ALERTNESS SAFETY AND PRODUCTIVITY

2016
Annual Report

Our Mission

- Promote the prevention and control of sleep loss and sleep disorders.
- Develop new tools and products for individuals and organisations to improve alertness, productivity and safety.

The Alertness CRC has brought together expert knowledge, state-of-the-art technologies and effective translation pathways from industry, government and university sectors to deliver:

- Improved workplace and community safety and alertness, through the development of effective, low cost validated tools for alertness assessment, including real time 'fitness for duty' and portable (roadside) alertness tests. Improved group level scheduling solutions have the capacity to reach more than 1.4 million shift working Australians. Healthcare and mining sectors are key high-risk target sectors for early adoption.

- Tailored and improved lighting in workplaces. Workplace lighting solutions will increase worker alertness levels, thereby reducing workplace accidents and mistakes, with the healthcare and mining sectors being key target sectors for early adoption.

- A better understanding of sleep disorders and individual differences between people to enable more personalised use of treatments. The Alertness CRC will develop user friendly sleep disorder treatment devices that will substantially improve the utilisation and access to effective treatment for major sleep disorders, such as sleep apnoea and insomnia.

Sleep is a fundamental necessity for the human body, essential for optimal functioning during the waking day. Unfortunately, it's neglected in today's 24-hour society because of shiftwork, family commitments and the rising prevalence of sleep disorders.

**Professor Doug McEvoy,
Senior Director of the Adelaide
Institute for Sleep Health**

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Executive Summary

The third year of operation for the Alertness CRC has been the most productive and exciting to date. It has been a critical period in terms of the research program as the consortium seeks to maximise the value of this industry-led approach.

The project teams have been expertly coordinating a complex series of world-class research activities that are generating a wealth of novel and powerful data. These data are underpinning the innovative solutions to alertness management that are now within sight.

With a seamless change in leadership at Board level, high levels of engagement across industry participants, and the success of the platform project approach, the Alertness CRC is well positioned to deliver its targeted outcomes.

The Alertness CRC has developed a standardised approach to decision-making to drive a commercialisation roadmap over the remainder of the life of the consortium. Each set of activities has distinct commercialisation options, business models, risks, timeframes and costs associated with achieving a successful outcome and by optimising the CRC portfolio around these key parameters, we are confident that we will deliver success.

Research and Collaboration

Our platform projects are the research engine of the Alertness CRC. From these projects, an array of sophisticated datasets have been established, and a number of subsequent, more targeted projects are underway. As such, we remain on track to develop innovation in the following areas:

- Sleep biomarkers for diagnosis of current circadian state
- Non-invasive, real time biomarker based test for alertness
- Non-invasive, individual alertness monitoring, prediction and feedback devices
- New fitness for duty and road safety guidelines
- Comprehensive, scalable and searchable sleep and alertness database
- Scheduling software system for group work scheduling and associated guidelines
- Individual level scheduling systems and associated guidelines
- Portable lighting devices
- Lighting design software
- Personalised sleep health management tools and associated guidelines

Through our industry partners, and against the backdrop of a formal commercialisation roadmap, the Alertness CRC project teams have been able to identify research translation partners and pathways that provide unique field testing and market opportunities for Alertness CRC outputs. For example, a project developed by Monash University and Austin Health – to develop group-based scheduling solutions to better manage shift work in a healthcare setting – is seeing the outputs from the platform project activity leveraged into a commercialisable software tool that has multiple applications in occupational settings. Through this process, we welcomed Opturion Pty Ltd as a new Alertness CRC participant.

The collaboration within the consortium itself has flourished during the reporting period. Participant meetings have been reconfigured to provide more exposure between researchers and industry stakeholders. There has also been further emphasis placed on industry-to-industry collaboration, to encourage more scrutiny of synergies and commercial opportunities that exist across the consortium.

The Alertness CRC also continues to develop the unique collaborative opportunity that has emerged through the involvement of the National Transport Commission. Developing a Heavy Vehicle Fatigue Data Framework in partnership with all state and national road safety stakeholders has formed the basis of a new project led by the Alertness CRC, which evaluates the impact of Heavy Vehicle National Law fatigue regulations on road safety risks.

Commercialisation and Utilisation

The Alertness CRC Board has established a formal Commercialisation Committee to effectively manage the translation and deployment of CRC outputs. Led by the Alertness CRC Chair, Deena Shiff, the Commercialisation Committee includes the CEO, Research Manager, Program Leaders and the Managing Director of SME partner Grey Innovation.

To further encourage innovation and commercialisation, the Deployment Program provides funding to fast-track research that is near ready to progress to product development. The first project to receive this funding will see the development of a group work scheduling tool that will integrate alertness modelling with rostering algorithms to automatically generate rosters that are safe, but also efficient in their response to specific workplace requirements.

Other Deployment projects in development include fitness for duty monitoring tools, personalised sleep health management systems, and new clinical tools for the detection and management of circadian phase disorders. Each project is supported by our platform project activity, which is helping to facilitate growth through clearly defined commercialisation pathways and high levels of industry participant engagement.

The Alertness CRC's biomarker discovery program has seen the development of a number of discrete opportunities around fitness for duty assessment and other tests to detect alertness-related changes associated with performance impairment.

Sleep disorder phenotyping systems are also being developed for integration with novel sensors to link with online consumer care models and new clinical tools, to improve disease management.

Education and Training

Led by the Alertness CRC Education Committee, the education program continues to provide practical and industry-focused capacity building for 'Early Career Researchers'.

Many of the 24 postdoctoral researchers involved in Alertness CRC project activity do so as Project (or stream) Leaders. They have been largely responsible for the significant progress that has been made across the platform project activity, through the management of day-to-day research activities and end-user liaison. Other 'postdocs' are managing components of project activity and working closely with Alertness CRC management to manage budgets and performance in accordance with agreements.

The PhD program includes 18 students currently enrolled and integrated into the platform projects and core activities of the Alertness CRC. This program is diverse, with many students getting high levels of industry exposure.

Executive Summary

The Masters program currently includes three students and is particularly vital to the creation of a 'pipeline' of PhD candidates, with two students subsequently converting to the PhD.

Alertness CRC activities are also providing opportunities for undergraduate research projects including honours and vacation scholarship students. For instance, there have been five Science Masters students assisting in our Modelling and Data Fusion Platform activities.

The Alertness CRC has also been a strong supporter of the Industry Based Learning (IBL) program established at Swinburne University, and has provided a total of 11 IBL scholarships that were either completed or commenced in the last 12 months.

Awards

Professor Ron Grunstein, Alertness CRC Program Leader / Investigator – Awarded the 2016 Thoracic Society of Australia and New Zealand Research Medal.

Professor Ron Grunstein has been a consultant physician in sleep disorders for over 30 years and a pioneer in improving patient care in sleep medicine in Australia and internationally. He heads the Sleep and Circadian Research Group at the Woolcock Institute of Medical Research and the NHMRC's Centre of Research Excellence in Sleep and Circadian Translational Neurobiology, known as 'Neurosleep'.

End-users

The Alertness CRC participant group continues to align well with the CRC objectives, with additional SME involvement through Opturion Pty Ltd and a proliferation of interest from other industry partners.

Multiple opportunities have been surfacing for SME participation in the commercialisation of Alertness CRC outputs, and high levels of proposal development have been stimulated by the progress of the platform project activity and deployment opportunities, keeping the level of engagement high.

Philips Respironics continues to provide a lead role in establishing the commercialisation roadmap, and has provided access to multiple research and technology stakeholders both within the Philips network and across the health technology sector.

The Alertness CRC has further secured a number of opportunities for short-term and long-term field testing as the outputs from the platform projects are converted into systems, tools or devices.

Access to the mining sector remains strong, with regular interaction through the International Council on Mining and Metals.

Work with the National Transport Commission is providing extraordinary opportunities to both inform regulatory change and field test novel solutions through a comprehensive national network of road safety stakeholders.

Figure 1: Alertness CRC Participants

Technology and Development End-Users

Constraint Technologies · COGSTATE · OPTALERT · BIOPLATFORMS AUSTRALIA · PHILIPS · SMART CAP · LightingScience · seeingmachines · GREY TECHNOLOGY COMMERCIALISATION · ELECTRO LIGHT · fmi · OPTURION

Industry and Employment End-Users

Austin Health · ICMM International Council on Mining & Metals · asmof nsw · Government of South Australia SA Health

Policy, Regulatory and Insurance End-Users

TAC Transport Accident Commission · WorkSafe VICTORIA · Bupa · NTC AUSTRALIA National Transport Commission

Research, Education and Training

AUSTRALASIAN SleepTrials Network · Sleep Health FOUNDATION · IBAS Institute for Breathing & Sleep · WOOLCOCK INSTITUTE of MEDICAL RESEARCH · Flinders UNIVERSITY · THE UNIVERSITY OF SYDNEY · CSIRO · MONASH University · NeuRA Discover. Conquer. Cure.

1 Research

The 2015–16 period saw the implementation of a comprehensive, integrated and state-of-the-art program set that is strongly complementary in the transfer of knowledge and supporting information.

Our major platform projects have been the key focus, supported by a number of new, more discrete projects centred on key product concepts. These projects have been developed on the back of industry priorities and the opportunities for innovation identified through the research and development expertise of the whole consortium.

Program One – Alertness Measurement, Testing and Prediction

Professor Shantha Rajaratnam, Monash University

Research Program One incorporates two themes to develop and validate tools to measure and predict alertness and other sleep-related states accurately. This work supports the development of practical alertness tests and management tools. Monitoring alertness in practical settings using validated technologies and biomarkers will permit individualised alertness assessment and use of targeted countermeasures.

Real-Time Biomarkers of Alertness

Biomarkers are biological characteristics that can be objectively measured to provide information on changes in alertness and provide an early warning of alertness failure. Other measures of alertness might include those that are based on neuro-behavioural performance and signals from the brain, eyes and other areas of the body. As the alertness state fluctuates due to factors such as biological time of day, duration of wakefulness, or chronic periods of restricted sleep, these measures should be sensitive to changes in the alertness state. The objective of this research theme is to identify novel real-time biomarkers and other alertness measures to assess and predict the risk of alertness failure.

Having standardised definitions and criteria for defining and evaluating alertness, the project team initiated a highly controlled study using state-of-the-art measurements in healthy volunteers. As part of the study, participants completed three weeks of unscheduled and scheduled sleep. A six-day, in-laboratory component included a 40-hour period of continuous sleep deprivation under constant routine conditions. This platform project is due for completion in early 2017 and will be directly informing: the development
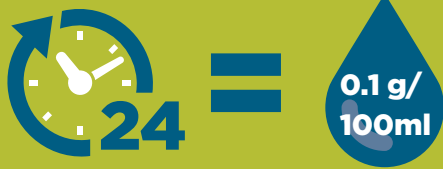
of an alertness test battery (which will include biomarkers and other measures of alertness, including established electrophysiological and neuro-behavioural markers, and novel "next generation" measures); the feasibility of a novel gold nanoparticle-based detection of alertness state from bodily fluids, such as urine or saliva (a project carried out in partnership with the CSIRO); and, the Alertness CRC biomarker discovery program, using proteomics and metabolomics to identify small molecule and protein markers of alertness and other sleep-related states (in collaboration with Bioplatforms Australia).

After initial laboratory testing of alertness outcomes, field-based validation will move to operational environments within Alertness CRC participant organisations. The biomarkers and alertness measures identified in these initial projects will then be incorporated into devices for assessing fitness for duty and roadside alertness tests as well as personalised alertness and sleep health management systems.

The collection of additional biological samples in the Sleep Disorders and Healthcare Platform projects has continued with blood and saliva samples stored for future analysis after candidate biomarkers are identified in the biomarker discovery program.

