# Christchurch Neurotechnology Research Programme

## Overview & Update – September 2014

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) [CDHB], University of Canterbury (Electrical & Computer Engineering, Communication Disorders, and Psychology) [UC], and University of Otago, Christchurch (Medicine) [UOC]. *NeuroTech* is physically based at the *New Zealand Brain Research Institute* (NZBRI – www.nzbri.org).

## *NeuroTech* personnel and projects

### *Staff*

- Professor Richard Jones, Director of NeuroTech – Medical Physics & Bioengineering, CDHB; Electrical & Computer Engineering, UC; Communication Disorders, UC; Psychology, UC; Medicine, UOC.
- Dr Carrie Innes – Medical Physics & Bioengineering, CDHB; Electrical & Computer Engineering, UC.

### *Affiliated staff & Research Fellows & Collaborators*

- Professor Philip Bones – Electrical & Computer Engineering, UC
- Professor John Dalrymple-Alford – Psychology, UC
- Professor Deak Helton – Psychology, UC
- Professor Michael Robb – Communication Disorders, UC
- Professor Fabio Babiloni – Neuroelectrical Imaging and BCI Lab, University of Rome
- Dr Maggie-Lee Huckabee – Communication Disorders, UC
- Dr Steven Weddell – Electrical and Computer Engineering, UC
- Dr Paul Gaynor – Electrical and Computer Engineering, UC
- Dr Juan Canales – Psychology, UC

- Dr Govinda Poudel – Monash Biomedical Imaging, Monash University
- Dr Michael Hlavac – Sleep Unit, Christchurch Hospital
- Dr Paul Kelly – Sleep Unit, Christchurch Hospital
- Dr Petra Hoggarth – Older Persons Health, CDHB
- Dr Leigh Signal – Sleep-Wake Unit, Massey University
- Dr Laura Astolfi – Neuroelectrical Imaging and BCI Lab, University of Rome
- Dr Jlenia Toppi – Neuroelectrical Imaging and BCI Lab, University of Rome
- Dr Lynn Caldwell – US Navy Medical Research Unit, Dayton, Ohio, USA
- Ms Esther Guiu Hernandez – Communication Disorders, UC

***Students*** *(+ degree sought + project)*

- Yaqub Jon Mohamadi – PhD (conferred), Medicine, UOC

  '*Enhancement and source imaging of electrical activity in the brain associated with behavioural microsleeps*'
- Simon Knopp – PhD, Electrical & Computer Engineering, UC

  '*Development of a head-mounted multi-modal device for lapse and drowsiness detection*'
- John LaRocco – PhD, Electrical and Computer Engineering, UC

  '*Automated detection and classification of behavioural microsleeps from the EEG*'
- Sudhanshu Ayyagari – PhD, Electrical and Computer Engineering, UC

  '*Detection of microsleeps from multi-channel EEG using reservoir computing*'
- Alex Palmer – PhD, Electrical and Computer Engineering, UC

  '*Exploration of new features for the detection of microsleeps from the EEG*'
- Reza Shoorangiz – PhD, Electrical and Computer Engineering, UC

  '*Bayesian approaches to detection and prediction of lapses of responsiveness*'
- Oshrat Sella – PhD (conferred), Communication Disorders, UC

  '*Skill versus strength in swallowing training: neurophysiological, biomechanical, and structural assessments*'
- Ramesh Kaipa – PhD (conferred), Communication Disorders, UC

  '*Evaluation of principles of motor learning in speech and non-speech motor learning tasks*'
- Kristin Lamvik – PhD, Communication Disorders, UC

  '*Incidence, aetiology, and pathophysiology of pharyngeal mis-sequencing in dysphagic patients with neurologic impairment*'
- Kerstin Lamvik – PhD, Communication Disorders, UC

  '*Cerebellar transcranial direct current stimulation in rehabilitation of dysphagia*'
- Myriam Kornisch – PhD, Communication Disorders, UC

  '*Brain activity in bilingual individuals presenting with a stutter*'
- Russ Buckley – MA (conferred), Psychology, UC ➔ PhD, Medicine, UO

