Christchurch Neurotechnology Research Programme (*NeuroTechNZ*™)

Richard Jones
Director

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Introduction

The *Christchurch Neurotechnology Research Programme* ('*NeuroTech*' & *NeuroTechNZ*™) was established in February 2001 (although its had a long informal history) as a formal joint venture between Canterbury District Health Board (CDHB – Medical Physics & Bioengineering [MPBE], Neurology), University of Otago, Christchurch (UOC – Medicine), and University of Canterbury (UC – Electrical & Computer Engineering [ECE], Psychology). *NeuroTech* was initially based in MPBE at Christchurch Hospital but moved into the new *Van der Veer Institute for Parkinson's and Brain Research* at 66 Stewart Street in May 2004. It remains administratively under, but autonomous from, MPBE.

Neurotechnology can be broadly defined as 'Technology for investigation, quantification, monitoring, and treatment of the nervous system and its disorders'. Within this, *NeuroTech*'s vision is to focus on neurotechnology concerning the brain via three broad long-term objectives:

- Undertake cutting-edge research leading to the development and validation of innovative neurotechnology, particularly techniques and devices aimed at accident prevention and improved rehabilitation which can 'make a difference' to humankind by preventing loss of life and injury and by maximizing quality of life.
- Maximize the health and financial benefits of the innovative neurotechnology through commercialisation – IP protection, pre-market prototype development and validation, and product manufacture and sales on the global market.
- Maintain an awareness of other research projects in the Van der Veer Institute and, where appropriate, foster collaborations with researchers so as to identify and stimulate basic and applied brain research which might lead to potential products suitable for channelling through *NeuroTech* for commercialisation.

NeuroTech's key personnel are:

Staff

- Associate Professor Richard Jones – Neuroengineer/scientist and Director of Programme, CDHB & UOC & UC
- Dr Carrie Innes – Neuroscientist and CMRF Postdoctoral Research Fellow, CDHB

Postgraduate students (+ degree sought)

- Malik Peiris – PhD, Electrical & Computer Engineering, UC
- Daniel Myall – PhD, Medicine, UOC
- Govinda Poudel – PhD, Medicine, UOC
- Amol Malla – ME, Electrical & Computer Engineering, UC
- Petra Hoggarth – PhD, Psychology, UC

Affiliated staff & Research Fellows

- Professor Philip Bones – UC
- Associate Professor John Dalrymple-Alford – VdVI & UC
- Professor Tim Anderson – VdVI & UOC & CDHB
- Dr Michael MacAskill – VdVI & UOC
- Dr Marcus Heitger – VdVI & UOC
- Dr Richard Watts – VdVI & UC
- Dr Richard Green – UC
- Grant Carroll – CDHB
- Dr Leigh Signal – Sleep/Wake Research Centre, Massey University, Wellington

Research Activity

NeuroTech's research largely falls with four Sub-Programmes, of which the following outlines activity and achievements over the past year.

A. Driving Assessment Research Programme

Building on research during her PhD project, Carrie has initiated four further research studies aimed at validation and improvement of our Canterbury Driving Assessment Tool's (*CanDAT*™) (Figure 1) ability to predict capability to drive safely on the road based primarily on performance on a battery of computerized tests of sensory-motor and cognitive function (*SMCTests*™):

- Study 1 – Validation and improvement of the Full Assessment version of *SMCTests* (i.e., for specialist driving assessment therapists) on the full car-rig assessment system ('*Chrissy*') at Burwood Hospital's Driving and Vehicle Assessment Service (DAVAS). This study involved independent off-road and on-road assessments of 200 referrals of persons with definite or suspected brain disorders. This study is completed and has provided important new data for the training and validating of our predictive models.
- Study 2 – Identical to the DAVAS study except for off-road assessment being on *CanDAT* (Chrissy's portable descendant) and undertaken by O'Leary Driving Assessment Services (Wellington and Palmerston North) and OTRS Group Ltd (Hamilton). This study involves 400 referrals of persons with definite or suspected brain disorders and is in progress.
- Study 3 – Validation and improvement of the briefer Screening Assessment version of *CanDAT*, which is targeted at GPs and specialists who have a mandatory responsibility to assess and certify driving abilities for older-aged drivers and for persons who have some form of neurological or musculoskeletal disorder. Pegasus Health has set up a driver screening service, specifically for their ~250 GPs, although this study has been put

Figure 1. Carrie being tested by Petra on *CanDAT*.

temporarily on-hold while refinements are made to our screening predictive model following completion of the following study.