Around
20%
of **fatal road accidents** involve driver fatigue.[1]

1   http://www.tac.vic.gov.au/road-safety/statistics/summaries/fatigue-statistics

24 = **0.1 g/100ml**

Drivers who have been awake for 24 hours will have a driving performance similar to a person who has a BAC of 0.1 g/100ml. They are **seven times more likely** to have an accident.[2]
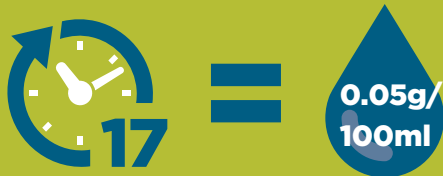
17 = **0.05g/100ml**

A person who has been awake for 17 hours faces the same risk of a crash as a person who has a BAC reading of 0.05 g/100ml. They are therefore **twice as likely** to have an accident as a person with a zero blood alcohol content who is not fatigued.[3]

Technologies for Detecting and Predicting Alertness

The Alertness CRC has been in the unique position of being able to bring together multiple technologies and to integrate them – along with new measurements developed – into a comprehensive and accurate multimodal system for alertness detection and monitoring. This approach is at the very core of the CRC mission, to bring together technologies to design more effective products for the future.

Within the Healthcare Platform project, medical staff from the Austin Hospital have been participating in a study aimed at developing sensitive measures of alertness impairment during nightshift work. This study is guiding the development of new objective tests of fitness for duty and improved alertness monitoring capabilities. The project also monitors rest-activity cycles and physiological rhythms in these individuals during shift work, to improve algorithms that monitor and predict biological (circadian) timing and alertness states. Hospital staff have been assessed through a battery of electrophysiological, behavioural and ocular alertness markers.
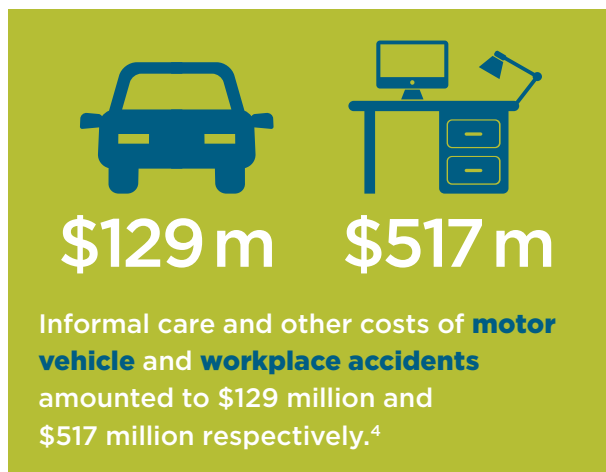
A 'spin off' project, involving Seeing Machines, Monash University and the Institute for Breathing and Sleep, continued to examine driver performance in hospital shift workers. A fully-instrumented vehicle providing vehicular-derived driving outputs, and the Seeing Machines technology providing driver-derived alertness outputs, allowed for the prediction and assessment of alertness failure and adverse driving outcomes. The project will contribute to the development of current monitoring systems for sleepiness-related driving impairment, and guide the development of roadside tests for sleepiness.

2   http://www.tac.vic.gov.au/road-safety/statistics/summaries/fatigue-statistics
3   Op. cit.

The Alertness CRC is working closely with Philips Respironics to improve the ability to predict biological clock timing, which is a critical step for individual-level management of alertness in shift workers and in a range of sleep disorders that are caused by biological clock disruption (such as Delayed Sleep-Wake Phase Disorder (DSPD)). This project includes assessing the accuracy of novel algorithms to predict the timing of the biological clock in a sample of rigorously screened patients with DSPD, against the current gold-standard method for assessing biological clock timing which is 'Dim Light Melatonin Onset' (DLMO).

In collaboration with the National Transport Commission (NTC), the Alertness CRC has developed a Heavy Vehicle Fatigue Data Framework. The NTC's final report on this work was endorsed by the Transport and Infrastructure Senior Officials Committee, and has formed the basis of a new project that seeks to scientifically evaluate the impact of Heavy Vehicle National Law fatigue regulations on road safety risks.

$129 m $517 m

Informal care and other costs of **motor vehicle** and **workplace accidents** amounted to $129 million and $517 million respectively.[4]

Program Two – Safety and Productivity Improvements

Professor Steven W Lockley, Monash University

Program Two is designed to demonstrate that alertness can be maximised at individual, workplace and community levels to deliver measurable improvements in safety and productivity. This program is developing, testing and validating new tools and approaches to improve alertness. To achieve these aims, the program is utilising all four CRC platform projects currently in progress and has recently developed new research avenues to further these aims.

Dynamic Scheduling Systems

The evidence-based framework for shift scheduling has been developed and is currently being incorporated into a prototype of work/duty scheduling software system and scheduling guidelines for groups of employees. This prototype has been developed through the Alertness CRC to permit the management of complex staff scheduling and constraints for both planning purposes and real-time changes.

To establish and test the framework, the CRC continues to complete comprehensive assessments of the alertness state of health workers and modelling of sleep and alertness through the Healthcare Platform activities. The work also draws upon the biomarker discovery program, and the modelling and data fusion outputs, to provide a system capable of monitoring and modelling multiple predictors of sleepiness.

4   http://www.sleephealthfoundation.org.au/ public-information/special-reports/reawakening-the-nation.html

1 Research

Around 16% of Australia's work force are employed as shift workers, which puts them at risk of safety and performance issues.[5]

The team made an extensive review of the current schedules and where they deviate from biologically-informed best practice recommendations, and are using the prototype software to recommend an alternative schedule that meets all the logistical and operational requirements while conforming to the Alertness CRC best practice recommendations. Final arrangements are being made to implement the revised schedules for both nursing and physician staff. The impact of the new schedules on medical error rate will be assessed as part of the Healthcare Platform project.

The project team is also working to incorporate the Alertness CRC's alertness model – and other models – into the scheduling software to predict the time course and extent of sleepiness under any given schedule, and provide information on key performance indicators. The software will permit different schedules to be compared and selected on the basis of the best alertness and safety profile, rather than simply logistical constraints.

This study represents the first validation of the group scheduling software, which will be productised by Opturion, initially for the healthcare industry but then more broadly. It also represents the first validation of the Alertness CRC 'Best Practice Recommendations' for healthcare work schedules.

Smart Lighting Solutions

Light has a number of 'non-visual' physiological effects including resetting our body clock and directly activating the brain to improve alertness and performance. Through work in both the laboratory and healthcare setting, the Alertness CRC is in the process of quantifying the benefits of different lighting types in safety critical occupations. These findings will direct lighting and architectural design tools to promote widespread use of improvement in lighting countermeasures.

The other focus of this activity is the development of 'smart' lighting systems that use combinations of light wavelength, intensity, timing and pattern to optimise the alerting or sleep-promoting, or body clock-resetting effects of light. These units are easily programmable and permit individualised 'smart' lighting interventions that interact with alertness assessment tools. To develop these smart lighting systems, the current lighting of a high-intensity inpatient setting was reviewed. The Alertness CRC is now developing a dynamic lighting system in partnership with Lighting Science Group Corporation that will optimise the lighting environment. The aim is to promote better alertness and productivity while at work, while promoting better sleep and circadian organisation at home.

Studies show 1/3 of shift workers fall asleep on the job once a week or more.[6]

5 http://www.abs.gov.au/ausstats/abs@.nsf/featurearticlesbyCatalogue/5461A9DAE97FF759CA2578C300153388?OpenDocument (2010 Australian Labour Market Statistics data)

6 http://content.safetyculture.com.au/news/index.php/03/new-study-focus-behaviours-predicting-fatigue-accidents-among-shift-workers/#.V80Hp0196Uk (Alertness CRC media release)

Several other projects are underway or in development, including the development of a customised lighting intervention to improve daytime wakefulness and night-time sleep for hospital patients, while also providing better on-the-job alertness for staff, and the testing of prototypes for portable lighting devices that will be used to enhance staff alertness during safety-sensitive times, for example, when directly observing patients.

The lighting team is also investigating a lighting design system to maximise alertness, safety and productivity. The Alertness CRC has partnered with one of the world's leading lighting design software companies, Solemma, to enhance its leading software product, DIVA-for-Rhino, by developing a software module that will allow designers to model the non-visual effects of light and ultimately predict the alertness, safety and productivity benefits of their design.

Program Three – Sleep Health

Professor Ron Grunstein, Woolcock Institute of Medical Research

The importance of sleep health cannot be underestimated, particularly when it comes to alertness, productivity and safety both at work and in the community. Insomnia and Obstructive Sleep Apnea (OSA) are two of the most common sleep disorders, collectively affecting one in five Australian adults. Understanding just how these sleep disorders develop and progress, and how they present in each individual, is crucial in determining the most effective treatment for sufferers. Personalised and effective treatment options are vital for the improvement of both alertness and productivity in the workplace, and are also key in mitigating the risk of workplace injuries.

Nightshift workers have a

30%

increased risk

of occupational injury or illness compared with regular day shifts.[7]

INSOMNIA

One in 10 Australians have insomnia, a persistent disorder that makes it hard to fall asleep, stay asleep or both. Sufferers often wake up feeling tired, unrefreshed and sapped of the energy needed to perform at work and get through the day.

7   https://www.iwh.on.ca/system/files/documents/iwh_briefing_shift_work_2010.pdf

Personalised Sleep Health Management

This theme of research recognises that the key features of insomnia and OSA vary substantially between individuals. As a result, the program is working to develop new systems for phenotyping patients with these disorders. Development and discoveries in this area of research will identify the varied underlying causes of the conditions leading to better tailored and individualised treatment options.

Fundamental information regarding the pathophysiology of OSA is currently lacking in clinical decision-making regarding treatment strategies. Research into respiratory phenotyping of OSA may help to explain why many patients fail to be adequately treated with continuous positive airway pressure (CPAP), the current 'one size fits all' treatment approach in respiratory sleep medicine. It is anticipated to lead to clinically practical stepped approaches for determining the main causes of OSA in individual patients, allowing for more targeted delivery of treatment.

Within this theme, we are also investigating vulnerability to alertness failure in OSA Phenotyping. This area of research focuses on the development and validation of better ways to identify OSA patients with significantly impaired alertness and elevated driving accident risk. Prior research shows that patients with OSA generally fall into one of two groups; either those who are

$4.3 billion

Indirect financial costs associated with sleep disorders and conditions attributable to them were estimated to be **$4.3 billion** in 2010. This includes **$3.1 billion** in lost productivity due to premature workforce separation and mortality, and absenteeism.[9]

vulnerable to sleep loss during safety critical tasks (e.g. driving), or those who are resistant. This research stream is working to develop a phenotyping toolkit of measures to help identify into which of these two groups OSA patients fall.

Through the use of detailed information from patients' physiological and psychological signals during testing in the laboratory and home environments, the Alertness CRC is also mapping how patients respond to insomnia therapy (insomnia phenotyping). This research is developing ways to better identify different subtypes of insomnia. Patients with insomnia have high rates of absenteeism, depression and anxiety, and neurocognitive impairment compared to good sleepers. Enhanced identification of how patients respond to therapy will improve treatment of this disorder.

Testing and research continues to occur across five sites within Australia. Teams of researchers at Adelaide's Institute of Sleep Health and Flinders University, Melbourne's Monash University and The Institute for Breathing and Sleep and Sydney's Woolcock Institute of Medical Research, are taking part in this collaborative approach.

1.5m

In 2010 there were an estimated **1.5 million Australians** (8.9% of the population) with the following most common sleep disorders, comprising approximately:

- **775,000** people with OSA (4.7%);
- **492,000** people with primary insomnia (3%); and
- **199,000** people with RLS (1.2%).[8]

8   http://www.sleephealthfoundation.org.au/public-information/special-reports/reawakening-the-nation.html

9   Op.cit

Integrated Platform for Data Management

The Alertness CRC's scalable and searchable database is a system designed to store data collected by the various research projects and capture essential details regarding how that data was collected. This context and access is now facilitating sophisticated data science investigations. Since its completion in mid-2015, the various research projects have commenced uploading their collected data into the database, and this process is continuing as these projects conclude their data gathering phases and commence cleaning and preparing data such that it is suitable for sharing across the Alertness CRC.

With the data collected so far, a number of data mining activities have already commenced to extract new knowledge and to identify new ways of analysing research data through cutting-edge machine-learning techniques.

