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# Using transfer entropy to measure the patterns of information flow though cortex: application to MEG recordings from a visual Simon task

M Wibral[1], Raul Vicente*[2], Jochen Triesch[2] and Gordon Pipa[2,3,4]

Address: [1]MEG Unit, Brain Imaging Ctr. Frankfurt, Frankfurt, Germany, [2]Frankfurt Inst. for Advanced Studies, Frankfurt, Germany, [3]Neurophysiology Department, Max Planck Inst. for Brain Research, Frankfurt, Germany and [4]Department of Anesthesia, Massachusetts General Hosp., Cambridge, MA, USA

Email: Raul Vicente* - raulvicente@gmail.com

* Corresponding author

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Functional connectivity of the brain describes the network of correlated activities of different brain areas. However, correlation does not imply causality and most synchronization measures do not distinguish causal and non-causal interactions among remote brain areas, i.e. determine the effective connectivity [1]. Identification of causal interactions in brain networks is fundamental to understanding the processing of information. Attempts at unveiling signs of functional or effective connectivity from non-invasive Magneto-/Electroencephalographic (M/EEG) recordings at the sensor level are hampered by volume conduction leading to correlated sensor signals without the presence of effective connectivity. Here, we make use of the transfer entropy (TE) concept to establish effective connectivity. The formalism of TE has been proposed as a rigorous quantification of the information flow among systems in interaction and is a natural generalization of mutual information [2]. In contrast to Granger causality, TE is a non-linear measure and not influenced by volume conduction.

We evaluate TE on MEG data recorded during a Simon task. Subjects were presented with a "L" or "R" letter in either the left or the right side of a screen and had to press a left-side key in response to the "L" letter and the right-side key in response to the "R" letter, independently of the spatial location of the stimulus. The sequential organization of this task allows us to infer gross effective connectivity: Visual input has to be processed and the letter recognized before motor action can be planned. Hence, effective connectivity from visual cortices to frontal and motor areas was expected. Our tasks directed visual input either to the left or right hemisphere in early visual cortex and required left or right hemispheric motor responses, presumably changing connectivity patterns.

TE of channel pairs was computed with a Kozachenko-Leonenko estimator while the statistical significance of the causal interactions was determined by a non-parametric permutation test. The flow of information revealed that different neuronal circuits (including long-range causal influences like inter hemispheric temporal lobe interactions) were recruited for the four different experimental conditions, in accordance to the physiological expectation. The effective networks of Simon versus non-Simon effect conditions were also compared to explore the use of effective connectivity as a tool to investigate cognitive processes.

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