Sequencing brain networks that support cognitive processes in a sub-TR timeframe using independent component analysis (ICA) and Granger causality

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Aim

By using fMRI, extract the brain networks that support a certain cognitive task and sequence them in order to have a logical arrangement.

1° step—Reduce the amount of data with ICA

Original fMRI data enter an ICA analysis as implemented in MeNeuL, part of the FSL package, to reduce the amount of data to a tractable size. The output are independent components (ICs) that contain active and deactivate voxels in network. In the case of this data set it yielded 164 ICs. Each IC has associated a time course. As an example the network in IC17 is depicted together with its time course:

2° step—Temporal series reconstruction

In the second step we disassemble the timecourses and reconstruct the temporal series that are characteristic to the event. By this way, in the end each IC has reduced time series that is the average of all events. In the example in the right the result for IC 17:

3° step—Testing correlation with the stimulus of interest

In this step the procedure searches and tests the existence of an hemodynamic response. Because the hemodynamic peak may happen at any time, the model has to be sensitive to such temporal variability. A generalized linear model (GLM) analysis is used as per the equation on the right (this equation and results from the expansion in Taylor series). The independent variable (\(Y\)) is the mean calculated in the previous step, and the dependent variables are a canical gamma function (\(X_1\)) and the respective first derivative (\(X_2\)). The resulting model is Pearson tested with the mean calculated in the previous step. An high value signifies that the IC correlates with the stimulus of interest, whereas a low value means that there is no correlation. Two extreme examples are depicted, one with high correlation and the other with no correlation. The table below includes all ICs (threshold at p-value = 0.01).

4° step—Applying Granger causality

Finally we apply the Granger causality test to the ICs' reduced time series that survived. The Granger causality tests sequences of the time series which are fed into it (finds Granger causes, or G-causes). In summary, it tests if putting one event before another would contribute to reduce the amount of unexplained variance.

In the example depicted the ICs in the rows significatively G-cause the ICs in the columns when the respective covert is red colored (p-value ≤ 0.01). These examples are for first, second, and third orders G-causes, i.e. respectively one step backward (or 500 ms), two steps (1000 ms), and three steps (1500 ms).

One advantage of this procedure is that it outputs the ICs relevant to the task in network. This network may be studied using the Theory of Graphs, e.g. highlighting the inputs and the outputs to certain nodes, or finding possible paths that connect two nodes (where the nodes correspond to ICs, which in turn represent brain networks).

The data set

Five categories of stimuli: preferred brands (Positive), indifferent brands (Indifferent), non-emotional words (NEW), and the fixation cross (ISI). To illustrate the procedure proposed in this poster the elected stimulus of interest is the preferred brands.

Participants had to rate the brands inside the scanner. Responses were recorded by a button box. The graphic below depicts the response pattern. The mean response time for preferred brands is 1546 ms, and 59.5% of the responses are made in the first 1500 ms.

The fixation cross is used as ISI and is variable: it ranges from 4000 until 9000 ms in 500 ms steps: this means that there are volumes being acquired that offset from the stimulus onset in 500 ms steps (0, 500, 1000, 1500, 2000, and 2500 ms, respectively 0, 1/6, 1/3, 1/2, 1/3, and 5/6 of the TR).

Analyzing the graph

IC17 holds the network that has more connections: 52 (29 in and 23 out) in first order, 42 (27 in and 15 out) in second order, and 28 (8 in and 20 out) in third order. It has then a pivotal role in the graph. It is not surprising because IC17 includes large active voxels in the left motor cortex and registering the Positive answer during the scanning session was done with the contralateral (right) hand.

In the other extreme, we looked for ICs that have active voxels in V1 (BA17) brain region. This is because stimuli was conveyed through vision and our assumption is that earlier visual areas should activate first. The following ICs have more than 1000 active voxels in V1: 1, 2, 3, 4, 5, 7, 14, 16, 24, 31, and 163. Then we searched for all the pathways that link ICs with extensive V1 activations with IC17. These pathways and respective ICs would reveal the brain areas that were involved in the decision-making process for preferred brands. Here we depict an example, from IC1 until IC17. We considered only the links with p-value < 0.01. The sequence below illustrates some of the ICs involved. In IC10 there is a clear participation of fusiform areas, whereas IC20 includes a network encompassing the frontal pole, temporal-parietal junction, posterior cingulate and precuneus, which has been found to participate in self-reflexive processes.

In summary, it tests if putting one event before another would contribute to reduce the amount of unexplained variance.