The data mining team has identified time-series data such as polysomnography and actigraphy as particularly rich data sets that are likely to yield new valuable information, and are directing investigations into exploring these. For instance, one investigation is looking for recurring breathing patterns in sleep apnea patients to aid automatic detection of different breathing events, and another is investigating whether there are distinct groups of insomniacs based upon their EEG behaviour during sleep.

The team is also investigating ways to combine multiple sources of data, such as actigraphy, heart rate and skin temperature, to accurately track sleep behaviour in subjects with sleep disorders, for whom standard techniques are known to be error-prone. Another activity is using EEG data collected during driving simulations to predict crash events caused by sleep deprivation, which could then have application in real driving conditions.

Education and Training

The Education Program for the Alertness CRC was overseen by the Education Committee comprising:

- Professor Ron Grunstein, Woolcock Institute for Medical Research (Chair)
- Dr Clare Anderson, Monash University
- Dr Peter Catcheside, Flinders University
- Dr Chris Gordon, The University of Sydney

This committee provides oversight regarding the selection, training and interactions of students and postdoctoral awardees of the Alertness CRC in the context of their institutional opportunities for training and professional development.

The Alertness CRC Education Program is designed to expose students and Early Career Researchers to all aspects of the collaborative process and provide direct contact with industry partners. We support placements and professional development through dedicated funding, and host an annual training event to further enhance the capacity of the future research leaders.

Postdoctoral Training

A total of 24 postdoctoral researchers are currently involved in various research studies across the three research programs. All eight Alertness CRC Project Leaders are postdoctoral researchers with an additional 11 managing a number of research studies within the platform projects.

These early career researchers have been instrumental in the successful completion of a significant and complex program of research. Project Leaders were responsible for the day-to-day project management with other 'postdocs' overseeing various components of project activity.

1 Research

PhD and Masters Program

Our PhD program has a total of 18 PhD students. Three scholarships for Masters students were also approved, with two students subsequently converting their Masters research to a PhD.

Alertness CRC activities are also providing opportunities for undergraduate research projects including honours and vacation scholarship students. For example, we have five Science Masters students assisting in the Modelling and Data Fusion activities.

The Alertness CRC has also been a strong supporter of the Industry Based Learning (IBL) Program established at Swinburne University, having provided a total of 11 IBL scholarships in the last 12 months.

Alertness CRC Education and Training – PhD Workshop

"Great choice of speakers! Very grateful for the experience."

"Commercialisation session was very inspiring and engaging."

"Enjoyed meeting colleagues from interstate and the CRC team."

Industry Training

Customised industry training initiatives in the last 12 months included the following:

- Intellectual property and publication risk workshop, delivered by FAL Lawyers (Melbourne).

- Project Management Workshop on basic project management (half day), delivered by an externally sourced experienced project manager.

- 'Sleep Retreat' workshop (Adelaide) with over 80 registrants attending. The program included a keynote presentation by Dr Tracey Sletten, Research Fellow and Alertness CRC Project Leader, and a Young Investigator session of high quality presentations.

- Annual two-day workshop for all postdoc researchers, PhD and Masters students (Melbourne). Attendees presented their PhD project work to identify synergies and opportunities for cross-disciplinary collaboration. The program included several high calibre and engaging speakers with a focus on commercialisation, innovative thinking, and sharing experiences as a researcher forging a career in industry or as an entrepreneur. Several presenters, including Alertness CRC industry participant representatives, expressed great satisfaction at the opportunity to access the researchers of tomorrow. Feedback from students indicated a high degree of satisfaction with the annual workshop and the opportunity to identify industry placement opportunities.

CASE STUDY 1

CSIRO and chemiresistor project

Project Leader: Dr Suzanne Ftouni

A major objective of the Alertness CRC is to develop a roadside or workplace alertness measurement test.

While a breathalyser can measure the concentration of alcohol in your breath, there is no equivalent device that can measure human alertness state. And yet the body exudes or displays biomarkers when in a state of fatigue.

CSIRO's gold nanoparticle chemiresistor sensor arrays were identified as an emerging technology that could potentially respond to biomarkers that correlate with alertness. As such, a two-phase research project commenced. In phase one, healthy individuals were kept awake for 40 hours, before providing biological samples. A unique set of samples was also analysed using CSIRO's chemiresistor sensor arrays, to evaluate whether differences due to this extended period of wakefulness could be observed. A key finding was that alertness state changes within a healthy individual could be detected.

Phase two of this research will further examine which biological samples are the most viable and accurate, with a view to developing a non-invasive roadside test.

1 | Research

Small to Medium Enterprises – SME Engagement

The Alertness CRC actively encourages the valuable involvement of SMEs as both Essential and Other Participants. The larger participant organisations remain eager to support the involvement of SMEs in project teams, and the Alertness CRC continues to highlight opportunities for collaboration within the CRC as well as beyond CRC-specific objectives.

The Seeing Machines alertness monitoring instrumented car

"Collecting such detailed, real-time and real-world data from tired drivers has not been possible until now. By being able to predict what triggers a drowsy event, we'll deepen our understanding of fatigue and develop new ways to combat it."
Professor Mike Lenné, Chief Scientist, Human Factors, Seeing Machines

All Alertness CRC participants have been appointed as members of both the Strategic Review and Research Translation Panels of the Alertness CRC. An annual meeting of these panels was held in Melbourne in April 2016, at which Research Program Leaders provided an update on current activities. There was a strong SME presence at these meetings and good opportunity for industry-to-industry discussions around the synergies within and outside the Alertness CRC program.

At a research project level, SMEs are actively engaged through the provision of vital background IP as well as in-kind contributions. Furthermore, data collection facilitated by the four platform projects has provided opportunities for smaller end-user projects to be developed.

For example, Australian technology company Seeing Machines initiated a project within the Healthcare Platform to assess the impact of shift work on driver alertness and driving behaviour in the healthcare setting. In this project, 20 nurses working nightshift are being monitored as they drive to and from their work in an alertness monitoring instrumented car. The Seeing Machines vehicle uses cutting-edge technology to monitor the drivers' steering behaviour and eye closures, providing world-first insight into behaviours that can predict when a fatigue-related accident is likely to occur. The results will be used to test out new work schedules, to develop alertness-boosting smart lighting systems, and to improve drowsiness detection technology.

In addition, following the appointment of Professor Mark Wallace (Chair at Monash University and Chief Technology Officer of Opturion Pty Ltd) as Alertness CRC Theme Leader, a project was initiated to fast-track the development of a scheduling software system for group work. The solution will be produced for the Austin Hospital in Melbourne by Opturion Pty Ltd who have become a new Alertness CRC industry partner. This system is being developed in collaboration with the Austin Hospital with a view to the hospital using the new software system for scheduling their medical staff. Opturion will then support and maintain the new solution and market it to other hospitals in Australia and worldwide. Opturion's contributions are also supporting the assessment of individual vulnerability to shift work and the development of integrated interventions for alertness management in a healthcare setting.

Another key SME partner organisation is Grey Innovation. Grey Innovation is a commercialisation technology company based in Melbourne, partnering with universities and research institutes in Australia and Germany. The company has representation on the Alertness CRC Commercialisation Committee due to their strong expertise in engineering, commercialisation, product development and manufacturing. They are providing key expertise in support of the committee's primary function, which is to develop, implement and oversee a project investment and prioritisation decision-making framework to maximise the economic value created through the Alertness CRC's industry-led collaboration.

> The Alertness CRC brings the best and brightest researchers together with passionate, safety-minded businesses and technologies that might otherwise compete. This results in the greatest possible insight into the fatigue problem with a genuine focus toward making sure everyone goes home safe every day.

Dr Daniel Bongers, Chief Technology Officer, SmartCap Technologies

Results
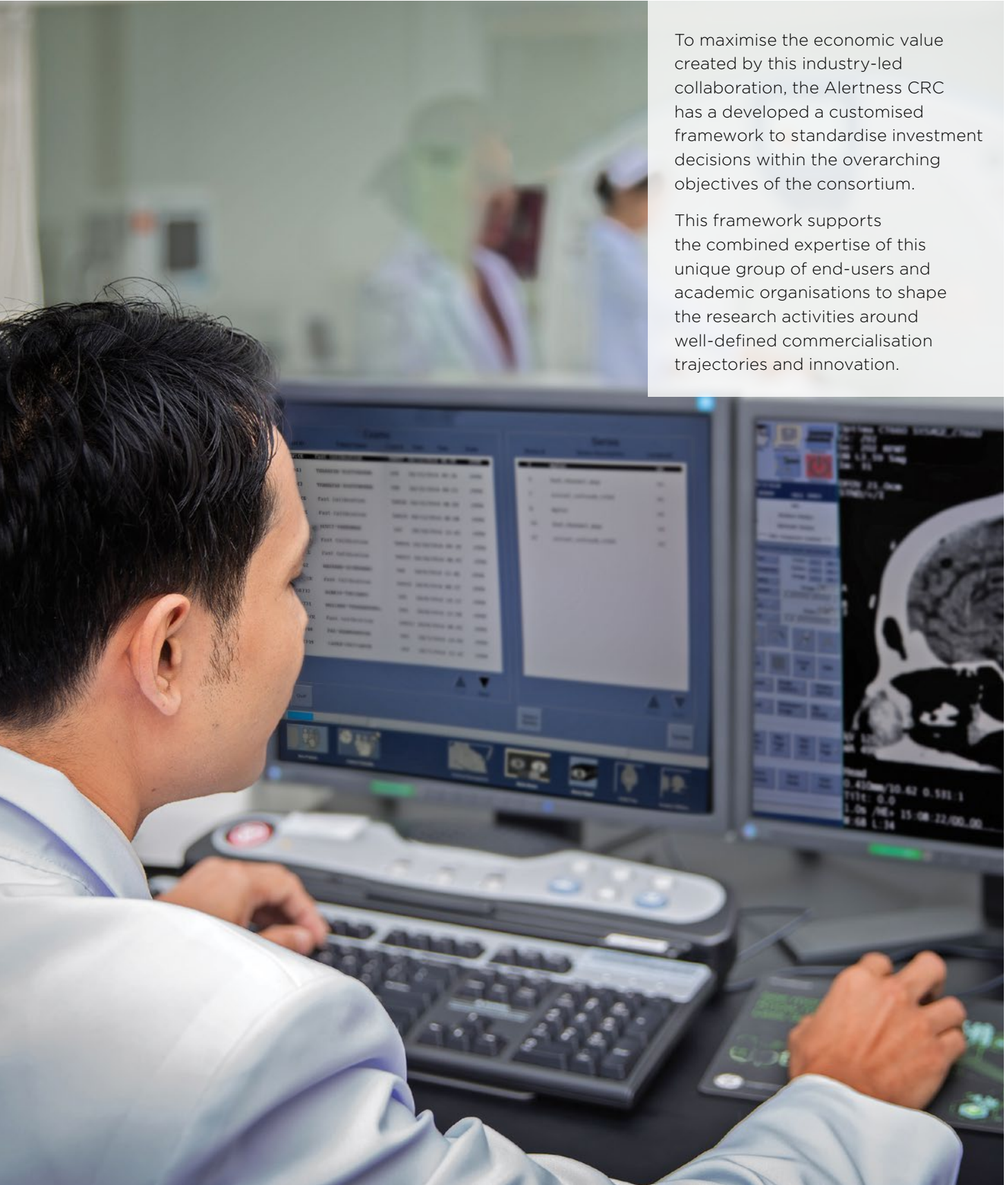
To maximise the economic value created by this industry-led collaboration, the Alertness CRC has a developed a customised framework to standardise investment decisions within the overarching objectives of the consortium.

This framework supports the combined expertise of this unique group of end-users and academic organisations to shape the research activities around well-defined commercialisation trajectories and innovation.

Utilisation and Commercialisation

The Alertness CRC brings together 29 organisations in the pursuit of commercial outcomes in the alertness management field.

Our three major research programs and the themes within reflect the high-level 'research and translation plan' that guides the development of project activity within the consortium. These activities are generating an array of novel and powerful data, scientific leads, product concepts and opportunity for well-defined intellectual property.

