Christchurch Neurotechnology Research Programme

Overview & Update – March 2016

www.neurotech.org.nz

Richard Jones
Director

Introduction

The *Christchurch Neurotechnology Research Programme* ('*NeuroTech*' – www.neurotech.org.nz) is a joint venture between University of Canterbury (Electrical & Computer Engineering, Communication Disorders (including Rose Centre for Stroke Recovery and Research), and Psychology) [UC], the Canterbury District Health Board (Medical Physics & Bioengineering) [CDHB], 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 & Rose Centre, 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 Michael Robb – Communication Disorders, UC
- Professor Fabio Babiloni – Neuroelectrical Imaging and BCI Lab, University of Rome
- Professor Lynn Meuleners, Curtin-Monash Accident Research Centre, Curtin University, Perth
- Associate Professor Maggie-Lee Huckabee – Rose Centre & Communication Disorders, UC

- Associate Professor Paul Gaynor – Electrical and Computer Engineering, UC
- Dr Stephen Weddell – Electrical and Computer Engineering, UC
- Dr Juan Canales – Psychology, UC => Psychology, University of Leicester
- Dr Govinda Poudel – Monash Biomedical Imaging, Monash University
- Dr Michael Hlavac – Sleep Unit, Christchurch Hospital
- Dr Paul Kelly – Sleep Unit, Christchurch Hospital
- Dr Yaqub Jonmohamadi – Physics, University of Auckland
- Dr Simon Knopp – Energy3, Christchurch
- Dr Laura Astolfi – Neuroelectrical Imaging and BCI Lab, University of Rome
- Dr Jlenia Toppi – Neuroelectrical Imaging and BCI Lab, University of Rome
- Dr Paul Roberts – Australian Road Research Board, Perth
- Dr Lynn Caldwell – US Navy Medical Research Unit, Dayton, Ohio, USA
- Ms Esther Guiu Hernandez – Communication Disorders, UC

Students *(+ degree sought + project)*

- Simon Knopp – PhD (conferred), 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*'
- Reza Shoorangiz – PhD, Electrical and Computer Engineering, UC
  '*Bayesian approaches to detection and prediction of lapses of responsiveness*'
- Abdul Baseer – PhD project - 'Improved detection and prediction of microsleeps via novel features in the EEG' (Co-Supervisor – Steve Weddell).
- Ramesh Kaipa – PhD (conferred), Communication Disorders, UC
  '*Evaluation of principles of motor learning in speech and non-speech motor learning tasks*'
- Myriam Kornisch – PhD (conferred), Communication Disorders, UC
  '*Brain activity in bilingual individuals presenting with a stutter*'
- Kristin Lamvik – PhD, Rose Centre & Communication Disorders, UC
  '*Incidence, aetiology, and pathophysiology of pharyngeal mis-sequencing in dysphagic patients with neurologic impairment*'
- Kerstin Lamvik – PhD, Rose Centre & Communication Disorders, UC
  '*Cerebellar transcranial direct current stimulation in rehabilitation of dysphagia*'
- Karin Ng – PhD, Rose Centre & Communication Disorders, UC
  '*Clinical classification of impairments of strength versus skill in dysphagia subsequent to stroke*'
- Sagarika Bhattacharjee – PhD, Rose Centre & Communication Disorders, UC

'*Is muscle hypertonicity a component of the pathophysiology of dysphagia?*'

- Zak Hamilton – PhD, Electrical and Computer Engineering & Communication Disorders & Rose Centre, UC

  '*Development of a device for improved risk estimation of aspiration pneumonia*'
- Claire Mills – MSc, Rose Centre & Communication Disorders, UC

  '*Measuring cough strength in healthy individuals using cough reflex testing*'
- Russ Buckley – PhD, Medicine, UO

  '*Can early treatment prevent sleep apnoea-related brain damage?*'
- Alex Lippitt – ME (conferred), Electrical and Computer Engineering, UC

  '*Electrical-impedance biofeedback instrument for swallowing rehabilitation: Smart device integration*'
- Asia Emslie – MSc (conferred), 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 – Psychology, UC

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

Research Programmes

1 – Lapses of Responsiveness

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

Collaborators – Yaqub, Fabio, Laura, Jlenia, Lynn C., Paul, Lynn M.

Postgrads – Simon, John, Sudhanshu, Reza, Abdul

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 'Lapses of responsiveness: A focus on the characteristics, dangers, underlying mechanisms, and detection of microsleeps' at *9th International Conference on Managing Fatigue* (Managing Fatigue 2015) in Fremantle, Australia, in Mar 2015. This, in turn, has led to a collaboration with C-MARC.

