Christchurch Neurotechnology Research Programme

Overview April 2011 – March 2012

www.neurotech.org.nz

Richard Jones
Director

Introduction

The *Christchurch Neurotechnology Research Programme* ('*NeuroTech*' – www.neurotech.org.nz) is a joint venture between the Canterbury District Health Board (Medical Physics & Bioengineering, Neurology) [CDHB], University of Canterbury (Electrical & Computer Engineering, Psychology) [UC], University of Otago, Christchurch (Medicine) [UOC], and the NZ Brain Research Institute [NZBRI]. *NeuroTech* is administratively hosted by the CDHB and is based in the NZBRI.

NeuroTech personnel

Staff

- Professor Richard Jones – Neuroengineer/scientist and Director of Programme: Medical Physics & Bioengineering, CDHB; Electrical & Computer Engineering, UC; Psychology, UC; Medicine, UOC; VdVI
- Dr Carrie Innes – Neuroscientist, Postdoctoral Career Development Fellow (Accident Compensation Corporation): Medical Physics & Bioengineering, CDHB; VdVI
- Dr Govinda Poudel – Neuroengineer/scientist, Postdoctoral Research Fellow (Marsden): Medical Physics & Bioengineering, CDHB; VdVI

Students *(+ degree sought)*

- Petra Hoggarth – PhD, Psychology, UC
- Yaqub Jon Mohamadi – PhD, Medicine, UOC
- Simon Knopp – PhD, Electrical & Computer Engineering, UC
- Russell Buckley – MA, Psychology, UC
- Shuang-Xiu Chuang – Summer Student, Electrical & Computer Engineering, UC

Affiliated staff & Research Fellows

- Professor Philip Bones – Electrical & Computer Engineering, UC
- Associate Professor John Dalrymple-Alford –Psychology, UC; VdVI

- Associate Professor Deak Helton – Psychology, UC
- Dr Dominic Lee – Mathematics & Statistics, UC
- Dr Daniel Myall – ex- Medicine, UOC
- Dr Malik Peiris – ex- Electrical & Computer Engineering, UC
- Amol Malla – ex- Electrical & Computer Engineering, UC
- Dr Leigh Signal – Sleep/Wake Research Centre, Massey University, Wellington

Lapse Research Programme

The Christchurch Lapse Research Programme comprises several short- and long-term projects focused on various aspects of lapses of responsiveness (*lapses*). Lapses are complete transient/phasic disruptions in sensory-motor/cognitive performance, from ~0.5–15 s, during an active task. They include (i) behavioural microsleeps (*microsleeps*), during which individuals have a brief episode of suspension of performance and appear to fall asleep momentarily, (ii) sustained-attention lapses, which are not directly related to level of arousal and can occur when alert, fatigued, or drowsy, and (iii) diverted-attention lapses, due to loss of task-orientated attention. Sleep episodes ('nodding off' for >15 s) can have the same adverse consequences as microsleeps but are considered physiologically distinct due to their duration (notwithstanding the arbitrariness of the 15-s demarcation) and the recovery of responsiveness after a brief period in microsleeps.

Overall, our Lapse Research Programme aims to (i) advance our knowledge on the behavioural characteristics of lapses, such as rate, duration, changes over time, and differences between individuals, (ii) advance our scientific understanding of the underlying mechanisms in the brain, and (iii) develop lapse and drowsiness detection and prediction technology. Ultimately, it is hoped that this research will help in the prevention of serious/fatal accidents due to lapses, particularly in the transport sectors (truck and car drivers, pilots, air-traffic controllers, train drivers, health professionals), medicine (e.g., surgeons, anaesthetists), and industry (e.g., process control workers, nuclear plant operators).

In our first fMRI+EEG study, we recorded fMRI, 64-channel EEG, video of eyes, and visuomotor performance on a continuous 2D tracking task – all concurrently in a 3T MRI scanner for 50 min – from 20 healthy subjects. Despite the loud noise in the scanner (even with ear-plugs), 16 of our non-sleep-deprived subjects had microsleeps during their after-lunch sessions, at an average 79 microsleeps per hour. Following substantial preprocessing and analysis of the fMRI data, Govinda was able to show both a rapid decrease in thalamic activity and a rapid increase in frontoparietal cortical activity during microsleeps (Figure 1). The decreased thalamic activity suggests a loss of arousal and responsiveness during microsleeps, whereas the increased cortical activity may constitute a mechanism by which these regions are able to restore responsiveness.