The broader marketplace for the deployment of Alertness CRC outputs is diverse, significant and presents a large range of potential commercialisation pathways. The Board of Alertness CRC Ltd has sharpened the commercialisation focus, which sees potential project success determined by factors such as its ability to bring the project to market – or conversely to move to proof of concept and adequately test uptake or relevance, its strategic fit with the overarching objectives of the Alertness CRC, and its long-term commercialisation value.

The Alertness CRC has established a Commercialisation Committee to formally map the output flow, interrelationships and business cases and to further refine research requirements, project review opportunities, and commercialisation partners for the consortium. In short, this committee is assessing the commercial value of project proposals, setting performance milestones, identifying industry partners to attach to a project, offering mentoring or business support and reviewing proposed commercialisation structures.

R&D Pipeline

In 2015–16 the research engine of the Alertness CRC saw an array of sophisticated datasets established that facilitated the growth of new project activity with clearly defined commercialisation pathways and high levels of industry participant engagement.

The biomarker discovery program saw the development of a number of discrete commercialisation opportunities around fitness for duty assessment. Work to assess the feasibility of novel nanoparticle sensors provides an avenue for the potential development of diagnostic kits of alertness-related changes associated with performance impairment.

With the participation of key end-user partners, the Alertness CRC has multiple streams of activity with well-defined commercialisation pathways including: the utilisation of alertness prediction models; technologies to reduce daytime sleepiness; and the development of personalised sleep health management systems.

With high levels of access and engagement within the healthcare sector, the Alertness CRC has established a project to develop a group work scheduling solution customised for specific settings and sectors. This project will integrate alertness modelling with sophisticated rostering algorithms in order to automatically generate rosters that are safe but also efficient in their utilisation of health employees and workplace specific requirements and constraints.

The potential for lighting-based solutions in alertness management remains high with plans to develop a software tools that will allow designers to model the non-visual effects of light and predict the impact on alertness of their designs.

CASE STUDY 2

National Transport Commission

Project Leader: Dr Andrew Tucker

"The regulation of driver fatigue is a complex policy issue and more detailed research needs to be done on its causes and impacts." Mr Paul Retter, Chief Executive of the National Transport Commission.

The Alertness CRC is conducting several research projects for the National Transport Commission; a collaboration that began when the two organisations co-hosted an Alertness Summit in Canberra in mid-2015, which brought together government, industry, fatigue and alertness experts, and heavy vehicle industry stakeholders, to develop a National Heavy Vehicle Fatigue Data Framework.

The fatigue data framework, which has been endorsed by the Transport and Infrastructure Senior Officials Committee, will help to ensure that data about the frequency and impact of driver fatigue is collected in a consistent and comparable way across Australia's states and territories.

The Alertness CRC projects will conduct new research to evaluate the fatigue impact of the current laws; develop nationally consistent definitions and measurements of fatigue; analyse commercial data to evaluate the frequency and impact of fatigue regulations; and review road agencies' ability to link crash data to driver accreditation.

Communications

A comprehensive communications plan was developed for 2015–16, which identified the communication and engagement activities that would best meet the needs of the consortium. Alertness CRC stakeholders include government regulatory authorities, end-users, industry bodies, trade unions and employers. The messaging around the work of the Alertness CRC was focused on building the brand as a collaborative mechanism and developing broader research translation networks.

Internal Communications

Internal communications has been a priority of the Alertness CRC to ensure the opportunities and synergies that exist within the consortium are realised.

The project activities themselves are based on discrete teams, with all parties represented. Regular meeting schedules and Project Leader oversight continues to ensure that all participants have routine opportunities to discuss progress and utilisation plans.

Participants also discussed the high-level strategic direction and research translation opportunities at the annual meeting of the Strategic Review and Research Translation Panels. These meetings have triggered more direct industry-to-industry collaboration, with a proposal to increase the frequency and efficiency of participant interaction processes.

The Alertness CRC continues to focus heavily on end-user engagement with regular meetings, workshops and delegations assembled as required. The Program Leadership continues to manage the research program in general, meeting at least quarterly to monitor progress and identify synergies across projects.

External Communications

The Alertness CRC website is regularly updated with new information. Google Analytics indicate that when measured against 2014, there has been a substantial increase in visitors and sessions, with an 87% increase in sessions, an 80% increase in the number of users and almost a 100% increase in the number of page views.

The Alertness CRC also worked closely with the Australasian Sleep Association to co-present a public webinar titled 'Drowsy Driving – Clinical Assessment and the Law', with Dr Mark Howard, an Alertness CRC Theme Leader. The webinar presented the evidence that the risk of vehicle crashes for those with sleep apnea or restricted sleep is equivalent or greater than the risk of driving while over 0.5% BAC.

To increase the broader stakeholder network, the Alertness CRC supported a short course on 'Alertness Management and Productivity', held in Melbourne as part of the Annual Scientific Meeting of the Australasian Sleep Association. The target audience for the course included occupational health and safety professionals, occupational physicians, students, researchers, and sleep clinicians wishing to engage with industry for research purposes.

Collaborating with partners Seeing Machines and the Sleep Health Foundation, the Alertness CRC sponsored a media event on World Sleep Day, which showcased the use of the instrumented car to monitor alertness in shift workers.

3 Resources

The Alertness CRC has a well-defined mission to promote the prevention and control of sleep loss and sleep disorders, and to develop new tools and products for individuals and organisations to improve alertness, productivity and safety.

In continuing to build a research and development facility that is efficient and effective, we involve carefully selected expertise – from professional CRC staff, to researchers, end-users and other valuable participants. Our overall collaborative approach to projects helps to ensure that we continue to focus on our mission, conquer our challenges, and deliver the right outputs for all stakeholders.

Governance – Board, Committees and Key Staff

The Governance structure is represented in Figure 2, the Alertness CRC Board Members are listed in Table 1, and the Alertness CRC Board of Directors Meetings for 2016 are outlined in Table 2.

The Board of Alertness CRC Ltd comprised between three and five independent Directors. It was previously led by Chair, Patricia Faulkner AO, with the position taken up by Deena Shiff in April 2016. The Board continues to operate with an Audit, Finance and Risk (AFR) Committee as a subcommittee of the Alertness CRC Board that meets biannually. This committee was chaired by Peter Maloney until his retirement, and is now chaired by Ian Farrar. Its primary functions are to review the appropriateness of the Alertness CRC's financial reporting, performance reporting, system of risk oversight and management, and system of internal control.

In addition, the AFR Committee is responsible for:

- monitoring the risk management framework, and making recommendations to the Board on changes to the framework;
- making recommendations to the Board on the appointment, assessment and removal of external auditors, and oversee their independence;
- annually reviewing and approving the external audit fees, plans and their scope;
- monitoring the internal control environment and procedures designed to achieve compliance with laws, regulations, internal standards and policies; and
- overseeing compliance with statutory and other legal requirements.

In 2015–16, the Board established the Alertness CRC Commercialisation Committee. This committee is chaired by Deena Shiff and includes the CEO, Program Leaders and Managing Director of SME participant Grey Innovation.

The Commercialisation Committee meets monthly as required and is tasked with:

- assessing the commercial value of project proposals;
- setting performance milestones;
- identifying industry partners to attach to a project;
- offering mentoring or business support by arrangement with specialists within participating universities and relevant partners;
- reviewing proposed commercialisation structures and returns for CRC project parties; and
- making recommendation to the Alertness CRC Board regarding resource allocation to project activities.

In accordance with the Essential Participants Agreement, two participant panels have been convened by the Board to assist them in their governance role: the Strategic Review Panel and the Research Translation Panel. All Participant Representatives are eligible to be a member of both committees.

Members of the two panels met in Melbourne on 13 April 2016.
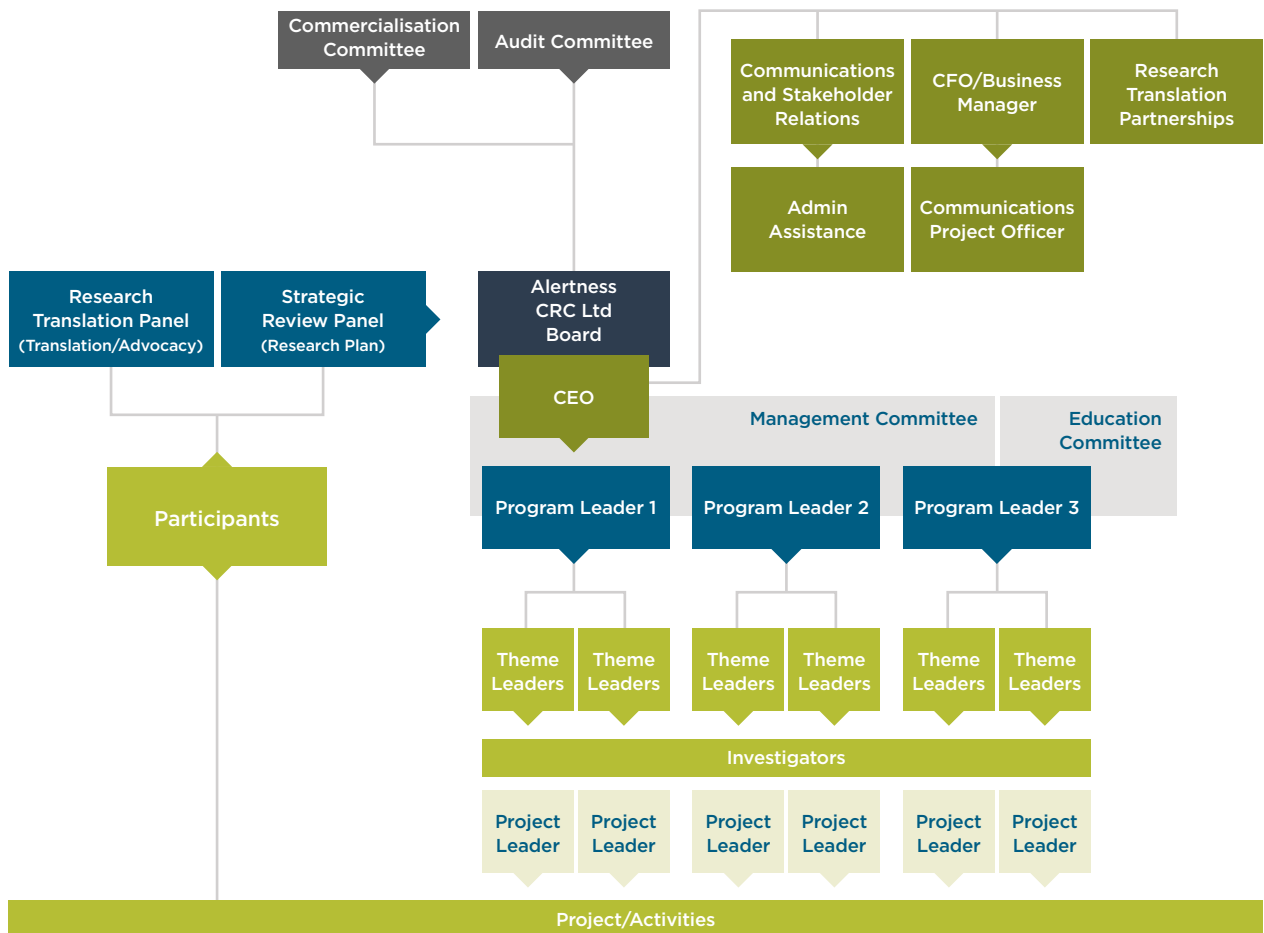
Resources

Figure 2: Alertness CRC Governance structure

Table 1: Board Members

Name	Role	Key skills	Independent/Organisation
Patricia Faulkner, AO	Chair until 23 April 2016	Patricia Faulkner, B.A. (Econ & Psych), Dip.Ed, M. Admin, has been CEO of large and complex government departments and a Partner in a major advisory firm (KPMG). Her career has spanned the most senior levels of the public, private and the not for profit sectors. She now has an extensive portfolio of Board and advisory roles, both as Chairman and member. Her most recent award was the degree Doctor of Laws honoris causa by Monash University in September 2013.	Independent