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

- **Neuroelectric Imaging and BCI Laboratory, Santa Lucia Foundation Scientific Institute, Rome, Italy (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. This has led to a recently-accepted paper in *NeuroImage*.

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

NAMRU has just completed data collection from 18 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) on physical and cognitive performance. This study included measurement of propensity for lapses, particularly microsleeps, using hardware and software from NeuroTech 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 has been sent to us for manual rating by Carrie for identification of lapses. The results from this 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. The study has also provided us with a valuable new behavioural+EEG dataset on changes in brain function during and prior to microsleeps.

- **Curtin-Monash Accident Research Centre (C-MARC) and Australian Research Board, Perth, Australia (Lynn M., Paul)**

C-MARC has recently purchased a high-end driving simulator (360 deg, motion-platform) which they wish to use for advanced studies of factors affecting driver safety. In particular, they are very keen for these studies to incorporate measurement of lapses/microsleeps and are collaborating with NeuroTech to best enable this. This requires the purchase and commissioning of a high-accuracy eye-lid/eye-gaze measurement system which is currently in progress.

Recent Publications

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.

Jones RD (2014). Measurement and analysis of sensory motor performance: Tracking tasks. In: Bronzino JD, Peterson DR (Eds). Medical Devices and Human Engineering. 4th ed. Boca Raton, Florida: CRC Press, Chap 31, pp.1-38.

Palmer A, Weddell S, Jones R (2015). A comparison of feature ranking metrics for microsleep detection from the EEG. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 191-192.

LaRocco J, Innes C, Bones P, Weddell S, Jones R (2015). Optimal EEG feature selection from average distances between events and non-events. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 195-196.

Arnal R, Jones R, Weddell S (2015). Multi-reference adaptive noise cancellation in the EEG. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 195-196.

Ayyagari S, Jones R, Weddell S (2015). EEG-based event detection using optimized echo state networks with leaky integrator neurons. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 193-194.

Ayyagari S, Jones R, Weddell S (2015). EEG-based microsleep detection using supervised learning. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 194.

Gibson M, Harris B, Markham C, Weston J, Weddell S, Jones R (2015). Brain-computer interface for thought-controlled mobility. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 192.

Ayyagari SSDP, Jones RD, Weddell S (2015). Optimized echo state networks with leaky integrator neurons for EEG-based microsleep detection. *Proceedings of Annual International Conference of IEEE Engineering in Medicine and Biology Society*, Milan, 37, 3775-3778.

Toppi J, Astolfi L, Poudel GR, Innes CRH, Babiloni F, Jones RD (2016). Time-varying functional connectivity of the cortical neuroelectric activity associated with behavioural microsleeps. *NeuroImage*, 124: 421-432.

Jonmohamadi Y, Jones RD (2016). Source-space ICA for MEG source imaging. *Journal of Neural Engineering*, 3: 016005 (16pp).

Lamvik KM, Guiu Hernandez E, Jones RD, Huckabee M-L (in press). Characterization and correction of pressure drift in high resolution manometry: In vitro and in vivo. *Neurogastroenterology & Motility*.

Jonmohamadi Y, Poudel GR, Innes CRH, Jones RD (in press). Microsleeps are associated with Stage-2 sleep spindles from hippocampal-temporal network. *International Journal of Neural Systems*.

2 – Swallowing Rehabilitation

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

Postgrads – Kristin, Kerstin, Karin, Sagarika, Asia, Claire, Alex, Zak

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) has been based since November 2014 in UC's *Rose Centre for Stroke Recovery and Research* at St Georges Medical Centre (www.science.canterbury.ac.nz/rosecentre.shtml). It has a close collaboration with MPBE (via 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. This has been further enhanced over the past year by the purchase and installation of (i) a 36-sensor high-resolution manometry system, (ii) a videofluoroscopy system for real-time x-ray visualization of swallowing, and (iii) a tDCS device for direct-current modulation of the brain aimed at enhancing swallowing rehabilitation.

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.

Over 10-12 May, the Rose Centre organized the inaugural International Multidisciplinary Conference on Stroke Rehabilitation 'Stroke Rehab: From No-Tech to Go-Tech' in Christchurch. The conference was a risky initiative but, in the end, was a great success, attracting ~100 attendees from throughout NZ and overseas (Australia, South Africa, USA, Japan, China, Italy, Egypt, Ireland, Singapore). There was a real mix of expertise and interests amongst the attendees, including speech-language pathologists, swallowing specialists, physiotherapists, occupational therapists, stroke rehab physicians, stroke researchers, and biomedical engineers (Esther, Alex, and me). There were five excellent keynote speakers, who also participated in panel discussions on recovery mechanisms, principles of neural recovery/rehabilitation, clinical research, and translational research/processes.

