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# Brain Sciences Institute




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## BSI Research Units

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### Brain Dynamics Research Unit

**Unit Leader:** A/Prof David Liley

#### Introduction:

How do brains work and how might you model them to try and find an answer to this question?

One of the most popular and common approaches is to view the brain as a large and densely interconnected network of neurons. However the brain consists of around a thousand billion neurons each of which makes many thousands of connections to nearby and distant neighbours. Modelling the brain as a neural network is really just not tractable or practical.

Fortunately there is a way around this problem. It consists of viewing the brain, and in particular the part that is the seat of our intellect, the cortex, as if the activity of all these neurons is continuously distributed in space. The advantage of this approach is that we change our view of the brain from being a synthetic information processing entity into a natural dynamically evolving entity. In this view the brain evolves less like a computer and more like a natural dynamical phenomenon such as a blizzard or hurricane.

This approach, which uses the language of partial and ordinary non-linear differential equations, has enabled us to develop important insights into how brain waves (the electroencephalogram or EEG) are generated and what they may be able to tell us about how the brain works. For

#### Further Information

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Brain Dynamics Research Unit

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instance how do anaesthetics work? Why do drugs like valium make us feel relaxed and less anxious?

These and other questions can be tackled using this 'dynamical systems' approach. Potential projects are available which aim to address aspects of these questions using sophisticated .

### **Key Members:**

**Name:** A/Prof David Liley,

Role in Unit: Research Unit Leader

(Personal web page: <http://marr.bsee.swin.edu.au> )

Involved in the development of physiologically plausible theories of the electroencephalogram and the application of these theories to better understand the relationship between the microscopic (molecular/cellular) targets of anaesthetic/sedative action and their macroscopic (EEG/behavioural) effects.

**Name:** Dr Ingo Bojak, Postdoctoral Research Fellow

(Personal web page: <http://users.on.net/ibojak> )\_

Role in Unit: Dr Bojak is, with A/Prof David Liley, the lead theorist in the group. In collaboration with A/Prof Liley he has developed a range of mathematical approaches for modelling and simulating the effects of drug action on the EEG. To date this has allowed an improved understanding of how anaesthetics and sedative agents alter the collective properties of cortical neurons as measured by the EEG. Dr Bojak makes extensive use of the Swinburne Supercomputer for full-grid numerical simulations of the defining partial differential brain wave equations.

**Name:** Dr Mathew Dafilis,  
Biomedical Research Scientist

Role in Unit: Dr Mathew Dafilis's area of expertise is in the application of non-linear dynamical methods to the human EEG. Using a range of techniques from dynamical systems theory Dr Dafilis is investigating the degree to which a range of anaesthetic and sedative agents alter the non-linear architecture of spontaneous EEG. The results of these analyses are expected to inform the ongoing commercial development of a depth of anaesthesia monitor by A/Prof Liley and Cortical Dynamics Pty Ltd.

**Name:** Mr Nicholas Sinclair,  
Biomedical Research Engineer, Cortical Dynamics Pty Ltd

Role in Unit: Mr Nicholas Sinclair oversees the commercial development and testing of all hardware and software for the electroencephalographic assessment of depth of

anaesthesia. Additionally he co-ordinates analysis of all data recorded arising from the clinical trials involving the depth of anaesthesia monitor

**Name:** Mr Brett Foster,  
PhD Scholar

**Role in Unit:** Mr Brett Foster is involved in electroencephalographically quantifying the effects of dissociative anaesthetic agents such as nitrous oxide. Mr Foster is involved in all aspects of participant recruitment, 64-channel EEG data collection and data analysis (time/frequency, linear/nonlinear).

### **Current Research Projects:**

Can spontaneous beta activity be explained dynamically?  
Analysis of spontaneous EEG recorded from healthy participants reveals that alpha and beta band activity exhibit a high degree of phase coherence suggesting that they may be the result of a common dynamical process. Using a physiologically detailed non-linear mathematical theory of the human EEG we are systematically investigating whether noise-driven input and/or noise-modulated parameters are capable of explaining the simultaneous appearance of alpha and beta activity.

Can input to cortex be determined using EEG?  
Linearisation of Liley et al's non-linear theory of electrocortical activity suggests new, more physiologically relevant, ways to derive information from spontaneous EEG. In particular, based on a number of reasonable assumptions, the input a given region of cortex receives from other distant cortical and subcortical areas, can be distinguished from its response to such input. This methodological approach is expected to have important implications in enabling better discrimination of the functional targets of drug action.

Implications of 40 Hz EEG activity in a physiological plausible mathematical model of the EEG. We have found our physiologically realistic theory of the alpha rhythm produces theoretically unanticipated dynamics that is expected to be of relevance in unravelling the relationship of "cognitively induced" 40 Hz activity to alpha and beta EEG activity. We have found that a large proportion of model parameter sets capable of producing "linear" alpha are also capable of producing "non-linear" 40 Hz when appropriately perturbed. We are currently investigating whether this "phase transition" represents a dynamical correlate of perception.

Does nitrous oxide alter the non-linear architecture of the EEG? Despite nitrous oxide being the first anaesthetic agent to be discovered and to enter routine clinical practice, its mechanism of action at both microscopic and macroscopic levels remains uncertain. Nitrous oxide is well know to

induce subtle and inconsistent EEG changes, which have confounded attempts to electroencephalographically quantify hypnosis induced by this agent. Based on the integration of experimental results with our theoretical modelling approach we hypothesise that nitrous oxide alters the non-linear architecture of the EEG. We are currently applying a range of non-linear measures in an attempt to help resolve the mechanism of nitrous oxide's hypnotic action.