Name	Role	Key skills	Independent/Organisation
Deena Shiff	Board Member Chair from 24 April 2016	Deena Shiff, B.Sc (Econ) Hons; B.A. (Law) Hons, has 15 years' experience as a non-executive director on both public and private sector Boards. Deena served as a Group Managing Director at Telstra Corporation between 2005 and 2013 and in 2011 was the founding CEO of Telstra's corporate venture capital arm, Telstra Ventures. Prior to that, Deena was a Partner at King & Wood Mallesons, in house corporate counsel at Telstra and a senior executive and adviser on legal and social policy reforms for the Australian Government. Deena serves as a director on a number of boards including ASX-listed Appen and the Citadel Group. She also chairs the global board of Bai Communications Ltd.	Independent
Anthony Williams	CEO	Anthony Williams B. App. Sci., MPH has extensive experience and a proven track record in clinical research and business development. As a team leader with international, national and regional roles, Anthony has expertise in research management, financial modelling, corporate governance, intellectual property management and contract development.	Independent
Ian Farrar	Board Member	Ian Farrar, B Comm, ANU, is an experienced company director who has chaired public, private and government organisations and is well versed in contemporary corporate governance issues. He is a skilled commercial manager with a strong track record of achievement in areas such as large-scale asset utilisation, funds management and strategic asset allocation, financial management, insurance, information systems, statistical analyses, occupational health and rehabilitation, research management and organisational change.	Independent
Peter Maloney	Board Member until 31 October 2015	Peter Maloney, B.Comm (University of Melbourne) MBA (Rochester) has wide experience as a business executive and company director, both in Australia and internationally, across a range of industries. Peter has held senior positions with Western Mining Corporation, Santos, F H Faulding, the Lion Selection Group and Lion Manager.	Independent

Table 2: Board of Directors Meetings, 2016

Name	Number eligible to attend	Number attended
Patricia Faulkner, Chair (resigned 23 April 2016)	3	2
Deena Shiff (appointed as Chair 24 April 2016)	4	4
Anthony Williams	4	4
Ian Farrar	4	4
Peter Maloney (resigned 31 Oct 2015)	1	1

Strategic Review Panel

The Strategic Review Panel:

- advises the Board on the project activities and research direction of the Centre;
- meets bi-annually in person or via telephone or video link;
- is chaired in any one Financial Year by a representative of the end-user Essential Participant which has the largest cumulative annual cash contribution budgeted for the Financial Year in which the meeting is held and who will report directly to the Board as required;
- includes one representative from each Participant which chooses to make an appointment; and
- includes the CEO, Research Program Leaders and the Education and Training Unit Leader as ex-officio members.

Research Translation Panel

The Research Translation Panel:

- advises the Board on the research translation activities of the Centre;
- meets bi-annually in person or via telephone or video link;
- is co-chaired by representatives of the SHF and BUPA, until either party ceases to be an Essential Participant or the Board decides to replace either or both co-chairs at its discretion;
- is comprised of up to one representative from each participant which chooses to make an appointment; and
- includes the CEO, Research Program Leaders and the Education and Training Unit Leader as ex-officio members.

Key Staff

Alertness CRC key staff are listed in Table 3.

The operations of the Alertness CRC are managed by the CEO and Business Manager. The CEO also chairs a Management Committee with the three Research Program Leaders, who meet fortnightly to ensure direct communication between the executive and the research teams.

Table 3: Alertness CRC Key Staff as at 30 June 2016

Name	Organisation	Position/Role
Anthony Williams	Alertness CRC Ltd	CEO
Wee Mong Wong	Alertness CRC Ltd	CFO
Andrew Tucker	Alertness CRC Ltd	GM, Research Translation
Margaret Miller	Alertness CRC Ltd	Communication and Stakeholder Engagement
Ron Grunstein	Woolcock Institute of Medical Research	Program Leader
Shantha Rajaratnam	Monash University	Program Leader
Steven Lockley	Monash University	Program Leader
Clare Anderson	Monash University	Theme Leader
Doug McEvoy	Southern Adelaide Local Health Network	Theme Leader
Karen Reynolds	Flinders University	Theme Leader
Mark Howard	Institute for Breathing and Sleep	Theme Leader
Mark Wallace	Monash University	Theme Leader
Sanjay Chawla	The University of Sydney	Theme Leader

Participants

Alertness CRC Participants are listed in Table 4.

The overall level of engagement of end-user participants has been high and productive.

In April 2016, Opturion Pty Ltd joined the Alertness CRC as an Other Participant. Opturion is an optimisation company working with Austin Health and Monash University to develop a group work scheduling tool. This novel approach will integrate alertness modelling with rostering algorithms to automatically generate rosters that are safe, but also efficient in their utilisation of health employees and workplace specific requirements and constraints.

Neuroscience Research Australia (Neura) remains involved in the respiratory sleep phenotyping stream of the sleep disorders platform project. Their involvement is helping to fast-track subject throughput, and enables the CRC to continue utilising the specific expertise of Associate Professor Danny Eckert, who continues to work closely with key end-user participant Philips Respironics in this area.

> Our involvement in the Alertness CRC has provided Cogstate with considerable benefits. First the research programs are providing valuable information about how our technology can be used to understand disruption to normal sleep wake cycles. It also provides our company with access to other emerging technologies and expertise that may be of use for us in the measurement of fatigue and productivity in our own area of business. Finally, we have been able to develop knowledge and relationships with expert staff from the universities and research institutes involved and gained access to the clever and motivated graduate students whose work is part of the Alertness CRC; some of whom we hope may be able to continue with us as employees

Dr Paul Maruff, Chief Scientific Officer, Cogstate

Table 4: Alertness CRC Participants

Participant Name	Participant Type	ABN/ACN	Organisation Type
Austin Health	Essential	96 237 388 063	State Government
Australian Sleep Trials Network	Other	88 002 198 905	Other
Australian Salaried Medical Officers Federation	Essential	56 536 563 722	Other
Bioplatforms Australia Limited	Essential	40 125 905 599	Other
BUPA Foundation (Australia) Pty Ltd	Essential	67 113 817 637	Industry/Private Sector
Cogstate Pty Ltd	Other	80 090 975 723	Industry/ Private Sector
Constraint Technologies International Pty Ltd	Essential	13 054 631 462	Industry/Private Sector
Commonwealth Scientific and Industrial Research Organisation	Other	41 687 119 230	Australian Government
Electrolight Pty Ltd	Other	93 288 579 088	Industry/Private Sector
Fatigue Management International	Other	UK company registration 06431894	Industry/Private Sector
Grey Innovation Pty Ltd	Other	14 083 304 214	Industry/Private Sector
Institute for Breathing and Sleep	Essential	39 093 685 879	Other
International Council of Mining and Metals	Essential	UK based	Industry/Private Sector
Lighting Science Group Corporation	Essential	US based	Industry/Private Sector
Monash University	Essential	12 337 614 012	University
National Transport Commission	Essential	67 890 861 578	Australian Government

3 Resources

Participant Name	Participant Type	ABN/ACN	Organisation Type
Neuroscience Research Australia	Other	94 050 110 346	Other
Optalert Australia Pty Ltd	Other	79 121 747 591	Industry/Private Sector
Opturion Pty Ltd	Other	13 146 662 053	Industry/Private Sector
Respironics Inc – A Philips Healthcare Company	Essential	24 008 445 743	Industry/Private Sector
Seeing Machines Limited	Other	34 093 877 331	Industry/Private Sector
SmartCap Technologies Pty Ltd (f.k.a EdanSafe Pty Ltd)	Other	61 094 352 959	Industry/Private Sector
Southern Adelaide Local Health Network	Essential	14 227 133 467	State Government
The Flinders University of South Australia	Essential	65 542 596 200	University
The Sleep Health Foundation	Essential	91 138 737 854	Other
The University of Sydney	Essential	15 211 513 464	University
Transport Accident Commission	Essential	22 033 947 623	State Government
Woolcock Institute of Medical Research Limited	Essential	88 002 198 905	Other
WorkSafe Victoria	Essential	90 296 467 627	State Government

Collaboration

With large-scale involvement of participants across the platform project activity and an increase in more discrete project plans around key product concepts, the extent of collaboration has increased dramatically during the reporting period.

Table 5 shows the level of participant involvement across project areas, but doesn't accurately reflect the increasingly higher level of direct contact between consortium personnel as project progress is reviewed and commercialisation plans are developed.

Table 5: Alertness CRC Projects and Participant Collaboration

Project Name	End-user Participants	Research Participants
Laboratory-based development of systems and biomarkers to assess circadian, sleep and alertness states.	10	3
Modelling and software development for prediction of alertness and optimisation of scheduling and a data fusion system for the estimation, prediction and control of individual alertness dynamics.	5	4
Assessing individual vulnerability to shift work and integrated interventions for alertness management in the healthcare setting.	18	5
Sleep disorder phenotyping.	7	6
Evaluation of Nanoparticle Chemiresistor sensor arrays to detect changes in alertness state – stage 1.	1	5
Development of Software System for Group Work Scheduling.	2	2
Prediction and Measurement of Circadian Phase in Patients with Delayed Sleep Phase Disorder or Insomnia.	1	4
Assessing vulnerability to shift work in the healthcare setting: monitoring alertness and driving performance during work commutes.	1	2

3 Resources

Alertness CRC Collaborations

The Alertness CRC continues to support research workshops and training initiatives. These provide an opportunity to engage with the broader research community around topics directly related to Alertness CRC activities, and also allows the CRC research personnel to participate directly in further shaping the research and translation strategies of the field.

- Australasian Chronobiology Society, 12th Annual Scientific Meeting (Melbourne, 2015)
- Adelaide Sleep Retreat 2015: Sleep and Fatigue: Risks and Management (Adelaide, 2015)
- Sleep Down Under – The Annual Scientific Meeting of the Australasian Sleep Association, Short Course 1: Alertness management and productivity – Bridging the gap between research and industry (Melbourne, 2015)

Who: Philips Respironics

What: Philips Respironics have significant involvement across the consortium, collaborating with all academic institutions and several other end-user participants.

Outputs: Through the diverse range of project activities academic institutions within the Alertness CRC are collaborating with technical, clinical, commercial and research representatives across a range of business units within the Philips organisation. Access to this industry expertise and focus is critical to the consortium's ability to execute innovative and output driven research.

Who: Opturion

What: This Australian optimisation company is participating in the development of a software system for group work scheduling. The aim of this project is to fast-track completion of a key CRC research milestone: the development of a prototype work/duty scheduling software system and scheduling guidelines for groups of employees. This prototype will be developed in collaboration with the Austin Hospital who will then use the system for scheduling their medical staff.

Outputs: It is expected the prototype system will be available for commercialisation in late 2017. This relationship and the opportunities for this software across other occupational sectors has resulted in leads for further collaboration in transport and mining.

Who: International Council on Mining and Metals (ICMM)

What: In October 2015, the Director Health and Safety at ICMM invited Dr Andrew Tucker, to outline the Alertness CRC's capabilities and research translation opportunities to ICMM members in London as part of their annual Health and Safety Forum. The Forum brings together mining industry OHS Executives to share information about new and emerging trends to improve occupational health and safety in mining operations.

Outputs: Networking with representatives from major international mining companies is ensuring that the research and innovative tools and processes developed by the Alertness CRC are informed by industry's real-world perspectives and priorities.

Who: Seeing Machines

What: Seeing Machines Pty Ltd continued with a collaborative project with Alertness CRC participants, Institute for Breathing and Sleep (IBAS) and Monash University.

Outputs: Outputs from the Healthcare Platform project have been leveraged to assess the impact of shift work on driver alertness and driving behaviour during work commutes using a state-of-the-art instrumented vehicle.

Who: National Transport Commission (NTC)

What: The Heavy Vehicle Fatigue Data Framework Project is a major collaborative initiative that followed the 2015 release of the 'Developing a heavy vehicle fatigue data framework' discussion paper. This report and subsequent public consultation identified the priority fatigue issues and data collection requirements for future research and was endorsed by the Transport and Infrastructure Senior Officials' Committee (TISOC) on 7 April 2016.