Recent Publications

Chester CJ, Gaynor PT, Jones RD, Huckabee M-L (2014). Electrical bioimpedance measurement as a tool for dysphagia treatment. *Healthcare Technology Letters*, 1:115-118.

Athukorala RP, Jones RD, Sella O, Huckabee M-L (2014). Skill training for swallowing rehabilitation in patients with Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, 95: 1374-1382.

Lippitt A, Gaynor P, Jones R, Huckabee M-L (2015). The development of an impedance-based swallowing biofeedback device. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 186.

Guiu E, Lamvik K, Jones R, Huckabee M-L (2015). Measurement consistency of high-resolution manometry. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 185-186.

Lamvik KM, Jones RD, Sauer S, Erfmann K, Huckabee M-L (2015). The capacity for volitional control of pharyngeal swallowing in healthy adults. *Physiology & Behavior*, 152: 257-263.

Lamvik KM, Guiu Hernandez E, Jones RD, Huckabee M-L (in press). Characterization and correction of pressure drift in high resolution manometry: In vitro and in vivo. *Neurogastroenterology & Motility*.

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 have commenced a new study, funded by CMRF and NZ Lotteries, to investigate 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. The study will recruit 20 referrals to the Sleep Unit at Christchurch Hospital with moderate OSA and 20 controls without OSA. MRI scans will be undertaken at baseline and after 6 months of compliant CPAP treatment for people with moderate OSA. Scans will include structural imaging and non-invasive quantitative measurement of total and regional cerebral perfusion (awake with eyes-open) via arterial spin labelling (ASL). 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.

Recent Publications

Innes CRH, Kelly PT, Hlavac M, Melzer TR, Jones RD (2015). Decreased regional cerebral perfusion in moderate-severe obstructive sleep apnoea during wakefulness. *Sleep*, 38: 699-706.

Innes C, Kelly P, Hlavac M, Melzer T, Jones R (2015). Decreased regional cerebral perfusion in moderate-severe obstructive sleep apnoea during wakefulness. (Abstract) *Australasian Physical & Engineering Sciences in Medicine*, 38: 186-187.

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. Our conclusion is 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 PA, Innes CR, Dalrymple-Alford JC, Jones RD (2015). Prediction of driving ability: Are we building valid models? *Accident Analysis & Prevention*, 77: 29-34.

5 – Addictions

Personnel – Juan (Leader), Richard

Postgrads – Jessica, Stephanie

Overview

Two studies are well underway 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.

Both of these studies are looking at neurophysiological mechanisms underlying these treatments and, hence, aiming to 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 are providing objective neural markers of increased inhibitory control and of decreased attentional bias to alcohol and smoking-cues.

6 – Communication Disorders

Personnel – Michael (Leader), Richard, Maggie-Lee

Postgrads – Ramesh, Myriam

Overview

We have now completed two projects in the area of communication disorders. Ramesh's first study compared the effects of constant, variable, random, and blocked practice on the spatial and temporal learning of a speech task as a function of aging in 80 healthy individuals (40-80 years). In contrast to learning a non-speech task, no differences in learning were found between the 4 types of practice. Ramesh's second study investigated these same practice conditions in 16 subjects with Parkinson's disease. Although the PD participants demonstrated diminished spatial and temporal learning in comparison to healthy individuals, no advantage was again found between the 4 types of practice.

Myriam's study investigated the relationship between stuttering and bilingualism to hemispheric asymmetry for the processing and production of language. She recruited 80 native speakers of German, 40 of whom participants were also proficient speakers of English as a second language. The participants were organised into four groups (20 per group) according to language ability and speech status, consisting of monolinguals who stutter (MWS), monolinguals who do not stutter (MWNS), bilinguals who stutter (BWS), and bilinguals who do not stutter (BWNS). A prevailing finding was that bilingualism seems to be able to offset deficits in executive functioning associated with stuttering. This appears to reflect a greater cognitive reserve and executive functioning in bilinguals.

Recent Publications

Kaipa R, Robb MP, Jones RD, Huckabee M-L (in press). Effectiveness of constant, variable, random, and blocked practice in speech-motor learning. *Speech, Language and Hearing*.