### **Grants received:**

Liley DTJ. Commercial testing of a physiologically based theory of oscillatory brain electrical activity in anaesthesia monitoring. Development Grant. National Health and Medical Research Council (\$182 500), 2007.

Deam R and Liley DTJ. Develop business case and TGA approval for echogenic modified needles. Swinburne Industry Experts in Residence and Industry Fellowship Scheme (\$19,300), 2006.

Liley DTJ, Complexity in a mesoscopic model of brain dynamics, Discovery Grant, Australian Research Council (\$247 K), 2005-2007.

Liley DTJ, International Biomedical Imaging Technology Transfer, Innovation Access Grant Program, AusIndustry, (\$52 K), 2004-2006.

Leslie K and Liley DTJ, Quantifying the effect of nitrous oxide on the depth of anaesthesia using theoretically based time series modeling, Project Grant, Australian and New Zealand College of Anaesthetists (\$30K), 2005.

Dewar et al, Complex Open Systems Network (COSNet), Australian Research Council, Research Network (\$1.5M), 2004-2008.

Liley DTJ and Hendtlass R, Verification of a theoretical model of the dynamical genesis of brain electrical activity, Discovery Grant, Australian Research Council (\$165 K), 2002-2004.

Cortical Dynamics Pty Ltd, BITS Incubator Program Grant, Department of Communications, Technology and Arts (DCITA), (\$30K), 2004.

Liley DTJ and Cadusch PJ, Complexity in the brain: a computationally intensive investigation of novel two dimensional brain wave equations, Victorian Partnership for Advanced Computing Expertise Program Grants Scheme (\$30 K), 2002-2003.

Liley DTJ and Cadusch PJ, An investigation of the theoretically predicted effects of the benzodiazepines on the

human electroencephalogram, Research Development Grants Scheme, Swinburne University of Technology (\$11 K), 2002.

Liley DTJ, A test of a continuum model of alpha electrorhythmogenesis. ARC/SUT Small Grant Scheme, Swinburne University of Technology (\$11 K), 2000.

Wright JJ, Sergejew AA, Liley DTJ, Simulation of neocortical electrorhythmogenesis as an emergent group property of realistic neural networks, Project Grant, Australian Research Council (\$150 K), 1996-1998.

### **Work with Community and Affiliates:**

*Development of the BAR Depth of Anaesthesia Monitor with Cortical Dynamics Pty Ltd* In collaboration with biomedical startup Cortical Dynamics Pty Ltd the Brain Dynamics Group is involved in the development, testing and trialling of a new processed approach to depth of anaesthesia monitoring.

### **Key Publications:**

Bojak I, Liley DTJ. Modelling the effects of anaesthesia on the electroencephalogram. *Physical Review E* 2005;71: 041902

Dafilis MP, Bourke PD, Liley DTJ, Cadusch PJ. Visualising chaos in a model of brain electrical activity. *Computers and Graphics* 2002;26:971-976.

Dafilis MP, Liley DTJ, Cadusch PJ. Robust chaos in a model of the electroencephalogram: Implications for brain dynamics. *Chaos* 2001;11:474-478

Liley DTJ, Dafilis MP. Electroencephalogram at mesoscopic scales. In A.C. Scott, *Encyclopedia Of Nonlinear Science*. Fitzroy Dearborn, London. 2006.

Liley DTJ, Bojak I. Understanding the transition to seizure by modelling the epileptiform activity of general anaesthetic agents. *Journal of Clinical Neurophysiology* 2005;22:300-13.

Liley DTJ, Cadusch PJ, Gray M, Nathan PJ. Drug-induced modification of the system properties associated with spontaneous human electroencephalographic activity. *Physical Review E* 2003;68: 051906.

Liley DTJ, Cadusch PJ, Dafilis MP. A spatially continuous mean field theory of electrocortical activity. *Network-Computation in Neural Systems* 2002;13:67-113.

Liley DTJ, Cadusch PJ, Wright JJ. A continuum theory of electro-cortical activity. *Neurocomputing* 1999;26-27:795-

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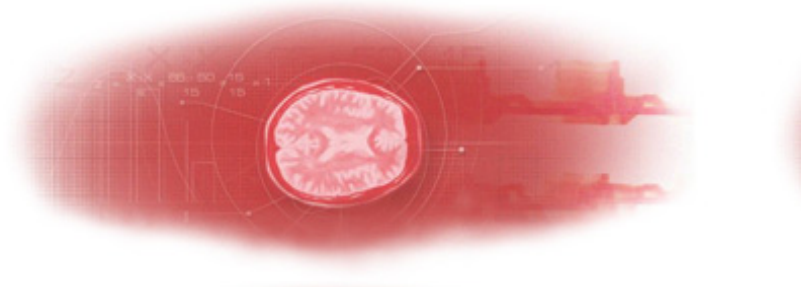
Liley DTJ, Alexander DM, Wright JJ, Aldous MM. Alpha rhythm emerges from large scale networks of realistically coupled multicompartmental model cortical neurons. *Network-Computation in Neural Systems* 1999;10:79-82.

Steyn-Ross ML, Steyn-Ross DA, Sleigh JW, Liley DTJ. Theoretical electroencephalogram stationary spectrum for a white-noise-driven cortex: Evidence for a general anesthetic induced phase transition. *Physical Review E* 1999;60:7299-7311

Wright JJ, Liley DTJ. Dynamics of the brain at global and microscopic scales: Neural networks and the EEG. *Behavioral and Brain Sciences* 1996;19:285-295.

Wright JJ, Liley DTJ. Multiscale modeling of brain dynamics depends upon approximations at each scale. *Behavioral and Brain Sciences* 1996;19:310-316.

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