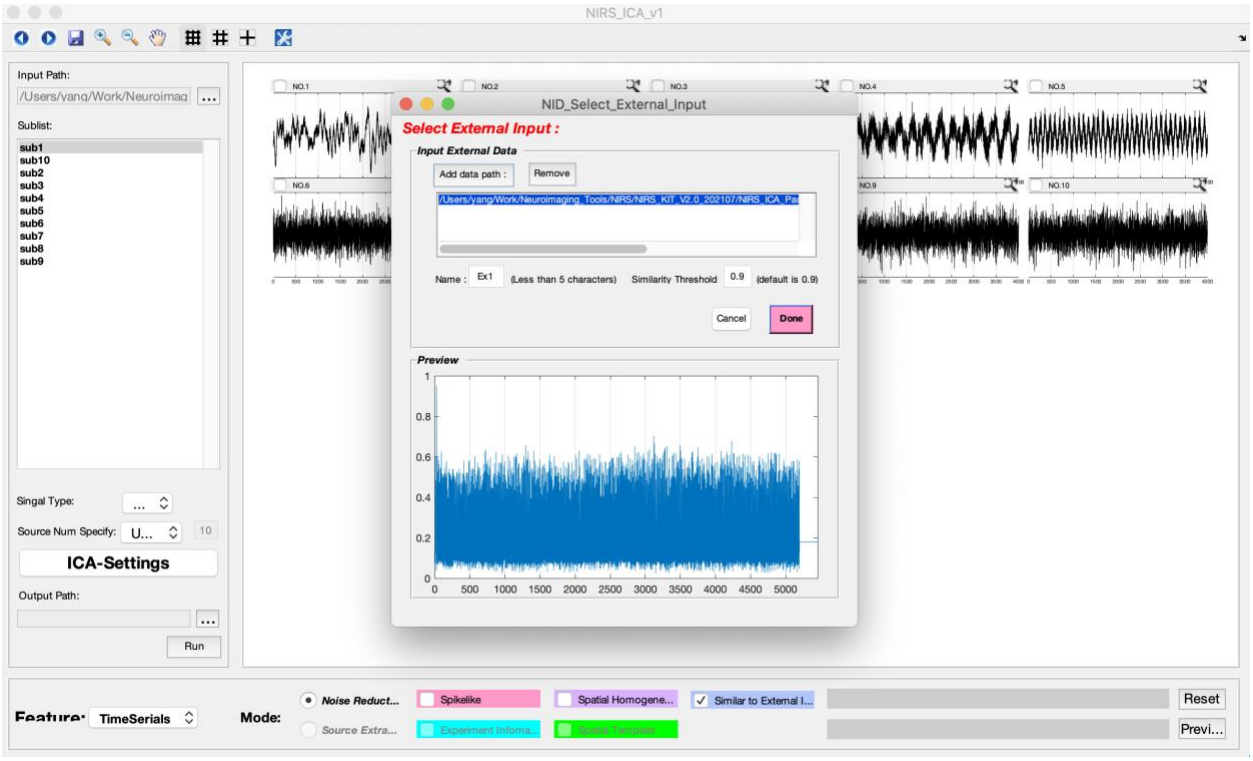
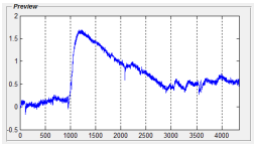


Figure 12. Evaluation of the separated sources using the similarity to external recordings.

The functionalities implemented in the GUI of input external recordings are listed in Table 5.

Table 5. Functionalities in the interface of input external recordings.

Name	Appearance	Functionality
Directory of data	Add data path :	Specify the directory of the external recorded data.
List of input data		Displaying all input data.
Remove the input data	Remove	Remove the selected data.
Naming the data	Name : Ex1	Naming the selected data.
Threshold of determining as a noise	Similarity Threshold : 0.9	Determine the source as a noise source if the similarity exceeds this value.
Cancel the detection	Cancel	Cancel the detection and return.
Accept the settings	Done	Accept the settings.

Preview the input time course		Users can preview the input data by clicking the file name in the list box.

1.8 Select neuronal activity-related sources

Evaluation of the similarity with the reference time course

Users can rank the separated sources using the similarity with reference time courses, which can be input via the GUI of creating reference time courses. It enables either input the onsets and durations of the task, or load them to create a neuronal activity-induced hemodynamic curve. The created time courses can also be saved for other subjects in one group.

