2007 Annual Report

ARC Centre of Excellence in Vision Science

VISION SCIENCE
ARC CENTRE OF EXCELLENCE

Australian Government
Australian Research Council

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2007 Annual Report

ARC Centre of Excellence in Vision Science

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1 Foreword from the Research Director

The Centre's second year

The ARC Centre of Excellence in Vision Science commenced operation in January 2006, and has thrived during its second year of research activities. The original group of 16 Chief investigators, 11 Partner investigators, and 18 Associate investigators who successfully applied for the ARC grant and who initiated the Centre in 2006 have now been joined by 13 postdoctoral and research fellows together with 25 PhD students and 5 Research assistants undertaking research for the Centre, after just two years of operation. During the year we appointed two Centre Fellows, one of whom commenced her post during 2007, and the other of whom starts in January 2008.

As a Centre, we were closely involved with seven scientific meetings during the year. In February, we held a very successful and enjoyable Centre Retreat (at Murramarang, on the NSW coast) where our members were able to combine research presentations with discussions about future collaborations, in very pleasant surroundings. Our Centre was a major sponsor of the Vision Down Under 2007 conference in Cairns in July, which brought together 240 Australian and overseas vision scientists, and where over 40 of our researchers presented their findings. We also sponsored a symposium (chaired by Professors Vaney and Srinivasan) at the IBRO World Congress of Neuroscience in Melbourne in July. In September the younger members of our Centre ran a Young Visionaries Retreat at the ANU's Kioloa campus, and universally declared the event a great success. In December our members were the driving force behind both the annual Australian Ophthalmic and Vision Science meeting, held at the ANU's John Curtin School of Medical Research, and the inaugural meeting of ACCORD, the Australasian Consortium for the Care of Retinal Dystrophies, held at the ANU's Research School of Biological Sciences. In April, the Centre supported the Australasian Society for the Study of Animal Behaviour Conference which was organised by Dr Jochen Zeil (Chief Investigator).

A significant development during 2007 was the relocation of Professor Mandyam Srinivasan from our ANU node to our University of Queensland node. This relocation has strengthened the robotics side of our research through the increased infrastructure support for this work provided at UQ.

During the year, two of our Chief Investigators have received notable appointments or awards. Professor Vaney was elected President of the Australian Neuroscience Society for 2008–2009, and Professor Mandyam Srinivasan was awarded the prestigious Smart State Premier's Fellowship.

Our outreach activities for 2007 included a joint venture with Questacon to set up an interactive display on visual illusions. The opening of that display at Questacon was accompanied by a public lecture from Professor Srinivasan, and we have arranged to continue this initiative with a series of lectures in the future.

ARC Centre of Excellence in Vision Science

Reports on the Centre's research projects are presented in section 3 (beginning on page 9), arranged according to our three Research Themes: '1. Vision for Living – Eye and Brain', '2. Vision for Action and Robotics', and '3. Vision for Life – The Challenge of Degenerative Diseases'.

In addition to those projects, that have been directly funded by our ARC Centre of Excellence grant, we have been very actively engaged in leveraging additional funding, and in extending Australia's research in vision science through new initiatives that have been made possible only through the existence of our Centre. These initiatives are reported upon in section 5 (beginning on page 57).

During 2007, Centre researchers published 43 peer-reviewed papers on Centre research. Of these, 23 were in journals with impact factors above 2.5, and we had 4 publications in journals with impact factors above 10. The Centre's performance, in terms of KPMs (Key Performance Measures) is set out in section 12, and I am delighted with our achievements during 2007.

Professor Trevor Lamb
Research Director
December 2007

Prof Srinivasan receiving Smart State Premier's Fellowship Award

2 About the Centre

Introduction

The Centre is a collaborative research venture between four Australian universities, and is funded under the Australian Research Council's Centres of Excellence program, with a grant of $11m over five years. The four participating universities, which each form a Research Node, are:

- The Australian National University (ANU)
- The University of Western Australia (UWA)
- The University of Queensland (UQ)
- The University of Sydney (USyd).