Outputs: Both interim and wider project steering committees have been formed across these organisations. Detailed standard operating procedures and preparations for the research protocol have been established. This project will lead to opportunities for other Alertness CRC partner organisations to participate.

Who: Sleep Health Foundation (SHF)

What: SHF is the leading national advocate for sleep health. The SHF Business Council is an industry advisory group set up to advise its board on matters of advocacy, public education and research support strategies. Through this relationship the Alertness CRC and other industry partners have recently joined the SHF to engage Deloitte Access Economics to estimate the prevalence and costs of inadequate sleep in Australia, including the contribution of shift work and potential policy responses.

Outputs: Through the SHF the Alertness CRC has access to an expanded network of industry stakeholders and consumer groups particularly in the area of sleep health service delivery. Working with the SHF to influence the national health agenda in recognition of the importance of sleep health the proposed Deloitte Access Economics report will provide accurate data on the economic impact of sleep disruption and sleep disorders.

Who: CSIRO

What: This proof of concept evaluation of CSIRO's chemiresistor sensor technology for measuring human alertness state utilised the Laboratory Platform project and access to participants being subjected to extended time awake (up to 40 hours awake). This provided a unique set of biological samples which could be analysed using CSIRO's chemiresistor sensor arrays to evaluate whether sample differences could be observed due to extended wakefulness.

Outputs: Key findings from the proof of concept phase showed that chemiresistor sensors could detect state changes within a healthy individual and that sensor array responses are associated with circadian phase and homeostatic sleep pressure. These findings have direct applications for roadside and clinical testing. The next phase will seek to validate portable testing devices and diagnostic kits suitable for in-field alertness state detection and the assessment of alertness-related changes associated with performance impairment.

Meet some of our PhDs

JULIA STONE,
BA (Hons),
PhD Candidate,
Monash University

ROHIT PHILLIP,
PhD Candidate,
Flinders University

BILLY MACMAHON,
PhD Candidate,
Monash University

I am working on projects to explore inter-individual variability in circadian response to shift work, and to test novel integrated modelling approaches for estimating circadian phase in normal living conditions. My work contributes to the Alertness CRC objectives in two ways. It informs interventions for shift work management based on individual characteristics and circumstances, and it helps in the development of a new method for measuring circadian phase which has potential for a new wearable device for real-time phase monitoring. Working within the context of a CRC allows for large-scale collaboration between multiple research, education and industry groups. This, along with access to combined resources as well as opportunities for exposure and research collaborations, continually improves the quality of my research education and development. I look forward to working further with industry for the translation and application of our research findings into everyday contexts.

My research looks at establishing whether quantitative sleep/wake EEG and sleep/wake HRV data are useful measures in differentiating between OSA patients who are vulnerable to alertness failure (VAF) and driving impairment, and those who are resistant. This would provide a useful clinical test readily translatable into clinical practice. This work addresses a major problem in sleep medicine and has the potential to reduce OSA related traffic or workplace accidents, improve safety and reduce societal cost by providing clinicians with novel tools to identify patients who are at high risk to alertness failure. I find that working within the CRC context I benefit from the opportunity to be involved with a large team and to be able to interact with experts in many fields, besides access to a large amount and variety of data, which otherwise would be very hard to obtain. The opportunities to attend CRC meetings and interact with other students and researchers about their work are also very valuable.

My research focus is identifying signatures of cognitive failure during sleep loss by using a test battery developed by industry partner Cogstate. This work contributes to the CRC aims of finding novel, valid measures of alertness that could be used to improve safety and productivity in workplace settings. Working within the CRC provides a unique opportunity to conduct research in both academic and industry settings. As part of my PhD within the CRC, I have completed an industry placement at Cogstate. This experience has taught me a lot about research in an industry setting, and has highlighted how beneficial industry partnerships in research can be.

KIRSTY DODDS,
MPh Candidate,
The University of Sydney

I am working on my research project at the Woolcock Institute of Medical Research, Sydney. I am investigating heart rate variability in patients with insomnia disorder. More specifically, I am exploring whether there are differences in heart rate variability amongst phenotypes of insomnia patients and, if so, whether this could be a biomarker. Ultimately this may enable us to personalise patient treatment. Working as a student with the Alertness CRC has given me a unique opportunity to be involved with a diverse range of research groups and have exposure to a number of industry partners. I am excited by my field of research and the potential it has to assist both clinical and consumer populations.

LAUREN BOOKER,
PhD candidate,
Monash University
and the Institute for
Breathing and Sleep

The project I am working on is based at the Austin Hospital. My thesis is focused on identifying shift workers in the healthcare industry who are most vulnerable to alertness failure due to shift work and circadian misalignment. To do this, we are screening health workers for sleep disorders, particularly shift work disorder. The impact of shift work disorder on staff wellbeing will be measured by exploring the relationship between individuals at high and low risk of shift work disorder and the severity of any depression and/or anxiety symptoms. We will also assess the relationship between shift work disorder, mental health and sick leave taken over a 12-month period and calculate the associated costs to the business. In addition, we will develop an individual-level intervention program to manage shift work disorder in those individuals identified as high risk. The findings will provide the CRC with a cost benefit analysis about the importance of screening for and treating shift work disorder and the process for screening and managing shift work disorder will be used by the CRC in future research and commercial developments. The major benefit working within the Alertness CRC is the support the organisation gives to students and the diversity of research that compliments each other; working towards common goals.

ANNA MULLINS,
PhD Candidate,
Woolcock Institute
of Medical Research

My research looks at quantitative analysis of brain activity measured by electroencephalography (EEG) during sleep to investigate predictive biomarkers of alertness, performance and vulnerability to fatigue in at risk populations. These EEG biomarkers also have potential clinical value when phenotyping sleep disorders such as insomnia and obstructive sleep apnea for both targeted therapeutics and in assessing responses to treatment. Characterising individuals using EEG contributes to a more personalised approach to medicine that can be utilised across research, clinical and ambulatory (home/office) settings. I believe the experience of working within the CRC is valuable to my career as it highlights potential commercial considerations in conducting research. These are important given the likely shift in how research will be funded in the future.

4 Financial Management
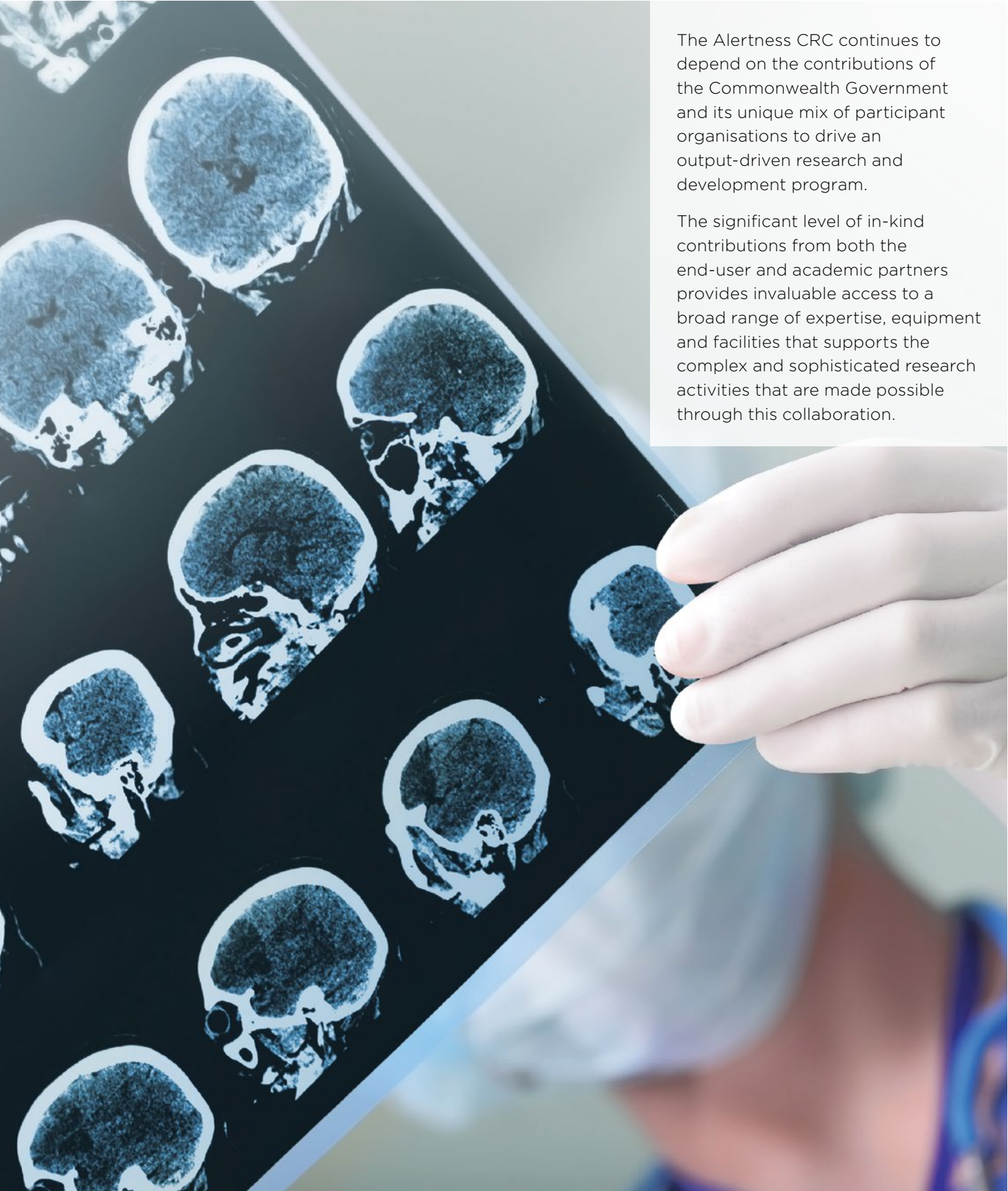
The Alertness CRC continues to depend on the contributions of the Commonwealth Government and its unique mix of participant organisations to drive an output-driven research and development program.

The significant level of in-kind contributions from both the end-user and academic partners provides invaluable access to a broad range of expertise, equipment and facilities that supports the complex and sophisticated research activities that are made possible through this collaboration.

During the 2015/16 financial year, 43% of the cash contributions were received from participant organisations, with 54% provided by the Commonwealth through the CRC funding agreement. The remaining 3% was made up of interest income and other revenue.

Cash contributions received from Essential Participants have shown an increase of approximately $50 thousand in 2015–2016 as compared to the Agreement, following catch-up payments and additional contributions. Other cash received ($139 thousand) during the year was made up of interest and other income (see Figure 3).