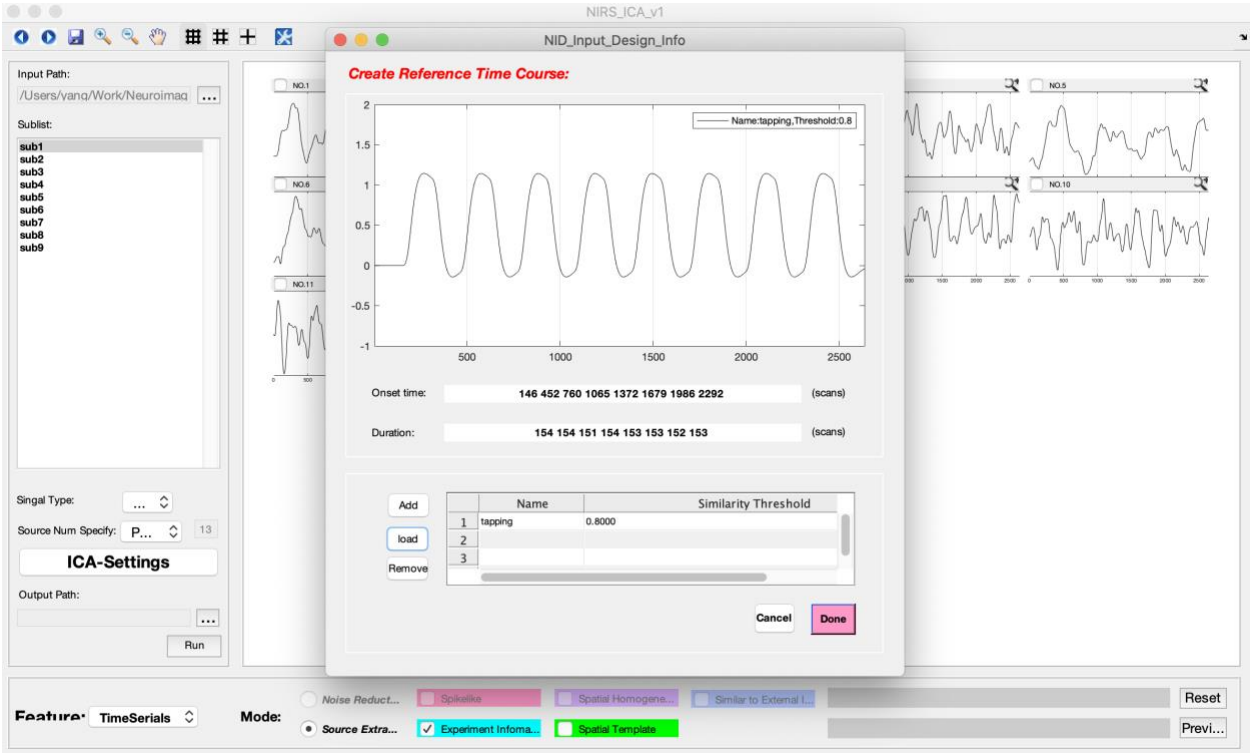
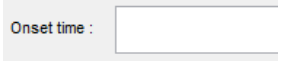
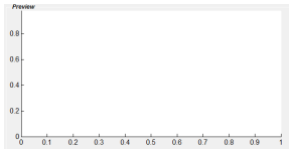
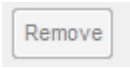
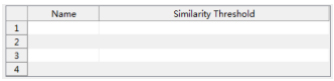


Figure 13. The interface of creating reference time courses.

Table 6. The functionality of the GUI of creating reference time courses.

Name	Appearance	Functionality
Display onset time		Display the added or loaded onsets of the task.

Display Task duration		Display the added or loaded onsets of the task.
Preview		Preview the created or loaded time course.
Add		Add new task design information.
Remove		Remove the selected reference time course.
List		List the name and threshold of existing reference time courses.
Accept		Accept the input reference time courses.
Cancel		Quit without save.

Input reference time courses:

Users can click the  button to input the onsets and durations of the task so that to create the reference time course (Figure 14). After input task information and pressing the OK button, NIRS-ICA will create the reference time course and added it to the list of the reference time courses.