  '*Behavioural microsleeps and attention lapses during continuous tracking, psychomotor vigilance, and dual tasks*'

'*Can early treatment prevent sleep apnoea-related brain damage?*'

- Christopher Chester – ME (conferred), Electrical and Computer Engineering, UC

  '*Electrical-impedance biofeedback instrument for swallowing rehabilitation*'

- Alex Lippitt – ME, Electrical and Computer Engineering, UC

  '*Electrical-impedance biofeedback instrument for swallowing rehabilitation: Smart device integration*'

- Asia Emslie – MSc, Communication Disorders, UC

  '*A skill-based approach to swallowing rehabilitation in Parkinson's disease*'

- Jessica Langbridge – MA, Psychology, UC

  '*Increasing sense of control and decreasing attentional bias in binge drinkers: Effects on cue-elicited ERPs and alcohol craving and consumption*'

- Stephanie Henderson – MSc, Psychology, UC

  '*Altering smokers' attentional bias and inhibitory control using mindfulness*'

- Chris Markham, Michael Gibson, Bernie Harris, Jared Watson – BE, Electrical and Computer Engineering, UC

  '*A brain-computer interface for thought-controlled mobility*'

- Romain Arnal – BE, Electrical Engineering, University of Bordeaux

  '*Multi-reference adaptive noise cancellation in the EEG: comparison with echo state network and implementation in hardware*'

# Research Programmes

## *1 – Lapses of Responsiveness*

***Personnel*** – Richard (Leader), Carrie, Phil, Steve, Govinda

***Collaborators*** – Leigh, Fabio, Laura, Jlenia

***Postgrads*** – Yaqub, Simon, John, Sudhanshu, Alex, Reza

***Overview***

Brief complete lapses of responsiveness (~0.5–15s) include microsleeps, sustained-attention lapses, and diverted-attention lapses. All of these can be very serious, not only disrupting performance but leading to accidents and, in some cases, multiple fatalities. We are a world leader in lapse research, particularly in terms of behavioural and EEG-based detection and characterization of microsleeps and investigation of the underlying mechanisms of microsleeps in the brain via simultaneous-fMRI+EEG. A major aim is the development of head-mounted multi-modality (EEG, eye-video, head position) devices able to detect — and potentially predict — lapses and provide early 'wake-up' warnings, for implementation in real-world environments.

Overall, the 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).

Recognition of the importance and challenge of microsleeps, and of our research leadership in this area, led to Richard being invited to give the Keynote Address on 'Microsleeps: fatal accidents, characteristics, detection, and underlying mechanisms' at an International Symposium on Somnolence and Safety (SomnoSafe 2014) in Brussels in Feb 2014.

In addition to our projects at NZBRI and ECE, we have two important collaborations with research groups overseas:

- Neuroelectric Imaging and BCI Laboratory, Santa Lucia Foundation Scientific Institute, Rome (Fabio, Laura. Jlenia) –

We sent 64-channel EEG data containing marked microsleeps from 10 healthy subjects to Rome. They applied functional connectivity analysis to the data and identified several distinctive features in the cortical activity and causal flow of information at various stages in and prior to microsleeps.

- US Navy Medical Research Unit (NAMRU), Dayton, Ohio, USA (Lynn) –

NAMRU is undertaking a study of 40 healthy young male adults aimed at determining the efficacy of different stimulants (modafinil, caffeine, modafinil + caffeine) in offsetting the effects of sleep deprivation (40 hours of continuous wakefulness, from 5.00am until 9.00pm the following day) on physical and cognitive performance. Following a talk by Richard, they were very keen to introduce measurement of propensity for lapses, particularly microsleeps, into their study. We supplied hardware and software to record data (2D tracking performance, eye-video, and EEG) during a 25-minute visuomotor task carried out several times during the experimental period. This data is being sent to us for manual rating by Carrie for identification of lapses. The results will allow us to determine increased propensity for lapses (rate, lapse type, duration) during the sleep deprivation period and the extent to which this can be countered by stimulants.