- Study 4 – Validation and improvement of the prediction models in both the Full and Screening Assessment versions of *CanDAT* when applied to a population of 60 healthy older-aged persons. This study was undertaken by Petra in the first stage of her PhD project in Psychology at UC, while concurrently undertaking her Postgraduate Diploma in Clinical Psychology. Petra is supervised by Richard, Carrie, and John and is based at the Institute. In addition to the full set of tests on *CanDAT*™ and a blinded on-road assessment, Petra assessed participants on a range of standard tests in the area of cognition/dementia, anxiety, aggression, and mood. Somewhat surprisingly, participants failed the on-road test!

- Studies 5 & 6 – Further studies are in planning to focus on (i) a 2-year follow-up of driving behaviour and accidents in the healthy older drivers of Study 4 and (ii) validation and improvement of the prediction *CanDAT* models when applied to drivers with mild cognitive impairment or early dementia. This will involve patients referred to DAVAS from the Psychiatric Services for the Elderly at PMH.

- **Development**

Maarten Van Hegen joined us over Nov-Feb as a Summer Student during his 4-month Biomedical Engineering Workshop Training at University of Twente (Enschede, The Netherlands). He successfully developed and validated a new feature in *SMCTests* for speech recognition and automated measurement of reaction times in the Divided-Attention test, aimed at improved clinic-based prediction of ability to safe driving ability.

- **Commercialisation**

Late last year, senior staff in Christchurch's *Canterbury Innovation Incubator* (www.cii.co.nz) visited us and were rather taken with our *CanDAT* system, in terms of its performance, utility, professional look, robustness, advanced stage of development and validation, and what appeared to be a largely unmet global market. They have since entered into an Agreement with CDHB whereby they are undertaking a systematic 'pre-incubation study' of *CanDAT*, including determination of the NZ and global need, alternative commercialisation possibilities, etc. Separate from this, Christchurch manufacturer Shape Technology Ltd has expressed a keenness to take on the role of larger-scale manufacture of *CanDAT* systems for taking to the international market – a necessary step in getting the benefits of our driving assessment research out into the big world.

B. Lapse Research Programme

Several long-term projects are under way looking at various aspects of complete lapses of responsiveness ('lapses'). These lapses are of 0.5–15 s duration and can be due to microsleeps, in which the brain turns off for a few seconds due to a brief shut-down in our arousal system, or lapses of sustained attention, which can occur even when a person is not drowsy. Our Lapse Research Programme is looking at various aspects of lapses and drowsiness, including (1) detection and prediction of lapses from electrophysiological and video data, (2) characteristics of lapses, such as rate, duration, changes over time, and differences between individuals, and (3) underlying mechanisms in the brain.

Congratulations to Malik, who, in June 2008, successfully defended his PhD thesis on his project looking primarily at the characteristics and EEG-based detection of lapses. He presented a paper at *WorldSleep2007* in Cairns in September 2007 on detection of lapses from spectral and non-linear features in the EEG changes in the EEG.

Amol is writing up his ME thesis on a computer-vision-based system he has developed for automated detection of drowsiness and lapses by measuring eye closure from video images of a person's face.

Govinda, Carrie, and Richard are making great progress towards finding out just what happens in the brain during lapses. Govinda's PhD project is investigating lapses via fMRI, 64-channel EEG, video of eyes, and visuomotor performance on a continuous 2D tracking task – all being carried out concurrently in a 3T MRI scanner for 1 hour (Figures 2 & 3). This exciting, but very demanding and expensive, project is benefiting from co-researchers with specialist expertise in MRI (Richard Watts), signal & image processing (Phil Bones), and sleep-wake research (Leigh Signal, Massey University). Govinda has built a mock-MR scanner, developed a novel 2-D tracking task able to detect behavioural lapses with high temporal accuracy, carried out a small lapse study in mock scanner, and carried out a small study of 10 subjects to determine and demonstrate the special features of the new tracking task.