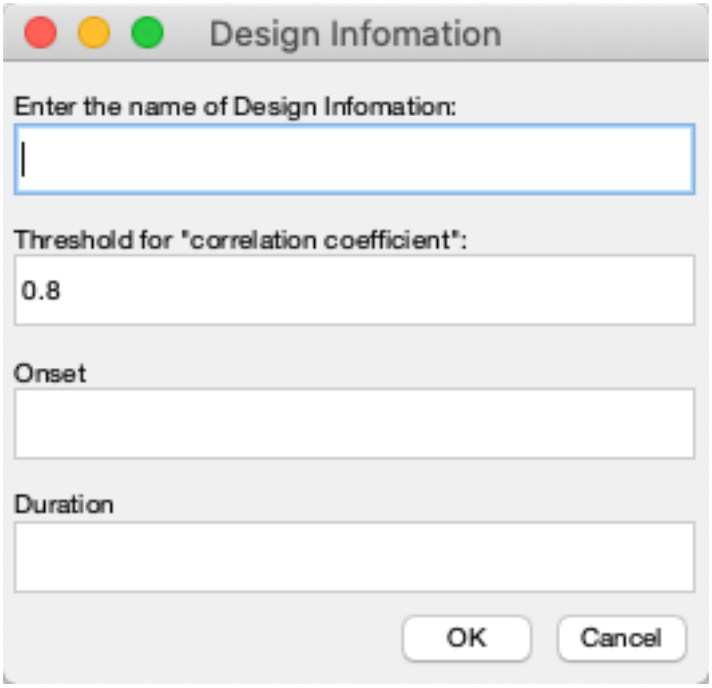


Figure 14. Input task information to create reference time courses.

Evaluation of the similarity with spatial template

Users can click the spatial template checkbox to add or load the spatial template, then NIRS-ICA will rank the sources based on the similarity between the spatial map of sources and the created spatial template (Figure 15). The functionality of this GUI is listed in Table 7.

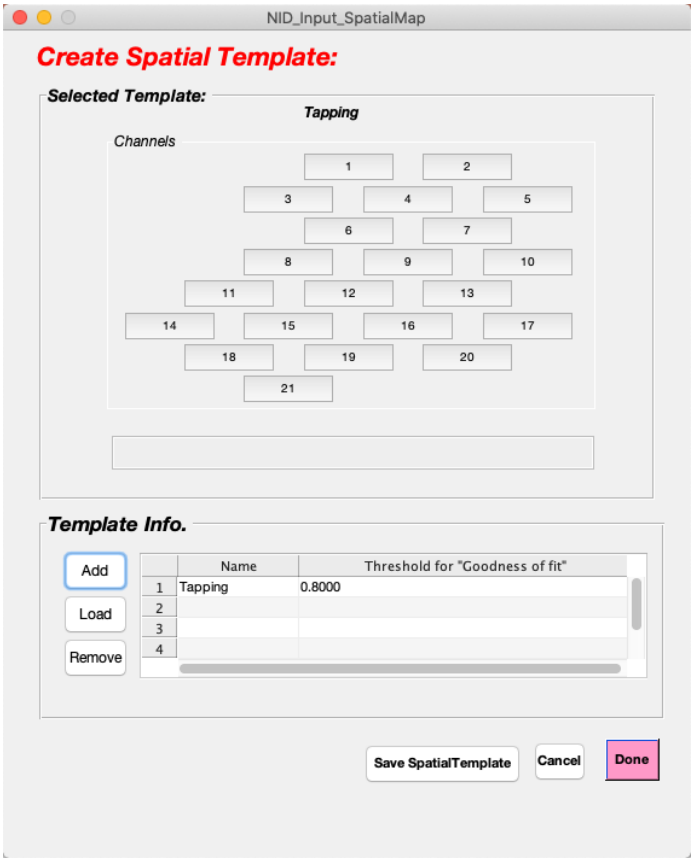
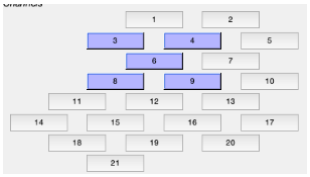
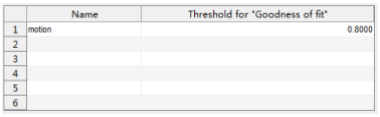


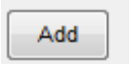
Figure 15. The interface of input spatial templates.