### *Recent Publications*


Poudel GR, Innes CRH, Jones RD (2013). Distinct neural correlates of time-on-task and transient errors during a continuous visuomotor task after sleep restriction. *NeuroImage*, 77: 105-113.

Innes CRH, Poudel GR, Jones RD (2013). Efficient and regular patterns of sleep are related to increased vulnerability to microsleeps following a single night of sleep restriction. *Chronobiology International*, 30: 1187–1196.

Jonmohamadi Y, Poudel GR, Innes CRH, Jones RD (2013). Electromagnetic tomography via source-space-ICA. *Proceedings of Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Osaka, 35, 37-40.

Knopp SJ, Bones PJ, Weddell SJ, Innes CRH, Jones RD (2013). A wearable device for measuring eye dynamics in real-world conditions. *Proceedings of Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Osaka, 35, 6615-6618.

Arnal R, Jones RD, Weddell SJ (2013). Electroencephalogram noise cancellation with reservoir computing. *Proceedings of Electronics New Zealand Conference (ENZCon)*, Auckland, 20, 100-105.

Poudel GR, Innes CRH, Bones PJ, Watts R, Jones RD (2014). Losing the struggle to stay awake: Divergent thalamic and cortical activity during microsleeps. *Human Brain Mapping*, 35: 257-269.

Jonmohamadi Y, Poudel GR, Innes CRH, Jones RD (2014). Voxel-ICA for reconstruction of source signal time-series and orientation in EEG and MEG. *Australasian Physical & Engineering Sciences in Medicine*, 37: 457-464.

Jonmohamadi Y, Poudel GR, Innes CRH, Weiss D, Krueger R, Jones RD (2014). Comparison of beamformers for EEG source signal reconstruction. *Biomedical Signal Processing and Control*, 14:175–188.

Jonmohamadi Y, Poudel GR, Innes CRH, Jones RD (2014). Source-space ICA for EEG source separation, localization, and time-course reconstruction. *NeuroImage*, 101:720–737.

LaRocco J, Innes CRH, Bones PJ, Weddell S, Jones RD (2014). Optimal EEG feature selection from average distance between events and non-events. *Proceedings of Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Chicago, 36, 2641-2644.

Ayyagari SSDP, Jones RD, Weddell S (2014). EEG-based event detection using optimized echo state networks with leaky integrator neurons. *Proceedings of Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Chicago, 36, 5856-5859.

Jonmohamadi Y, Poudel G, Innes C, Jones R (in press). Application of source-space ICA in detection of brain connectivity. (Abstract). *New Zealand Medical Journal*.

Buckley RJ, Helton WS, Innes CR, Dalrymple-Alford JC, Jones RD (2014). Sustained attention lapses and behavioural microsleeps during tracking, psychomotor vigilance, and dual tasks. *SLEEP*, 37(Abstract Supplement), A51-52.

Jones RD (in press). Measurement and analysis of sensory motor performance: Tracking tasks. In: Bronzino JD, Peterson DR (Eds). *The Biomedical Engineering Handbook – Biomedical Engineering Fundamentals*, 4th Edition, CRC Press, Boca Raton, Florida.

## *2 – Swallowing Rehabilitation*

***Personnel*** – Maggie-Lee (Leader), Richard, Phoebe, Paul, Esther

***Postgrads*** – Oshrat, Kristin, Kerstin, Asia, Christpher, Alex

### *Overview*

Swallowing dysfunction (dysphagia) is often a serious sequela of several neurological disorders (e.g., stroke, Parkinson's disease, traumatic brain injury). UC's Department of Communication Disorders *Swallowing Rehabilitation Research Laboratory* (www.cmds.canterbury.ac.nz/swallow) is based in the NZBRI and involves a close collaboration between NeuroTech and ECE on several key projects. These are focused on biofeedback of muscle activity and of bioelectric impedance across the throat for rehabilitation of dysphagia, particularly as an alternative to invasive and uncomfortable manometry (pressure catheter through nose).

The Swallowing Laboratory is arguably the most sophisticated and well-appointed laboratory of its kind in the southern hemisphere in terms of instrumentation and expertise. As such, the Laboratory has been quite productive in research endeavours since its transition to the NZBRI in 2004.