Understanding what happens in the brain between the arousal and attention networks 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 the eyes. We have the only system in NZ able to carry out simultaneous fMRI+EEG investigations of the brain and consider sim-fMRI+EEG to be the ultimate tool for non-invasive investigation of the brain.

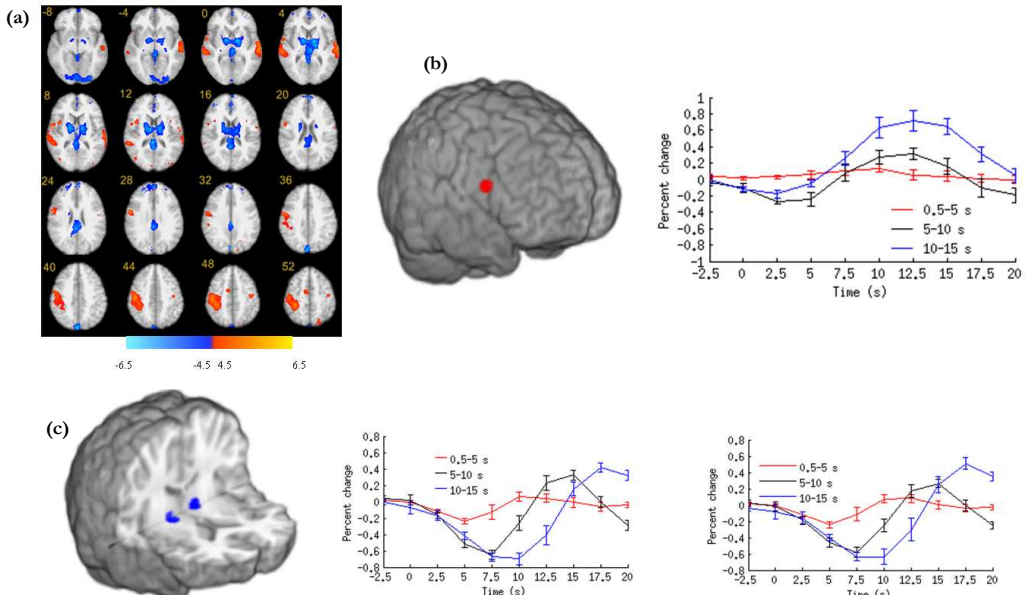

Figure 1. (a) Spatial map of activation (red) and deactivation (blue) during behavioural microsleeps obtained after group-level analysis. Time-resolved analysis of BOLD activity for three bins of 0.5–5 s, 5–10 s , and 10–15 s in the (b) right inferior frontal gyrus and (c) bilateral thalamus. Time-resolved analysis shows duration-dependent modulation in BOLD activity during microsleeps.

Also from our first fMRI+EEG study, Carrie was able to show that both the propensity for, and duration of, microsleeps are correlated with subjective estimates of daytime sleepiness (Epworth Sleepiness Scale) but, surprisingly, not with other measures of sleep, such as sleep quality, disturbance, duration, and efficiency, and circadian type. This indicates that propensity to fall asleep in situations in which sustained performance is required appears to be primarily a trait characteristic in normally-rested people.

We have not long completed the collection of data from our follow-up Marsden-funded fMRI+EEG study, which involved a further 20 healthy participants coming in for 2 sessions, one week apart: one in which they were normally-rested and the other in which their sleep during the prior night had been restricted to 4 hours. In addition to allowing us to replicate findings from our first study, this study will allow us to answer questions on the effects of sleep deprivation on (i) level of observer-rated alertness, (ii) behavioural characteristics of microsleeps and attention lapses, (iii) neural mechanisms of microsleeps and attention lapses, (iv) ability of a psychomotor vigilance task to predict drowsiness and microsleeps over an extended following period, (v) problem identification and cognitive processing, (vi) differences in the brain between being at rest and when performing a continuous visuomotor task, and (vii) cerebral blood flow (CBF) throughout the brain when at rest (using a relatively new fMRI technique of arterial spin labelling). Most of our data analyses are still in progress but some very interesting findings are already appearing at this early stage.