Table 7. The functionality of the input spatial template.

Name	Appearance	Functionality
Add	Add	Add new spatial template
Remove	Remove	Remove the selected template
Save	Save SpatialTemplate	Save the created template
Accept	Done	Save the created templates and quit the GUI
Cancel	Cancel	Cancel the input and quit the GUI

Select the channel within ROI		Display the montage arrangement and enable users to select channels within ROI
List		List the created spatial templates

Input spatial templates:

Users can click the  button to add spatial templates, then NIRS-ICA will rank the sources based on the similarity of the spatial templates with the spatial maps of the separated sources using the goodness of fit (GOF).

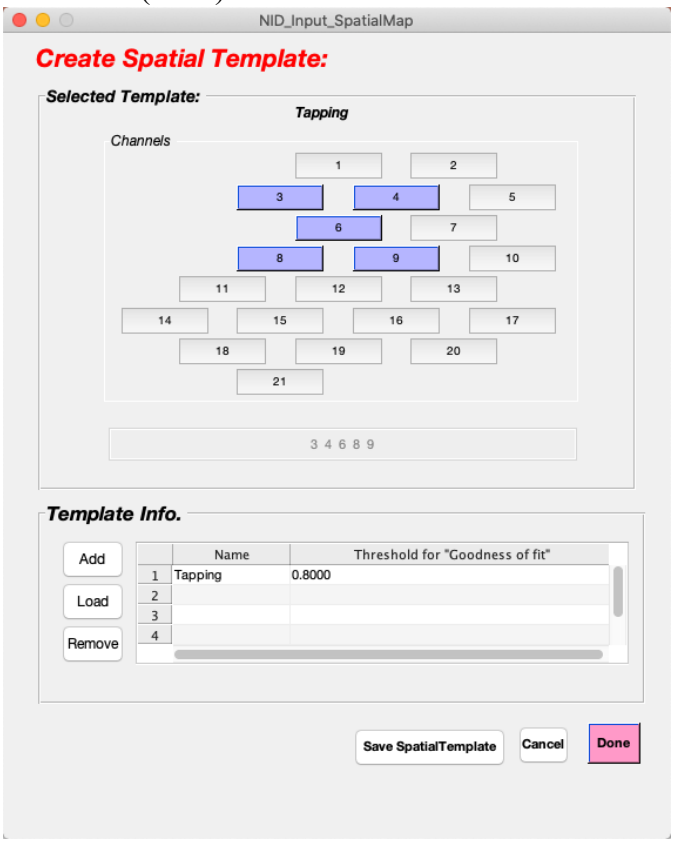
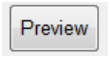


Figure 16. Input spatial templates by selecting channels within ROI.

6. Visualizing the ICA results

After ICA decomposition, users can use the main GUI to select noise-related sources and sources of interest. The separated results are arranged as a grid. The functionality of the objects on the main GUI is listed in Table 8.

Table 8. The functionality of the objects on the main GUI.

Name	Appearance	Functionality
Save		Save the results
Magnifier		Zoom in or zoom out the plotted data
Move		Move the plotted data
Change page		If the sources cannot be displayed on one page, use these buttons to change the page.
Change the size of the blocks in the grid		The block size of displaying the separated results consists of small, medial, and large with associated to the three icons. 25, 12, and 4 blocks are displayed using these three sizes of blocks respectively.
Features of the sources		Switching the displayed features between time courses, spatial maps, and frequency spectrums of the time course.
Results preview		Previewing the noise reduction results by arbitrarily input the number of noise sources to be removed.
Metric		Order the separated sources with the selected metrics.
The number of sources selected		Display the selected numbers of sources.
Reset		Empty the already selected sources.
Preview		Preview the data quality after remove the selected sources.

Detailed displaying sources for selecting neuronal activity-related sources

Users can press the magnifier on the left of the top bar of a source to view the detailed information of the source (Figure 17).

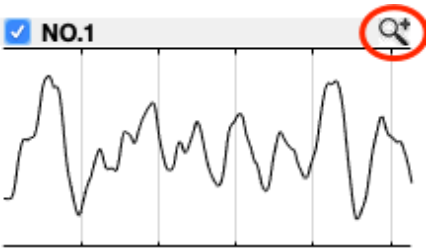


Figure 17. Pressing the magnifier to open the detailed information of the source.