The research profile has focused heavily on development of neurorehabilitation approaches and delineation of rehabilitative effects on neural, muscular, and behavioural function. These treatment approaches include neuromuscular exercise programmes focusing heavily on the use of sensory stimulation and neuromuscular electrical stimulation, among others. The uses of biofeedback modalities to enhance skill training in swallowing are emphasized and have allowed collaboration with engineering colleagues to develop software and hardware platforms for this application. In short, we want to answer the question: When it is broken, how do we fix it?

Later this year, the Research Programme moves its base from the NZBRI to the University of Canterbury's *Rose Centre for Stroke Recovery and Research* at St Georges Medical Centre (www.science.canterbury.ac.nz/rosecentre.shtml).

### *Recent Publications*


Macrae PR, Jones RD, Myall DJ, Melzer TR, Huckabee M-L (2013). Cross-sectional area of the anterior belly of the digastric muscle: Comparison of MRI and ultrasound measures. *Dysphagia*, 28: 375-380.

Macrae PR, Jones RD, Huckabee M-L (2014). The effect of swallowing treatments on corticobulbar excitability: A review of transcranial magnetic stimulation induced motor evoked potentials. *Journal of Neuroscience Methods*, 233: 89-98.

Huckabee M-L, Lamvik KM, Jones RD (2014). Pharyngeal mis-sequencing in dysphagia: Characteristics, rehabilitative response, and aetiological speculation. *Journal of the Neurological Sciences*, 343: 153-158.

Lamvik K, Sauer S, Erfmann K, Jones R, Huckabee M-L (in press). The capacity for cortical control of pharyngeal swallowing in healthy adults. (Abstract). *Dysphagia*.

Athukorala RP, Jones RD, Sella O, Huckabee M-L (*on-line* – May 2014). Skill training for swallowing rehabilitation in patients with Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*. DOI: 10.1016/j.apmr.2014.03.001

Chester CJ, Gaynor PT, Jones RD, Huckabee M-L (*in press* – Sep 2014). Electrical bioimpedance measurement as a tool for dysphagia treatment. *Health Technology Letters*.


## *3 – Obstructive Sleep Apnoea*

***Personnel*** – Carrie (Leader), Paul, Michael, Richard

***Postgrads*** – Russ

### *Overview*

In obstructive sleep apnoea (OSA), muscles that normally keep the airway open, relax during sleep and partially or fully block the airway. This leads to events where breathing stops or becomes very shallow for up to 2 min and blood oxygenation decreases. Continuous positive airways pressure (CPAP) during sleep is used to treat severe OSA and works by blowing air into the pharynx to hold the airway open.

Untreated OSA is associated with hypertension, cardiovascular disease, stroke, diabetes, excessive daytime sleepiness, and cognitive dysfunction. The mechanisms underlying these effects are not clear but they appear to chronic intermittent hypoxia which alters regulatory mechanisms of cerebral circulation. Recently, we found decreased perfusion in the brains of people with not only severe, but moderate, OSA (while awake) compared to healthy controls. This is of concern as people with moderate OSA are usually not eligible for hospital-funded CPAP treatment and it is thought that the intermittent episodes of oxygen deprivation in the brain associated with long-term non-treatment of OSA may lead to permanent structural and chemical changes in the brain.

We are about to commence a new study, funded by CMRF, aimed at investigating brain structure, cerebral blood flow, cognition, and microsleep propensity at baseline and following six months of continuous positive airway pressure (CPAP) treatment in people with moderate OSA. Ultimately, this research aims to reduce OSA-related vascular and cognitive impairment, and microsleep-related deaths and injuries by providing evidence

to support inclusion of patients with moderate OSA in hospital-funded OSA screening and treatment programmes.