The data collection phase of Russ's MA project in Psychology (supervised by Richard, John, Carrie, and Deak) is well underway and nearing the end of the data collection phase. His study is looking at the differences in propensity for microsleeps versus attention lapses on different types of tasks (2-D tracking vs. vigilance) and task complexity (independent tests vs. combined).

Two new PhD projects have commenced during the past year. Yaqub (supervised by Richard, Govinda, and Carrie) commenced his project last July on enhancement of deep electrical activity in the brain associated with microsleeps. He has implemented a

beamformer (adaptive spatial filter) using both multi-layer spherical and boundary-element realistic head models and produced preliminary results of enhancement of deep simulated signals.

In March this year, Simon (supervised by Richard, Govinda, Carrie, and Phil) commenced his project aimed at the development of a head-mounted multi-modal device for lapse and drowsiness detection.

Over the 2010/11 university vacation, Shuang-Xiu Chuang, on a UC Summer Scholarship (supervised by Richard, Govinda, Carrie, and Phil), completed a 10-week research project to successfully develop and validate a software-based tool for automated detection of lapses from behavioural data obtained in an MRI scanner. In addition, she made solid progress towards a related goal of quantifying video-based eye closure.

Following a visit by Richard to Rome last year, we have established a research collaboration with Prof. Fabio Babiloni's Research Group and the Neuroelectric Imaging Laboratory in the Santa Lucia Foundation – Scientific Institute for Hospitalisation and Treatment in Rome. This is focused on applying and extending their expertise in functional connectivity analysis to determining the sequence, flow of information, and causality of the neural processes underlying microsleeps.

Similarly, we are establishing a research collaboration with the Prof. Mimi Galiana's Research Group in the Department of Biomedical Engineering at McGill University in Montreal. This Group is a leader in research into eye movement control systems and they are keen to see whether a recent technique they have developed – 'hybrid identification method' of vestibulo-ocular reflexes – might prove useful in seeing whether eye movements, as measured by EOG or video, can be used to estimate level of drowsiness and/or predict imminent microsleeps.

During the past year, Govinda had a paper published in *IEEE Transactions on Neural Systems and Rehabilitation Engineering* and Malik a paper in *Journal of Neural Engineering*. The Lapse Research Group also made an impact at *EMBC'10* (Buenos Aires), with Richard chairing and presenting an overview paper in a Mini-Symposium on 'Impaired attention: Drowsiness and microsleeps' and Govinda, Carrie, and Amol presenting papers in a Special Session on the same topic.

Driving Assessment Research Programme

Carrie, Petra, John, and Richard completed two research studies aimed at (i) validation and improvement of our Canterbury Driving Assessment Tool's (*CanDAT*™) (Figure 2) ability to predict 'medical fitness to drive' and 'ability to drive safely' based primarily on performance on a battery of computerized tests of sensory-motor and cognitive function (*SMCTests*™) and (ii) improving our understanding of the complex task of driving and the medical and non-medical factors which can prevent a person from driving safely:

- Dementia and Driving study – Petra's third study focused on persons with mild cognitive impairment (MCI) or dementia referred for a driving assessment to Burwood Hospital's Driving and Vehicle Assessment Service. These type of patients have previously proven particularly problematic as some have been found to perform very poorly on *CanDAT* but still pass the on-road assessment.

Figure 2. Carrie being tested by Petra on *CanDAT*.

Thirty two DAVAS referrals (aged 58-92 years) with MCI or Alzheimer's dementia were recruited into the study and undertook *SMCTests,* several standard cognitive tests, a blinded on-road assessment, and provided information on medical conditions. A binary logistic regression found that a combination of a measure of verbal fluency, the presence of heart disease, and an overall measure from the cognitive screen was best able to predict performance on the road. It was concluded that these three measures could be made in a primary health setting (taking 35-50 min) and used to predict, with reasonable accuracy, patients with MCI or Alzheimer's dementia who would go on to pass or fail an on-road driving assessment.