Users can also switch to view the detailed information of other sources by pressing  , on the top menu.

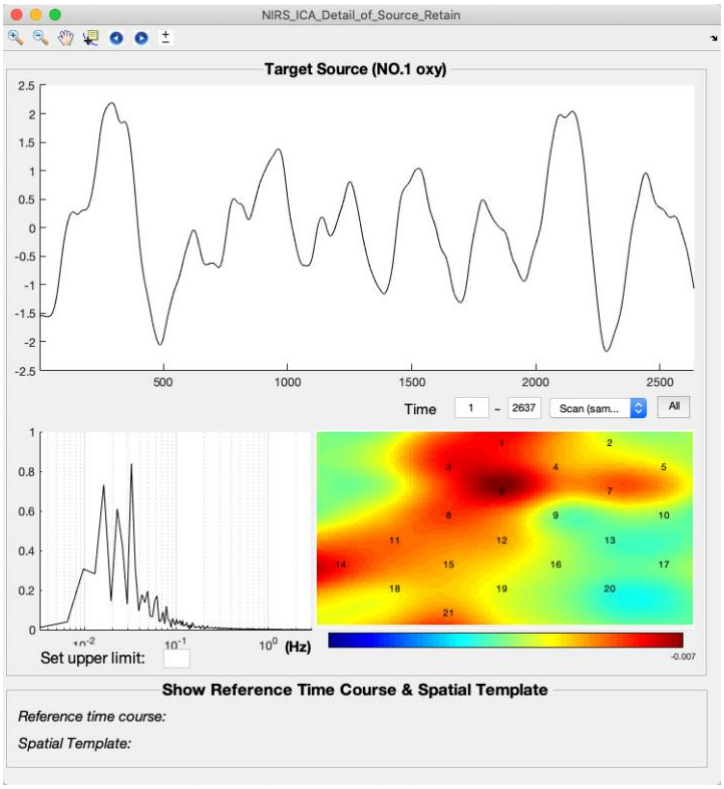


Figure 18. Detailed displaying a source of interest.

Detailed displaying sources for selecting noise sources

Using NIRS-ICA to remove noise sources, the GUI of detailed displaying sources is shown in Figure 19. The GUI consists of three parts, i.e., the detailed information of the sources (red box), the raw data of fNIRS (green box), and baseline control (yellow box). To facilitate inspecting the

relationship between the time course of the current source and the original signal of each fNIRS channel, the fNIRS time course is displayed in the right panel. Users can examine the contribution of the current source to the time course of each fNIRS channel by pressing the channel buttons on the right panel. To enable users to preview the performance of removing the current source, the cleaned fNIRS time course, i.e., reconstructed without the current source, can be overlaid with the raw fNIRS time course by selecting the checkbox at the bottom of the left panel. The fNIRS time course or baseline time course displayed can also be the time course without the already-selected noise sources by selecting User-defined Baseline NIRS Data at the bottom of the left panel. The functionality of the objects on the GUI is listed in Table 9.