## *4 – Driving Assessment*

***Personnel*** – Richard (Leader), Carrie, Petra, John DA

### *Overview*

We have carried out five research studies aimed at (i) validation and improvement of our Canterbury Driving Assessment Tool's (*CanDAT*™) 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. These studies involved blinded on-road and off-road assessment of healthy older subjects and patients with brain disorders – primarily stroke, Alzheimer's disease, head injury, Parkinson's disease, multiple sclerosis – referred for driving assessment and, in one study, involved several occupational therapy based driving assessment services elsewhere in NZ.

Overall, despite our very considerable and careful efforts over many years, the results have been disappointing. It is possible to predict ability or inability to drive safely on the road but with an accuracy too low to achieve the goal of making at least the majority of costly and sometimes unsafe on-road assessments unnecessary. It is our belief that accurate off-road prediction of on-road ability is not possible. This was particularly evident with patients with moderate Alzheimer's disease who performed terribly on the off-road tests but yet were considered safe to drive by a driving assessment occupational therapist who was intentionally not privy to the off-road results.

Notwithstanding, driving occupational therapists still value the ability of *SMCTests* to provide them with insightful and quantitative information on physical and cognitive function of patients prior to taking them onto the road.

### *Recent Publications*

Hoggarth P, Innes CR, Dalrymple-Alford JC, Jones RD (2013). Prospective study of healthy older drivers: No increase in crash involvement or traffic citations at 24 months following a failed on-road assessment. *Transportation Research Part F: Traffic Psychology and Behaviour*, 16: 73-80.

Hoggarth P, Innes CR, Dalrymple-Alford JC, Jones RD (2013). Predicting on-road assessment pass and fail outcome in older drivers with cognitive impairment using a battery of computerized sensory-motor and cognitive tests. *Journal of the American Geriatrics Society*, 61: 2192–2198.

## *5 – Addictions*

***Personnel*** – Juan (Leader), Richard

***Postgrads*** – Jessica, Stephanie

### *Overview*

Two studies are close to starting at the NZBRI to investigate the efficacy and mechanisms underlying two major health-related addictions in NZ: (i) binge drinking and (ii) cigarette smoking.

- Binge drinking – *Treatment by attention bias and sense of control modification*

Alcohol users have a greater attention bias for alcohol cues than light drinkers or abstainers. This means that alcohol cues (e.g., a picture of a beer bottle) will grab the attention of heavy users more than other people. Alcohol attention bias modification is a way of cognitively training individuals not to focus on these alcohol cues and increase their sense of control.

- Cigarette smoking – *Treatment by altering attentional bias, emotional processing, and inhibitory control using mindfulness*

Tobacco smoking is *the* most common cause of preventable death in the world. The success rate for NZ-based smoking cessation aid *Quitline* is only around 24%, suggesting a need for more effective interventions. Tools such as Quitline are unable to effectively dismantle the smoking 'habit loop' which is the critical target of a more recently researched intervention called mindfulness. This study will compare treatment efficacy of mindfulness (via an iPhone app called 'Craving to Quit') and Quitline.

A major aim in both of these studies is to investigate neurophysiological mechanisms underlying these treatments and, hence, provide indicators for improved therapies. Behavioural measures (e.g., reaction times) and physiological measures (cue-elicited event-related potentials) in response to various visual stimuli will provide objective neural markers of increased inhibitory control and of decreased attentional bias to alcohol and smoking-cues.

## *6 – Brain-computer interface*

***Personnel*** – Steve (Leader), Richard

***Final year*** – Chris, Michael, Bernie, Jared

***Overview***

This final-year project in ECE at UC is aimed at 'A brain-computer interface for thought-controlled mobility'. A major motivation for such systems is to provide a means whereby persons with severe physical disabilities (e.g., 'locked-in' syndrome due to a brainstem stroke or motor neurone disease) can communicate and gain some control over their environment. Low-cost EEG-based thought-controlled systems are becoming available but require long training periods, generalize poorly to other users, and have relatively poor/unreliable performance. Although there is considerable research effort being directed world-wide into this area, we felt that, with our expertise in EEG state classification aimed at microsleep detection, we thought that it would also be worth us having a crack at it. Still very early days for us in this 'holy grail' challenge but the system developed this year by the four students is able to provide limited thought-control over a 'wacky racer'.