Figure 3: Composition of Cash Received During FY16 vs Agreement
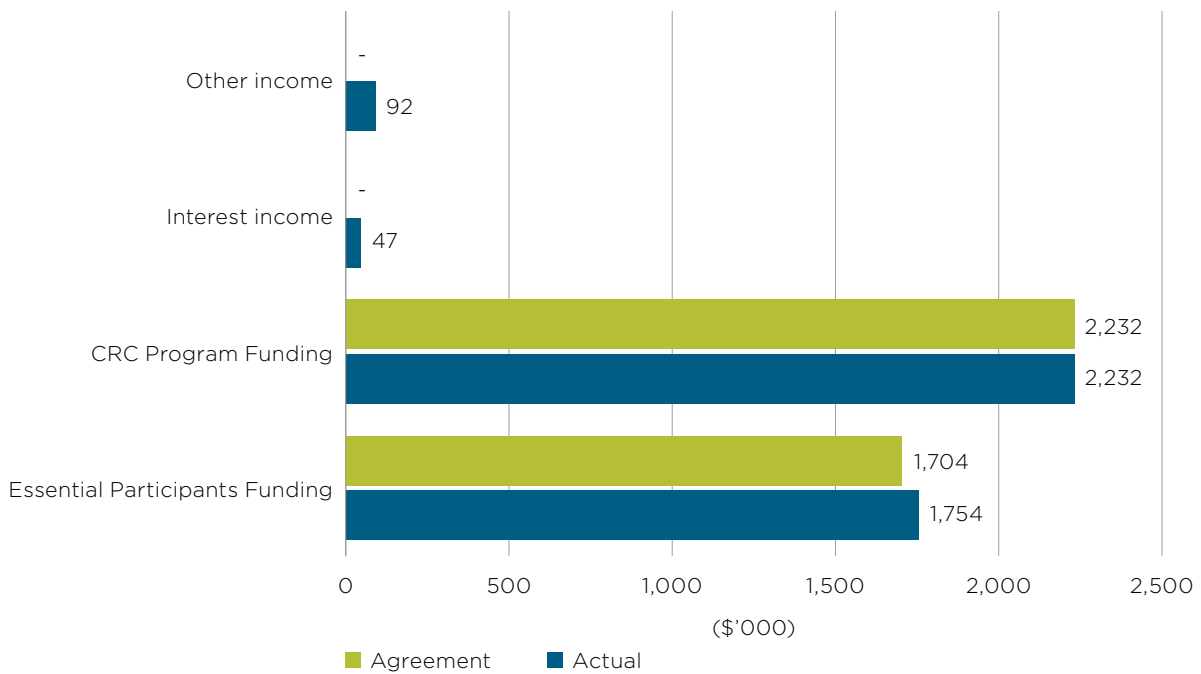
Figures 4 and 5 highlight the breakdown by category relative to original participant commitments for the year ended 30 June 2016 (Year 3) and its comparative status for the year ended 30 June 2015 (Year 2).

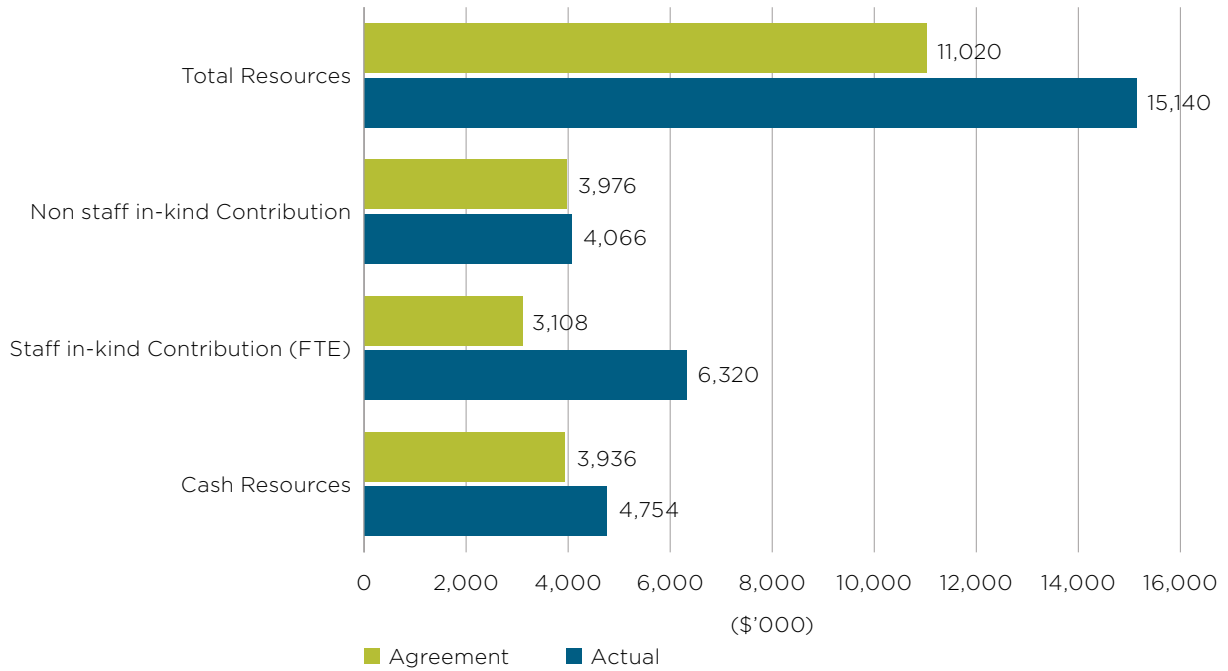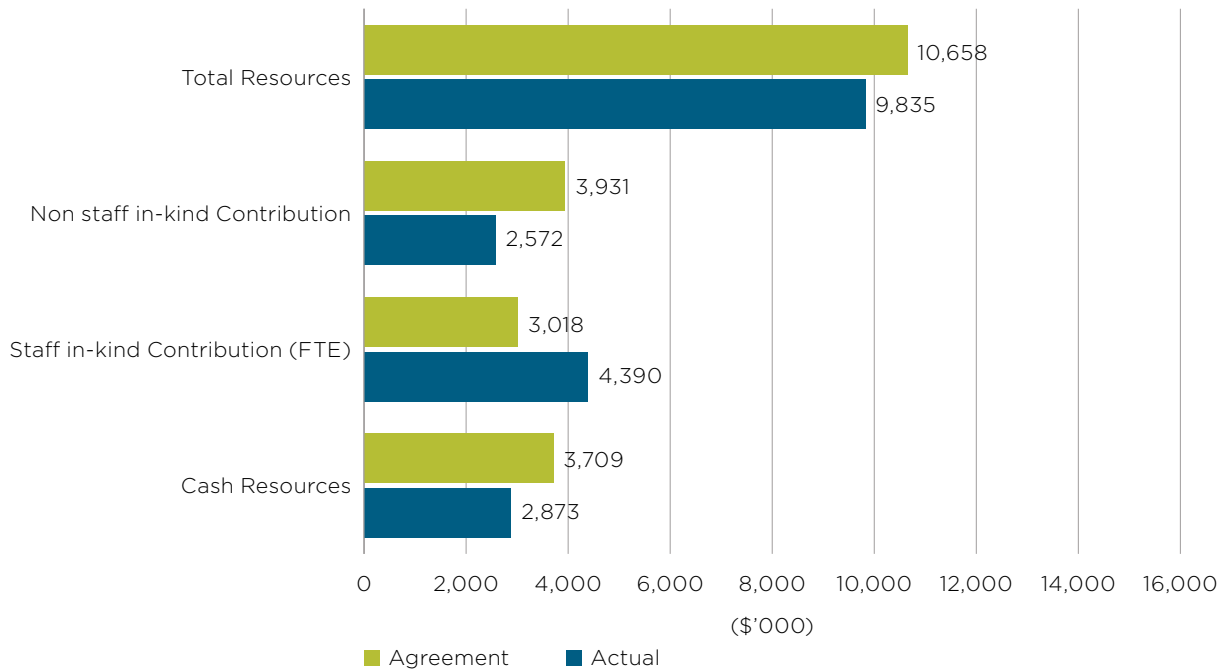**Figure 4: FY16 Allocation of Resource Category – Actual vs Agreement**

Figure 5: FY15 Allocation of Resource Category – Actual vs Agreement

Some notable highlights of audited financial results for 2015–2016 are:

- net assets (accumulated surplus) of $2.75 million (FY15: $3.53 million);
- total revenue recorded during financial period FY16 of $3.97 million (FY15: $3.97 million); and
- total operating expenses during financial period of $4.75 million (FY15: $2.87 million).

The independent auditor's report to the members of the Alertness CRC, for the 2016 financial year, has confirmed that the financial report of the Alertness CRC has been prepared in accordance with the Australian Charities and Not-for-profits Commission Act 2012 and complies with the Australian Accounting Standards – Reduced Disclosure Requirement and the Australian Charities and Not-for-profits Commission Regulation 2013.

Their opinion further states that:

- the financial statements as at 30 June 2016 gives a true and fair view of the Company's financial position as at that date and of its performance for the year ended on that date;
- contributions both cash and in-kind have been made and recorded in accordance with the budget as specified in accordance with the terms of the Commonwealth Agreement;
- the Commonwealth funding and the contributions have been expended solely for the Activities and in accordance with the Commonwealth Agreement and Australian accounting concepts and applicable Australian standards; and
- all transactions for the Activities as specified in Commonwealth Agreement have been conducted through the Account.

Appendices

Appendix 1: Publications

Postnova S, Lockley SW, Robinson PA 2016 Sleep propensity under forced desynchrony in a model of arousal state dynamics. J Biol Rhythms. pii: 0748730416658806. [Epub ahead of print] http://www.ncbi.nlm.nih.gov/pubmed/27432116.

Dodds, KL, Miller, CB, Kyle, SD, Marshall, NS and Gordon, CJ, 2016. Heart rate variability in insomnia patients: a critical review of the literature. *Sleep Medicine Reviews.*
DOI: http://dx.doi.org/10.1016/j.smrv.2016.06.004.

Dodds, K.L., Marshall, N., Miller, Kim, J-W., C.B., Bartlett, D.J., Grunstein, R.R., Gordon, C.J. (October, 2015). Heart Rate Variability in Insomnia Patients: A Preliminary Analysis, *Sleep and Biological Rhythms*, Vol. 13, Issue S1, p. 85.

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Papers in refereed conference proceedings

Miller, C.B., Bartlett, D.J., Mullins, A.E., Dodds, K.L., Gordon, C.J, Kyle, S.D., Kim, J.W., D'Rozario, A.L., Lee, R.S.C., Marshall, N., Yee, B.J., Espie, C.A., Grunstein, R.R. (June, 2016). Phenotypes of Insomnia Disorder built from cluster analysis of objective sleep parameters reveal differences in neurocognitive functioning, quantitative EEG and heart rate variability. 30th Anniversary Meeting of the Associated Professional Sleep Societies, Denver, U.S.A. *SLEEP*, Vol. 39, Abstract Supplement, p. A196.

Papers presented at conferences

Rajaratnam, S. Sleep and Health Research to Practice Conference, 14–16 April 2016, Melbourne, VIC Australia.

Sletten, T. Sleep loss and performance: the physiological and cognitive implications Research to Practice Conference, 14–16 April 2016, Melbourne, VIC Australia.

Other invited presentations

International Council on Mining & Metals (ICMM) Health and Safety Forum, October 8–9 2015, London – Presentation by Dr Andrew Tucker, General Manager Research Translation Partnerships, Alertness CRC, Title: 'Alertness CRC 'Safety & productivity improvements in high-risk occupational settings: Opportunities through collaboration'.

The Institute for Safety, Compensation and Recovery Research (ISCRR) Research Forum, IICSOT: "If I Could Say One Thing" Seminar Series, Wednesday 25 November 2015, Melbourne – Presentation by Dr Andrew Tucker, General Manager Research Translation Partnerships, Alertness CRC, Title: 'Alertness, safety & productivity in the workplace: The importance of sleep'.

National Sleep Foundation, Sleep Health and Safety Conference, November 2015, Washington – Presentation by Professor Shantha Rajaratnam, Alertness CRC, Title: 'Collaboration Models and the Alertness CRC'. This presentation was designed to allow attendees to gain knowledge on the impacts of circadian rhythm misalignment on health, safety and performance outcomes; appreciate the diverse government, university and industry stakeholders required to significantly impact the field of alertness management; and be informed about the Alertness CRC and its primary outputs.

Australian Army 2nd Commando Regiment Transformation Day, Thursday 24 March 2016. Holsworthy Barracks in Sydney – Invited by Defence Science and Technology Group to present to select senior and operational members of Army and Special Operations Command (SOCOMD). The purpose of the Transformation day was to focus on methods and means of enhancing the human (cognitive and psychological) and technological aspects of decision-making, decision support, and decision pathways relevant to 2nd Commando Regiment core roles, missions and tasks. – Presentation by Dr Andrew Tucker, General Manager Research Translation Partnerships, Alertness CRC, Title: 'Managing alertness and performance in operational settings'.

30th Annual Meeting of the Association of Professional Sleep Societies, June, 2016, Denver USA – Presentation by Professor Shantha Rajaratnam, Alertness CRC, Title: 'Circadian phase: Developing practical tools through collaboration with government, industry and universities'. This presentation was designed to allow attendees to gain knowledge on the impacts of circadian rhythm misalignment on health, safety and performance outcomes; appreciate the diverse government, university and industry stakeholders required to significantly impact the field of alertness management; and be informed about the Alertness CRC and its primary outputs.