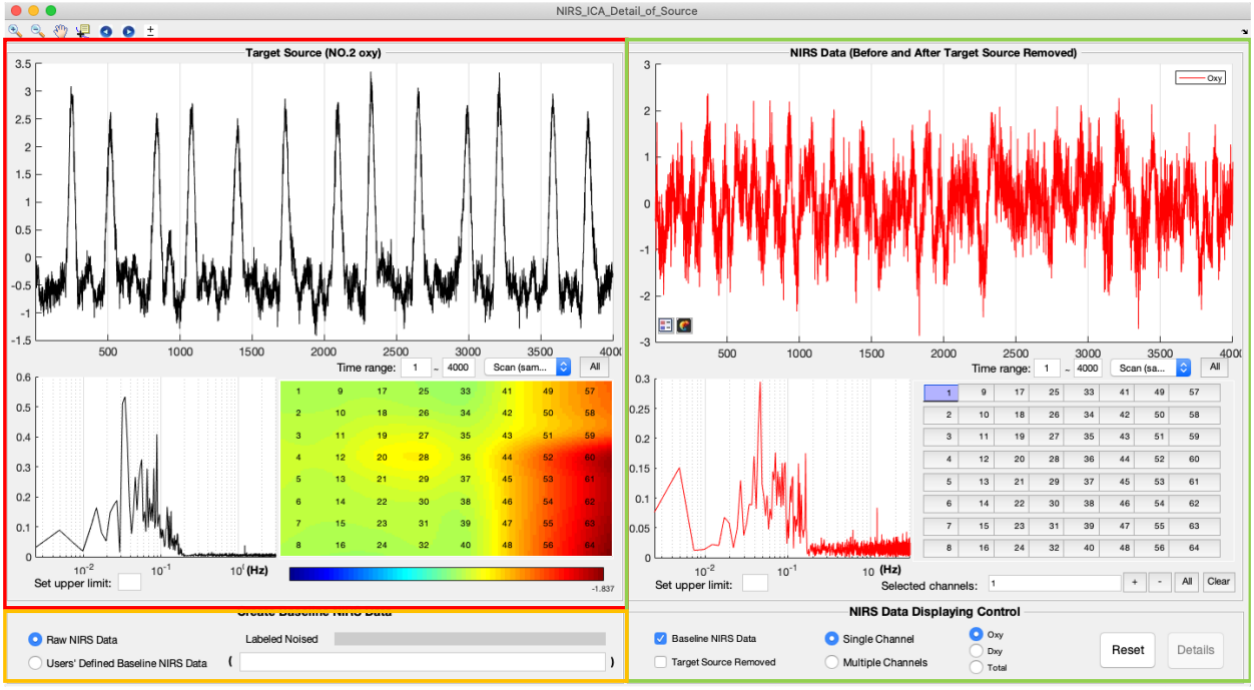
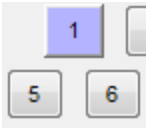
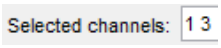
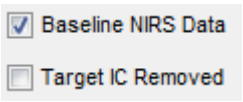
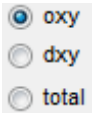
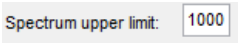


Figure 19. The GUI of detailed displaying sources for noise reduction.

Table 9. The functionality of the objects on the GUI of detailed displaying noise sources.

Name	Appearance	Functionality
magnifier		Zoom in or zoom out the plotted data.
Move		Move the plotted data.
Switch		Switch to the detailed information of the previous or next sources.

Channel number		Select the channel number of the displayed time course.
Input channel number		Change the displayed time courses by input the channel numbers
Move		Move to the next channel.
Move		Move to the previous channel.
All		When displaying multiple channels, it can be used to show the time courses of all channels.
Clear		Clear the selected channels
Switch		Displaying the time course of a single channel or multiple channels.
Raw data or Clean data		Displaying raw data or noise-removed data.
Hb type of the raw data		Switch the Hb type of the displayed fNIRS data.
Time range		Users can view the specific segment of the time course by input the start and end time.
Scale		The scale of the axis for displaying time courses can be either scans or seconds.
Limit the Frequency spectrum		Set upper limit for better displaying the frequency spectrum.
Reset		Clear all the displayed time courses.

Preview the denoised fNIRS signals

Users can press the Preview button to preview the noised reduced fNIRS signals. By selecting both Baseline NIRS Data and Target IC Removed, one can simultaneously visualize the fNIRS signals before and after removing the selected noise sources (Figure 20).