The Centre also has formal links, both nationally and internationally, with thirteen other academic and commercial partners including:

- University of L'Aquila, Italy
- University of Bielefeld, Germany
- Swiss Federal Institute of Technology, Switzerland
- Smith-Kettlewell Eye Research Institute, USA
- Emory University, USA
- Centre for Information Science, Kokushikan University, Japan
- Helsinki University of Technology, Finland
- Royal Holloway, University of London, UK
- CSIRO – ICT Centre, Australia
- Seeing Machines Pty Ltd, Australia
- ObjectiVision, Australia
- Advanced Ocular Systems, Australia
- The Canberra Hospital.

Across the nodes there are currently 16 Chief Investigators (11 at ANU, two at UWA, two at UQ, and one at USyd). The ANU node is the administering institution and spans three separate Schools, the John Curtin School of Medical Research (JCSMR, one Chief Investigator), the Research School of Biological Sciences (RSBS, 9 Chief Investigators), and the Department of Psychology in the Faculty of Science (Psychology, one Chief Investigator).

Vision

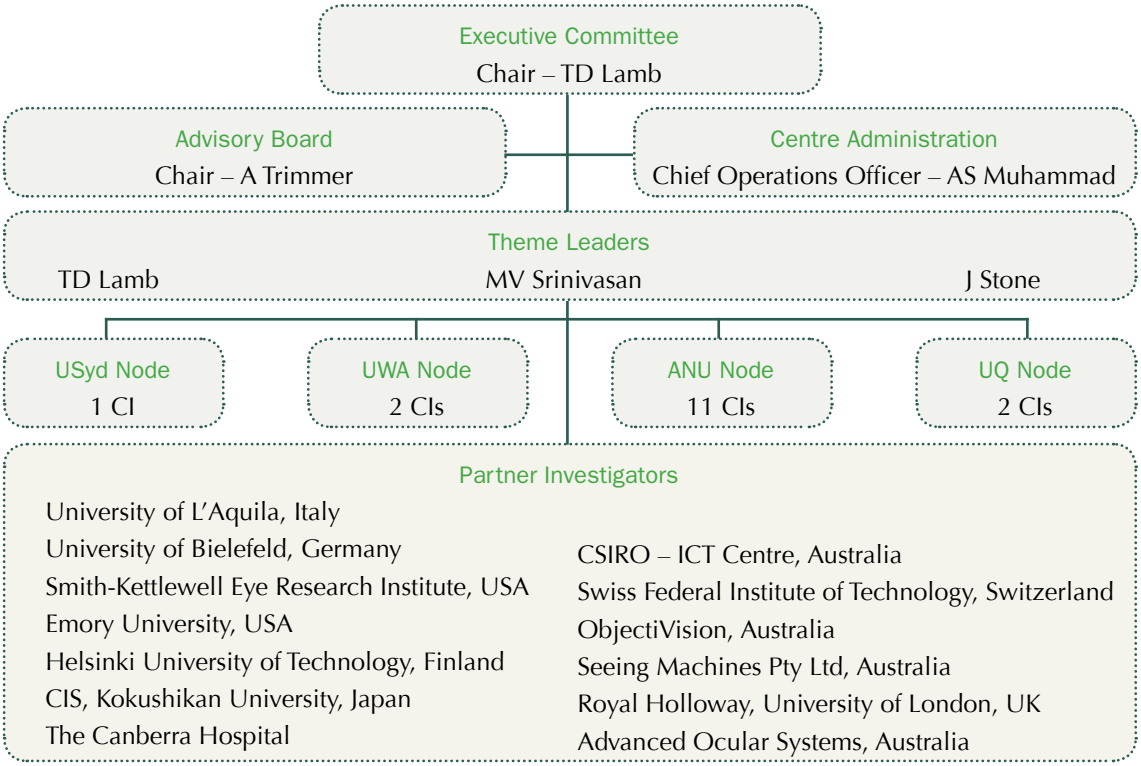
Vision is our most highly developed sense, enabling us to code the detail and the expanse, the colour and the shadow, and the shape and movement, of the world around us. Correspondingly, it dominates large regions of the brain. Vision is the platform for a wide range of behaviours, from hunting to reading and face recognition, and it is hardly surprising, then, that developments in robotics rely largely on advances in our understanding of the principles of visual processing in animals and humans. Because of its central role in human behaviour, loss of vision can be devastating – and this is becoming increasingly common as the population ages. Despite its relatively small population, Australia is fortunate in having an unusually strong and diverse pool of vision researchers. The ARC Centre of Excellence in Vision Science is assembling and focussing this talent, so as to pursue research in three related themes:

- Theme 1: Vision for Living – Eye and Brain
- Theme 2: Vision for Action and Robotics
- Theme 3: Vision for Life – The Challenge of Degenerative Diseases

Projects in Theme 1 are analysing the way that photoreceptors establish their exceptional sensitivity and speed, and their rapid adaptation to the ever-changing light environment, and are examining how the retina and brain process the information captured by the photoreceptors. Projects in Theme 2 are addressing such issues as the visual control of flight, and how nerve cells code and process complex visual information, so that visual input can control complex behaviour. Projects in Theme 3 are exploring the cell biology of the eye, to identify how the retina and eye develop and remain stable throughout adulthood and why, in a range of diseases, their growth is abnormal or their stability fails, leading to disease (e.g. macular degeneration, retinitis pigmentosa, pathological myopia). Each theme is internally coherent, and a number of projects involve scientists from two or three themes, collaborating in cross-disciplinary ways to generate unique outcomes.

Governance

The governance structure of the Centre is shown below.



The Centre's Governance Structure

The governing body of the Centre is the Executive Committee. This body meets regularly, to discuss overall Centre-related issues, to oversee the operations of the Centre, to review the Centre's performance, and to make decisions on financial matters including allocation of funds. The Research Director of the Centre chairs the Executive Committee. Membership of the Executive Committee is given in Table 1.

NAME	TITLE	AFFILIATION
Professor Trevor Lamb FRS FAA (Chair)	Research Director	ANU
Professor Jonathan Stone FAA	Theme Leader	ANU
Dr Michael Ibbotson	Chief Investigator	ANU
Mr Adnan Syed Muhammad	Chief Operations Officer	ANU
Professor Mandyam Srinivasan FRS FAA	Theme Leader	UQ
Professor David Vaney	Chief Investigator	UQ
Professor Dao-Yi Yu	Chief Investigator	UWA
Professor Bogdan Dreher	Chief Investigator	USyd