Figure 2. Richard, Govinda, and Carrie doing some final checks on the EEG cap on Sebastian before he enters the GE 3T MRI scanner for a 1-hour fMRI+EEG session in the lapse study.

Figure 3. Sebastian, just before fully entering the scanner, with the MagLink 64-ch. EEG cap, the Avotec binocular video display & eye camera, and the 2-D joystick (all MR-compatible).

We are now well underway with a study requiring simultaneous-fMRI+EEG of 20 healthy subjects. Despite the noise in the scanner (even with ear-muffs), most of our non-sleep-deprived subjects have had multiple microsleeps during their afternoon sessions. Analysis of this data is still at an early stage but has given us what are provisionally the world's first fMRI-images of what happens during definitive behavioural microsleeps. Understanding just what happens in the brain between arousal, attention, default mode, and other networks in the brain during lapses is of considerable interest in its own right but also has the potential to provide important information for use in substantially improving the accuracy of detection and, possibly, prediction of lapses solely from the EEG or in combination with video of eyes/face. We have the only system in NZ able to carry out simultaneous fMRI+EEG investigations of the brain. This has been made possible with (i) access to the GE 3T MRI scanner immediately below the Institute in Hagley Radiology, (ii) funding from Lottery Health Research to purchase a Neuroscan MagLink system, which allows us to measure 64 channels of EEG while a person is in the undergoing fMRI, and (iii) further funding from LHR to allow us pay for scanner time and other research expenses incurred in running our study. We consider sim-fMRI+EEG to be the ultimate tool for non-invasive investigation of the brain.

Carrie is closely involved with all of the above studies and, in addition, is placing a focus on what happens in the brain near the *end* of lapses. This aims to answer the question 'Once a person has gone into a lapse, why does he/she come out of it rather than continue to meet the brain's presumed need to sleep or rest?'

Prior to his departure in October 2007, Paul also provided important input to all of the above projects. He also forged new directions for detection of lapses, with his detection system based on recurrent neural networks being able to detect lapses from EEG better than any other system in the literature. He presented a paper at *WorldSleep2007* on spectral dynamics of lapses. However, as impressive an achievement as this is, the level of accuracy of detection is still too low to be viable as a device for accurate detection of lapses in, say, various transport sectors.

C. *Traumatic Brain Injury Research Programme*

Marcus's research into the subtle sub-clinical motor deficits which occur following mild TBI is continuing strongly. Together with Tim and Richard, he has shown that some of these deficits will not, at least at the group level, have completely recovered even several months after the accident. He has also shown that the early subtle oculomotor, somatomotor, and visuoperceptual deficits are predictive of outcome, including postconcussion syndrome. These findings are being further validated through more extensive studies of acute TBIs and of patients referred to the Burwood Head Injury Clinic several months after their injury due to non-resolving sequelae. Once validated, these techniques have the potential for incorporation into devices which can predict outcome following mild head injury with possibilities for commercialisation. Marcus's research has led to a further publication, in *Journal of Rehabilitation Medicine*, over the past year. A new study has been started which is using advanced MR imaging techniques to study anatomical and physiological changes in persons who have sustained a mild TBI.

D. *Virtual-Environment Neurorehabilitation Research Programme*

Daniel's impressive 3-D multi-sensor/multi-display platform for studies of movements in a virtual environment (Figure 4) – based in our Movement & Virtual Environment (MoVE) Lab at the Institute – has led to a paper on this system, with examples from pilot applications, in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*.