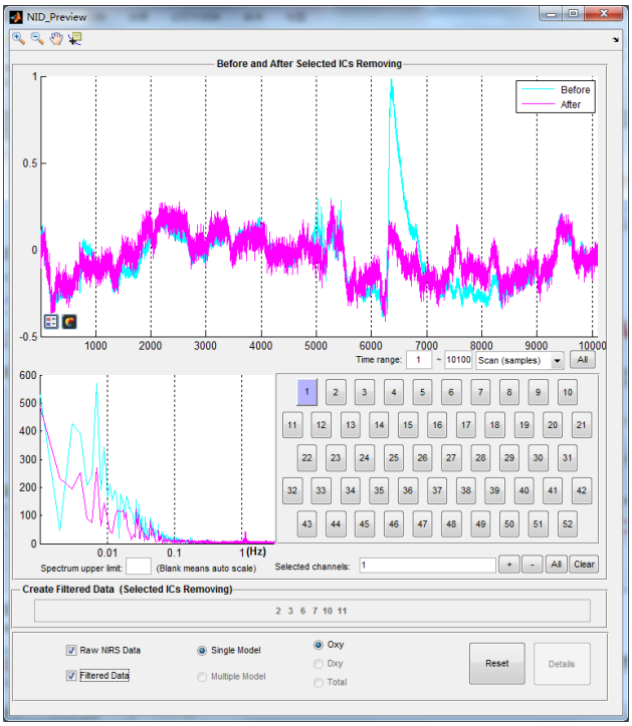


Figure 20. The interface of previewing the denoised fNIRS signals.

7. Result saving

After selecting noise or neuronal activity-related sources, users can press  on the top menu to save the results (Figure 21). The results will be saved to the user-specified output directory based on the mode of applying ICA, i.e., for noise reduction or selecting sources of interest. Note that the file name is the same as the subject ID displayed in the list box.

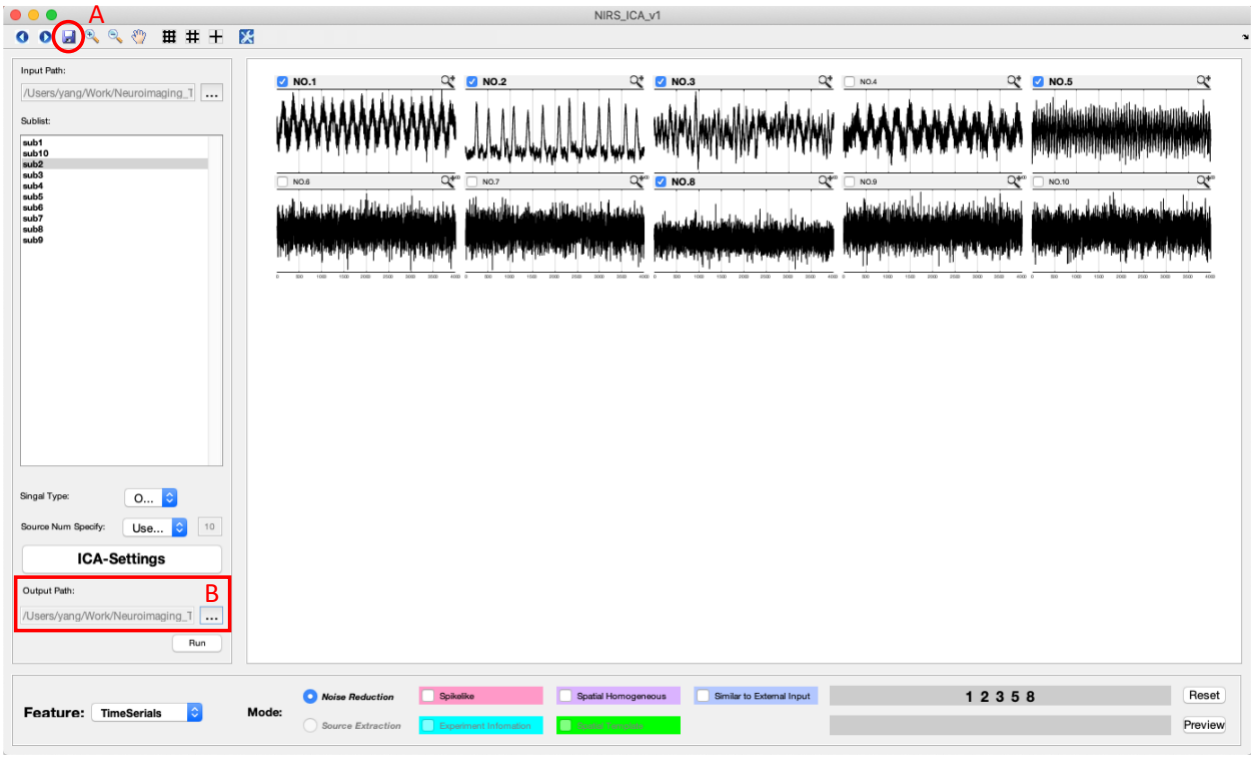


Figure 21. Save the results to the specified output path. (A) Save button for saving the results. (B) Output directory specified by users.

8. References

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