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The effects of physiologically plausible connectivity structure on local and global dynamics in large scale brain models

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ABSTRACT

Functionally relevant large scale brain dynamics operates within the framework imposed by anatomical connectivity and time delays due to finite transmission speeds. To gain insight on the reliability and comparability of large scale brain network simulations, we investigate the effects of variations in the anatomical connectivity. Two different sets of detailed global connectivity structures are explored, the first extracted from the CoCoMac database and rescaled to the spatial extent of the human brain, the second derived from white-matter tractography applied to diffusion spectrum imaging (DSI) for a human subject. We use the combination of graph theoretical measures of the connection matrices and numerical simulations to explicate the importance of both connectivity strength and delays in shaping dynamic behaviour. Our results demonstrate that the brain dynamics derived from the CoCoMac database are more complex and biologically more realistic than the one based on the DSI database. We propose that the reason for this difference is the absence of directed weights in the DSI connectivity matrix.

1. Introduction

An ever increasing volume of research is being devoted to the investigation of connectivity in the human brain (e.g. Sporns et al., 2005). This is true for both structural investigations as well as in the analysis of electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI), where the attempted uncovering of the brain network or networks activated during “rest-state” or when undertaking specific cognitive task is one of the dominant pursuits (Fox and Raichle, 2007). This focus on the uncovering of networks is natural given that the intrinsic structure of the brain is that of an architecturally complex spatially distributed network. However, this work is largely proceeding without an explicit detailed understanding of how the specific connectivity structure at various scales influences the dynamic processes operating on these networks.

Existing models of large scale brain activity, which by necessity have typically averaged over this complexity, have been in active development for over 30 years. Only relatively recently have the detailed quantitative data expressing the complex connectivity structure started to become available (Kötter, 2004; Hagmann et al., 2008). With the availability of this data, it has become possible to incorporate biologically realistic connectivity into dynamic network models (Zemanová et al., 2006; Zhou et al., 2006; Honey et al., 2007; Ghosh et al., 2009). These models have been shown to produce dynamics which reflect properties of the “rest state” networks observed in EEG, MEG, and fMRI. Further, the dynamics of these networks has been shown to depend critically on details of the underlying connectivity structure, as well as the time delays via signal transmission. As the connectivity structure can so profoundly influence the dynamic properties of the simulated activity, it is essential that future development of large scale brain models appropriately include this structure.

Investigating the behaviour of relatively simple dynamic components coupled through physiologically derived networks is an essential first step in developing more realistic models of whole

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Fig. 1. A flat map representation of the cortical parcelation used to construct the CoCoMac connectivity matrix.

brain dynamics. While it is necessary that initial investigations focus on basic stability properties and simple noise-driven activity in these models, the latter being interpreted as a model for "rest-state" activity, an ultimate goal is to construct models built on this connectivity structure capable of providing insight and understanding of the network structures' impact on task related neural behaviour and brain dynamics in clinical settings, such as the evolution of epileptic seizures.

In this paper we detail a specific implementation of this style of model and investigate the functional dynamics and its differences due to variation in connectivity; in particular, we will focus on the differences due to the specific methods used to derive a connectivity

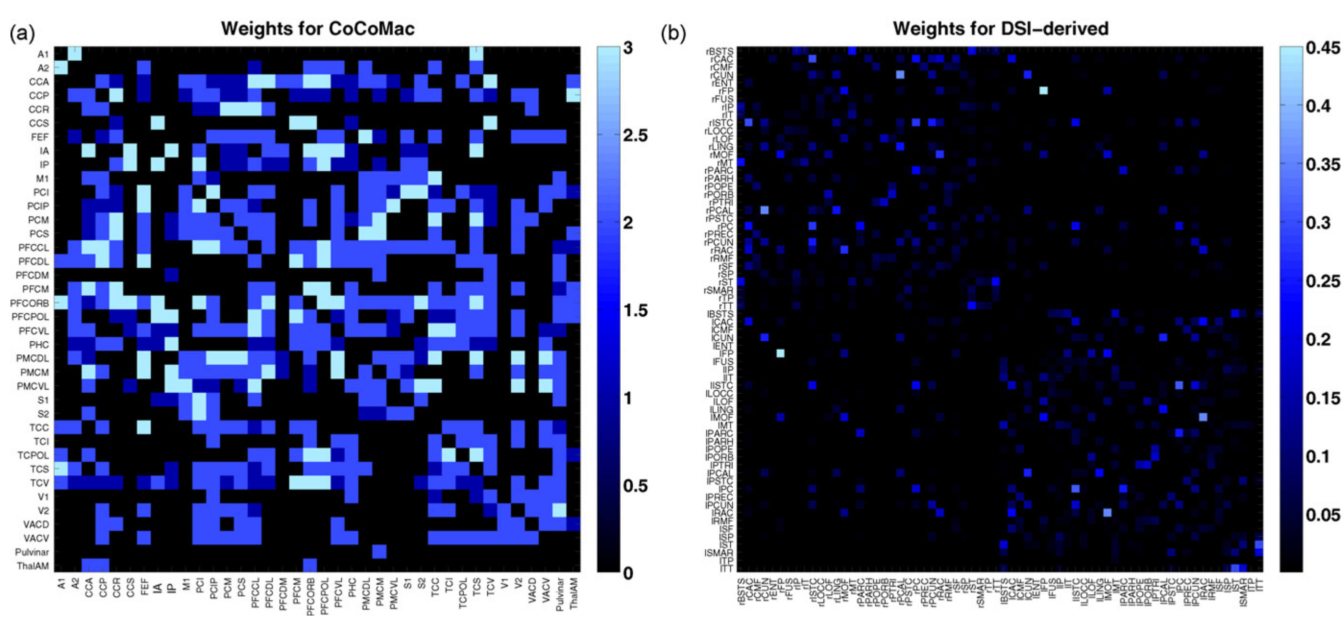

Fig. 2. Weighted connectivity matrices: (a) CoCoMac and (b) DSI-derived. Rows (vertical axis) represents target nodes with connection strength colour coded, black indicating no connection and light blue the strongest connections. Connections in the CoCoMac matrix go from columns into rows, the DSI matrix is symmetric. Node order in (a) and (b) are as in Tables 1 and 2, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)