Appendices

Appendix 2: Education

Table 6: Post-Doctoral Fellows 2015–16

Name	Research Project (Program No.#)	Research Organisation
Andrew Vakulin	Sleep disorder phenotyping (RP3)	Flinders University
Angela D'Rozario	Sleep disorder phenotyping (RP3)	Woolcock Institute Of Medical Research
Angus Wallace	Device Development (RP1, RP2 & RP3)	Flinders University
Ben Fulcher	Laboratory (RP1)	Monash University
Bradley Edwards	Sleep disorder phenotyping (RP3)	Monash University
Bryn Jeffries	Database Development (RP3)	The University of Sydney
Christopher Gordon	Sleep disorder phenotyping (RP3)	The University of Sydney/ Woolcock Institute of Medical Research
Christopher Miller	Sleep disorder phenotyping (RP3)	Woolcock Institute Of Medical Research
David Stevens	Sleep disorder phenotyping (RP3)	Flinders University
Emily Andersons	Device Development (RP1, RP2 & RP3)	Flinders University
Gleb Belov	Group Work Scheduling (RP2)	Monash University
Jennifer Cori	Healthcare (RP2) & Sleep disorder phenotyping (RP3)	Institute for Breathing and Sleep
Jong Won Kim	Modelling and Data Fusion (RP1)	The University of Sydney/ Woolcock Institute of Medical Research
Maria Comas	Sleep disorder phenotyping (RP3)	Woolcock Institute Of Medical Research
Michelle Magee	Healthcare (RP2)	Monash University
Nicole Lovato	Sleep disorder phenotyping (RP3)	Flinders University
Pasquale Alvaro	Healthcare (RP2)	Institute for Breathing and Sleep
Peter Catcheside	Sleep disorder phenotyping (RP3)	Flinders University
Romesh Abeysuriya	Modelling and Data Fusion (RP1)	The University of Sydney
Shane Landry	Sleep disorder phenotyping (RP3)	Monash University

Name	Research Project (Program No.#)	Research Organisation
Simon Joosten	Laboratory (RP1) & Sleep disorder phenotyping (RP3)	Monash University
Suzanne Ftouni	Laboratory (RP1)	Monash University
Svetlana Postnova	Modelling and Data Fusion (RP2)	The University of Sydney
Tracey Sletten	Healthcare (RP2)	Monash University

denotes:

Research Program 1 (RP1) – Alertness Measurement, Prediction and Testing

Research Program 2 (RP2) – Safety and Productivity Improvements

Research Program 3 (RP3) – Sleep Health

Table 7: PhD Degree Scholarships 2015–16

Name	Date commenced	Research Project Program Number	Project Title	Research Organisation	Expected Completion Date
Amal Osman	14-Jul-15	Sleep Disorder Phenotyping Platform (RP3)	Development of a simple clinical technique to quantify upper airway collapsibility	Neuroscience Research Australia (NEURA)/ UNSW	13-Jul-18
Anna Mullins	22-Jan-15	Sleep Disorder Phenotyping Platform (RP3)	Quantitative Analysis of Polysomnograph: from sleep macrostructure to microstructure	The University of Sydney	21-Jan-18
Charmaine Diep	22-Feb-16	Laboratory Platform (RP1)	The impact of sleep deprivation, circadian misalignment and sleep augmentation on cognitive and physiological outcomes	Monash University	21-Feb-19
Devaang Kevat	22-Jan-15	Healthcare Platform (RP2)	Examining worker safety and productivity in the healthcare setting	Monash University	21-Jan-16
Haidar Naqvi	1-Sep-14	Sleep Disorder Phenotyping Platform (RP3)	Neuro-behavioural effects of sleep loss in patients with obstructive sleep apnoea	Woolcock Institute of Medical Research	31-Aug-17

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Name	Date commenced	Research Project Program Number	Project Title	Research Organisation	Expected Completion Date
Jade Murray	1-Feb-14	Healthcare Platform (RP2)	Investigating circadian misalignment in a population of patients with symptoms of delayed sleep phase disorder	Monash University	31-Jan-17
Julia Stone	2-Mar-15	Healthcare Platform (RP1)	Assessing Individual vulnerability to shift Work and integrated interventions for alertness management in the healthcare setting	Monash University	1-Mar-18
Kelsey Bickley	1-Feb-15	Sleep Disorder Phenotyping Platform (RP3)	To perform a comprehensive investigation of daytime functioning in individuals with insomnia across a range of insomnia subtypes	Flinders University	31-Jan-18
Lauren Booker	21-Dec-15	Sleep Disorder Phenotyping Platform (RP3) & Healthcare Platform (RP2)	Impact of Insomnia, Shift work and OSA management on individual outcomes in healthcare shift workers	Monash University	20-Dec-18
Leilah Grant	1-Feb-14	Laboratory Platform (RP1)	Identification and validation of biological and physiological biomarkers of the alertness state	Monash University	9-Feb-17
Marie Jinny Collett	27-Jan-16	Laboratory Platform (RP1)	Specific vulnerability of attention mechanisms due to sleep loss, circadian misalignment and age	Monash University	26-Jan-19
Megan Mulhall	1-Mar-16	Healthcare Platform (RP2)	Monitoring Alertness and Driving Performance during Work Commutes	Monash University	1 Mar-19
MS Zobaer	1-May-15	Modelling and Data Fusion (RP1)	Quantitative Modelling of the Effects of Light Spectrum On Circadian Phase	The University of Sydney	30-Apr-18
Rohit Philip	1-Feb-15	Sleep Disorder Phenotyping Platform (RP3)	Vulnerability to alertness failure phenotyping	Flinders University	31-Jan-18
Sachin-kumar Nilkantha Wasnik	1-Sep-14	Sleep Disorder Phenotyping Platform (RP3) & Modelling and Data Fusion (RP2)	Modelling/data fusion and phenotyping projects with potential value in biomarkers and healthcare	The University of Sydney	31-Aug-17

Name	Date commenced	Research Project Program Number	Project Title	Research Organisation	Expected Completion Date
Saranea G	22-Jan-15	Healthcare Platform (RP2)	Cognitive markers of shift work vulnerability	Monash University	21-Jan-18
Simon Joosten	1-Sep-14	Sleep Disorder Phenotyping Platform (RP3)	Test a simplified method for sub-classifying OSA patients into their underlying causal phenotype	Monash University	31-Aug-15
William McMahon	1-May-15	Laboratory Platform (RP1)	Predicting individual vulnerability to alertness challenges following sleep deprivation	Monash University	30-Apr-18

denotes:

Research Program 1 (RP1) – Alertness Measurement, Prediction and Testing

Research Program 2 (RP2) – Safety and Productivity Improvements

Research Program 3 (RP3) – Sleep Health

Table 8: Master Degree Scholarships 2015–16

Name	Date Commenced	Research Project (Program No.#)	Project Title	Research Organisation	Expected Completion Date
Helenmary McMeekan	22-Jan-15	Sleep Disorder Phenotyping Platform (RP3)	Individual-level Toolkit for Sleep Health Management in Occupational Settings	Flinders University	Withdrew in Mar-16
Kirsty Dodds	22-Jan-15	Sleep Disorder Phenotyping Platform (RP3)	Cardiovascular markers of autonomic dysregulation in Insomnia Disorder	The University of Sydney	21-Jan-17

denotes:

Research Program 1 (RP1) – Alertness Measurement, Prediction and Testing

Research Program 2 (RP2) – Safety and Productivity Improvements

Research Program 3 (RP3) – Sleep Health

Appendices

Table 9: Short term project funding 2015–16

Name	Date commenced	Research Program	Project Title	Research Organisation	Completion Date
Baptiste Jolivet	11-May-15	Modelling and Data Fusion (RP1)	Stretched exponential functions in modelling the effects of chronic sleep restriction on alertness	The University of Sydney	17-Aug-15
Gunther Klobe	16-Nov-15	Modelling and Data Fusion (RP1)	Mechanisms of the variability in the phase angle between DLMO and sleep onset	The University of Sydney	15-Mar-16
Merijn Driessen	10-Jan-16	Modelling and Data Fusion (RP1)	Modelling effects of sleep inertia on alertness in a quantitative model of sleep-wake cycles	The University of Sydney	9-Jul-16
Stephen McCloskey	13-Jan-15	Modelling and Data Fusion (RP1)	Incorporation of the direct alerting effects of white light in the physiologically based model of sleep-wake cycle developed at The University of Sydney	The University of Sydney	24-Feb-15
Thibaut Lacroix	11-May-15	Modelling and Data Fusion (RP1)	Modelling the effects of prophylactic naps on alertness and sleep	The University of Sydney	10-Aug-15

denotes:
Research Program 1 (RP1) – Alertness Measurement, Prediction and Testing
Research Program 2 (RP2) – Safety and Productivity Improvements
Research Program 3 (RP3) – Sleep Health

Table 10: Industry Based Learning scholarships 2015–16

Name	Date Commenced	Research Project (Program No.#)	Research Organisation	Expected Completion Date
Aaron Johnson	27-Jan-15	Healthcare (RP2)	Swinburne University	26-Jan-16
Adrienne Bell	27-Jan-15	Laboratory (RP1)	Swinburne University	26-Jan-16
David Litewka	27-Jan-16	Laboratory (RP1)	Swinburne University	26-Jan-17
Elly Spiteri	27-Jan-16	Laboratory (RP1)	Swinburne University	26-Jan-17
Jessica Papleo	27-Jan-15	Healthcare (RP2)	Swinburne University	26-Jan-16
Kaitlyn Crocker	27-Jan-16	Healthcare (RP2)	Swinburne University	26-Jan-17
Matthew McLaren	27-Jan-15	Healthcare (RP2)	Swinburne University	26-Jan-16
Michelle Bravo	27-Jan-15	Laboratory (RP1)	Swinburne University	26-Jan-16
Niamh McDonald	27-Jan-16	Healthcare (RP2)	Swinburne University	26-Jan-17
Phaybian Penita	27-Jan-16	Laboratory (RP1)	Swinburne University	26-Jan-17
Todd Pickering	27-Jan-15	Laboratory (RP1)	Swinburne University	26-Jan-16

denotes:
Research Program 1 (RP1) – Alertness Measurement, Prediction and Testing
Research Program 2 (RP2) – Safety and Productivity Improvements
Research Program 3 (RP3) – Sleep Health

Appendices

Glossary of Terms

Actigraphy – provides measurement of the motion associated with rest and activity. In the case of sleep studies, a watch-like device is attached to the wrist.

Biomarker – short for biological marker, it is a characteristic that is objectively measured and evaluated as an indicator of normal biological processes, disease or the effect of an intervention.

Chemiresistor – a material that changes its electrical resistance in response to changes in the nearby chemical environment.

Circadian rhythms – are physical, mental and behavioural changes that follow a roughly 24-hour cycle, responding primarily to light and darkness in an organism's environment. They are found in most living things including animals and plants.

CPAP – Continuous Positive Airways Pressure Treatment for sleep apnea to keep the airways open.

EEG – An electroencephalogram (EEG) is a test that detects electrical activity in your brain using small, flat metal discs (electrodes) attached to your scalp. Your brain cells communicate via electrical impulses and are active all the time including during sleep.

Electrophysiological – the production of electrical phenomena, particularly in the nervous system, and their consequences in the living organism.

Melatonin – a hormone naturally secreted with the onset of fading natural light which helps tune the circadian rhythm as it moves in to a sleep cycle.

Metabolomics –the non-targeted detection and quantification of small molecules (metabolites) in biological materials (e.g. plasma, urine, tissue, plant and microbial extracts).

Nanoparticle – a particle between 1 and 100 nanometres in size.

Obstructive sleep apnea (OSA) – when the airway at the back of the mouth is repeatedly partly or completely blocked during sleep reducing or stopping breathing altogether. When oxygen levels fall, the sleeper wakes up briefly and starts breathing again.

Phenotype – the observable characteristics of a person in the context of specific trait, behaviour or susceptibility to a certain condition.

Proteomics – the study of proteins.