

# Reliability of Dynamic Causal Modeling using the Statistical Parametric Mapping Toolbox

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## ABSTRACT

*Dynamic causal modeling (DCM) is a recently developed approach for effective connectivity measurement in the brain. It has attracted considerable attention in recent years and quite widespread used to investigate brain connectivity in response to different tasks as well as auditory, visual, and somatosensory stimulation. This method uses complex algorithms, and currently the only implementation available is the Statistical Parametric Mapping (SPM8) toolbox with functionality for use on EEG and fMRI. The objective of the current work is to test the robustness of the toolbox when applied to EEG, by comparing results obtained from various versions of the software and operating systems when using identical datasets. Contrary to expectations, it was found that estimated connectivities were not consistent between different operating systems, the version of SPM8, or the version of MATLAB being used. The exact cause of this problem is not clear, but may relate to the high number of parameters in the model. Caution is thus recommended when interpreting the results of DCM estimated with the SPM8 software.*

**Keywords:** *Dynamic Causal Modeling, Effective Connectivity, MATLAB, Statistical Parametric Mapping (SPM8), Robustness*

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## 1. INTRODUCTION

The human brain is regarded as an ensemble of dynamic systems. Communication between neural centers is of the utmost importance in executing a mental task and many different cortical and subcortical brain areas have to coordinate for an individual to respond effectively to sensory

DOI: 10.4018/ijstda.2014040101

input. Brain organization can be quantified by connectivity measures which aim to provide measures of the strength, direction, and timing information on the connections between brain areas.

Brain connectivity is sometimes broken down into three categories: structural, functional, and effective connectivity (Daunizeau et al., 2011). Structural connectivity describes the anatomical structure of the brain and the pattern of anatomical links inside the brain (Daunizeau et al., 2011). Functional and effective connectivity measurements of the brain have become very popular topics in the field of neuro-science and neuro-engineering in recent years. Functional connectivity (Chan et al., 2013; Jalili & Knyazeva, 2011; Lachaux et al., 1999) can indicate if there is a relationship between the activities of two different brain areas but it cannot reveal the direction of the connection (information flow). The latter is referred to as the causality in the connections and can be probed through effective connectivity analyses which has attracted much attention in recent research (Baccala & Sameshima, 2001; David et al., 2006; Sakkalis, 2011).

Generally, causality refers to the relation of cause and effect. In other words, causality indicates which event/signal is the consequence of the other. It can be quantified according to different statistical measures such as Granger Causality (Granger, 1969), Partial Directed Coherence (Sameshima & Baccalá, 1999), and Directed Transfer Function (Korzeniewska et al., 2003) which all fit a linear multivariate autoregressive model to the EEG data. Nonlinear extensions of this approach, such as nonlinear Granger Causality (Ancona et al., 2004; Freiwald et al., 1999), have also been introduced allowing for a wider range of functional connectivities. The conventional linear methods have the advantage of parsimony, are generally easier to implement, need fewer assumptions, and thus are likely to be more robust than non-linear methods but can only approximate biological systems which are never entirely linear. It should also be noted that none of the above methods (either linear or non-linear ones) explicitly take prior knowledge of structural or functional connectivity into account. For extended reviews on functional and effective connectivity measurements the reader is referred to other publications (Friston, 2011; Gourévitch et al., 2006; Pereda et al., 2005).

In contrast to the above approaches, Dynamic Causal Modeling (DCM) was developed on a neurobiological basis (David et al., 2006; Friston et al., 2003). It is a biologically informed model which in principle gives it many advantages over other connectivity methods and has become popular among researchers in recent years. Whilst DCM has potential advantages over other models, a possible weakness in the approach is its large number of parameters and initial assumptions which may affect the robustness of the algorithm, reducing the reliability of results. The Statistical Parametric Mapping (SPM8) software is a freely available MATLAB®-based toolbox in which the DCM algorithm has been implemented (<http://www.fil.ion.ucl.ac.uk/spm/>). However, the robustness of the implementation of DCM does not appear to have been tested extensively.

In order to address this and following preliminary work that indicated potential problems with the toolbox, we tested the consistency of results between different versions of SPM8 and MATLAB® and different operating systems on identical data. If results differ widely, even on just a few examples, this would raise concern as to whether results allow robust inference on functional connectivity. To the best of our knowledge, our work is the only publication testing the robustness of the implementation of DCM in the software SPM8.

In the next sections, a review of related previous work on the reliability of DCM is presented, followed by the methods section which includes a brief explanation of DCM, and materials section which explains the data used and how this was analyzed. The results and their discussion then lead to the conclusions.

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