With this new system, Daniel, Michael, Tim, and Richard have instigated a major research

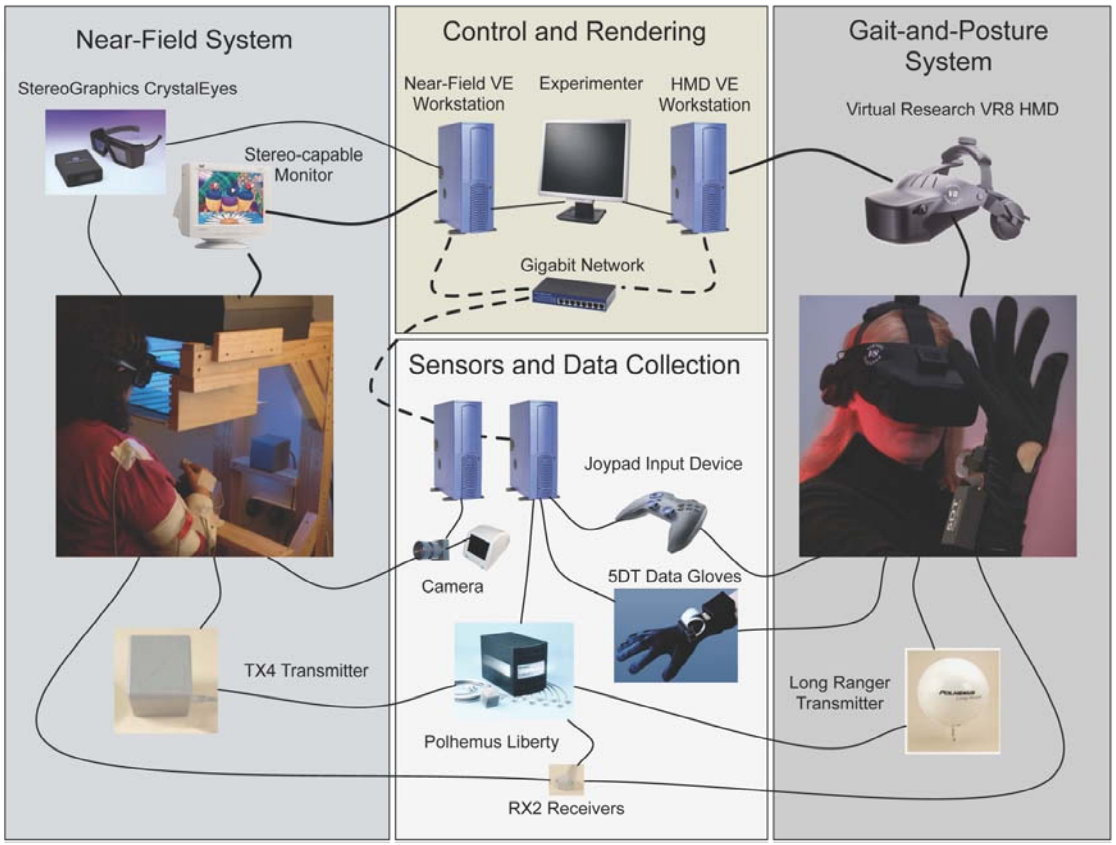

Figure 4. The virtual environment platform comprises a near-field system and a gait-and-posture system. Both systems share input devices.

study involving 24 patients with Parkinson's disease and matched controls. The data-collection phase is now complete and comprised 4 sessions per subject, several movement and adaptation paradigms (including visual/memory-guided movements and response delays), ballistic and smooth arm movements, and on- and off-medication; this all happens in a virtual environment in which manipulations (some obvious to subject, some not) can be made to the target, the visual environment, and to target-response relationships. Results from the study will be used to gain a fuller understanding of movement deficits in PD and to test and improve a computational model of the brain and its ability to account for the various deficits seen in PD. Daniel presented a paper on how Parkinson's disease affects eye and arm movements differently at *International Basal Ganglia Society Conference* in September 2007 in The Netherlands. Daniel's analysis of the data from the PD study is currently focusing on a technique for decomposing what can look to be bumpy single step/reaching movements into series of submovements – this looks to be an important means for understanding the underlying causes of differences in reaching tasks between PD and age/sex-matched normal subjects.