- Predictive modelling study – Carrie completed a comprehensive investigation into the ability of six models to predict driving ability in people with brain disorders. This large study used independent off-road and on-road assessment data from 501 referrals of persons with definite or suspected brain disorders from three occupational therapy-based driving assessment services in New Zealand: Burwood Hospital, O'Leary Driving Assessment Services (Wellington and Palmerston North), OTRS Group Ltd (Hamilton and South Auckland). The classification/predictive modelling techniques explored were discriminant analysis, binary logistic regression, non-causal resource analysis, product kernel, kernel product, and support vector machine. Although the more complex kernel-based models were shown to have a substantially higher accuracy at modelling and classifying data within a training set, the ability of all of the techniques to generalize to prediction of on-road performance in an independent test set proved to be surprisingly similar.

In March 2011, Petra submitted a superb PhD thesis on 'Prediction of driving ability in healthy older adults and adults with Alzheimer's dementia or mild cognitive impairment'. She also had a paper published in *Accident Analysis & Prevention* and had another accepted for publication in *Australasian Journal on Ageing*.

Carrie has a paper in press in *Quarterly Journal of Experimental Psychology* and presented a paper in a Special Session at *EMBC 2010* in Buenos Aires on her investigation of different models for predicting driving performance.

Publications & Presentations

Full papers in refereed journals –

Hoggarth PA, Innes CR, Dalrymple-Alford JC, Severinsen JE, Jones RD (2010). Comparison of a linear and a non-linear model for using sensory-motor, cognitive, personality, and demographic data to predict driving ability in healthy older adults. *Accident Analysis & Prevention*, 42: 1759-1768.

Poudel GR, Jones RD, Innes CRH, Watts R, Bones PJ (2010). Measurement of BOLD changes due to cued eye-closure and stopping during a continuous visuomotor task via model-based and model-free approaches. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 18: 479-488.

Norrie J, Heitger MH, Leathem JM, Anderson T, Jones R, Flett R (2010). Mild traumatic brain injury and fatigue: A prospective longitudinal study. *Brain Injury*, 24: 1528-1538.

Peiris MTR, Davidson PR, Bones PJ, Jones RD (2011). Detection of lapses in responsiveness from the EEG. *Journal of Neural Engineering*, 8 (016003): 1-15.

Hoggarth P, Innes C, Dalrymple-Alford J, Croucher M, Severinsen J, Gray J, Oxley J, Brook B, Abernethy P, Jones R (*in press*). Assessment of older drivers in New Zealand: the current system, research, and recommendations. *Australasian Journal on Ageing*.

Innes CRH, Lee D, Chen C, Ponder-Sutton AM, Melzer TR, Jones RD (*in press*). Predicting driving ability in people with brain disorders: Do complex models increase prediction of complex behaviours? *Quarterly Journal of Experimental Psychology*.

Short papers in refereed and published conference proceedings –

Jones RD, Poudel GR, Innes CRH, Davidson PR, Peiris MTR, Malla AM, Signal L, Carroll GJ, Watts R, Bones PJ (2010). Lapses of responsiveness: Characteristics, detection, and underlying mechanisms. *Proceedings of 32nd Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 32, 1788-1791.

Poudel GR, Innes CRH, Bones PJ, Jones RD (2010). The relationship between behavioural microsleeps, visuomotor performance and EEG theta. *Proceedings of 32nd Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 32, 4452-4455.

Innes CRH, Poudel GR, Signal TL, Jones RD (2010). Behavioural microsleeps in normally-rested people. *Proceedings of 32nd Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 32, 4448-4451.

Malla AM, Davidson PR, Bones PJ, Green R, Jones RD (2010). Automated video-based measurement of eye closure for detecting behavioral microsleep. *Proceedings of 32nd Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 32, 6741-6744.

Innes CRH, Lee D, Chen C, Ponder-Sutton A, Jones RD (2010). Different models for predicting driving performance in people with brain disorders. *Proceedings of 32nd Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 32, 5226-5529.

Published Abstracts –

Heitger MH, Watts R, Jones RD, Keenan R, Wells S, Ardagh MW, Anderson TJ (2010). Links between white matter integrity, eye movement function, and health in postconcussion syndrome. (Abstract) *Proceedings of the 16th Annual Meeting of the Organization for Human Brain Mapping*, Barcelona, Spain, June 2010,
http://ww3.aievolution.com/hbm1001/index.cfm?do=abs.viewAbs&abs=1615