TABLE 1 – EXECUTIVE COMMITTEE MEMBERSHIP

ARC Centre of Excellence in Vision Science

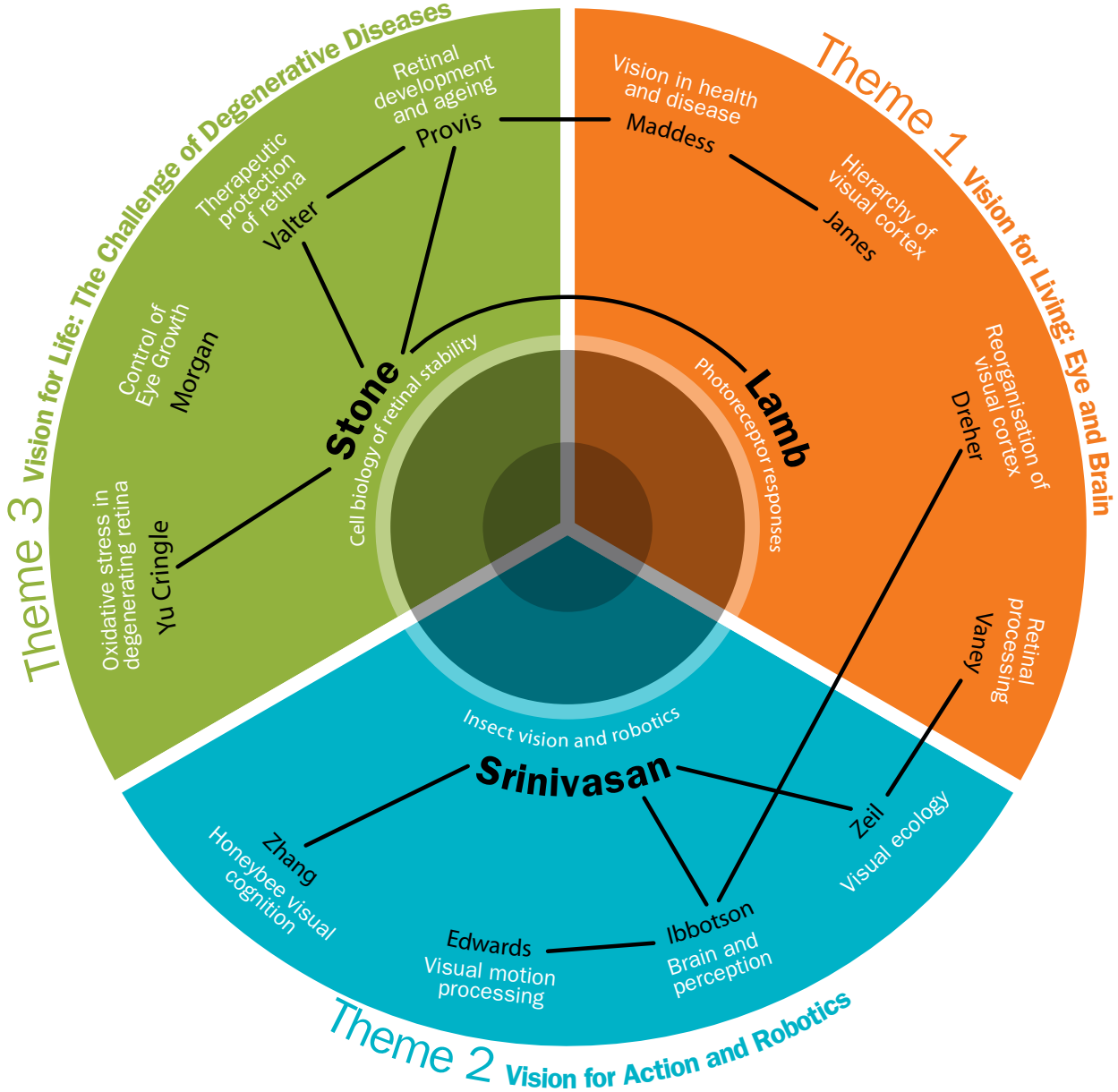
The Executive Committee receives advice from an Advisory Board on strategic issues. The Advisory Board meets at least annually to assess the progress of the Centre against its Key Performance Measures and to assist in developing future strategies. The membership of the Advisory Board is set out below.

NAME	AFFILIATION
Ms Anne Trimmer (Chair)	CEO, Medical Technology Association of Australia, Deputy Chancellor of the University of Canberra, Chairman of the Commonwealth Government's Advisory Council on Intellectual Property
Professor Michael Arbib	Fletcher Jones Professor of Computer Science, Biology and Biomedical Engineering, University of Southern California, USA
Emeritus Professor John Ross	Emeritus Professor of Psychology, University of Western Australia
Professor Peter McCluskey	Head, Department of Ophthalmology, Royal Prince Alfred Hospital
Professor Hugh Taylor AC	Director, Centre for Eye Research Australia; Head, Department of Ophthalmology, University of Melbourne
Professor Paul Martin	Director of Research, National Vision Research Institute, University of Melbourne
Dr Arthur Ho	Program Director, CRC for Vision, University of New South Wales
Dr Philip Penfold	Scientific Director, Eye Co Ltd
Ms Robyn Wright	President, Retina Australia (until 28 Aug 2007)
Professor Trevor Lamb	Research Director, ACEVS, ANU
Professor Mandyam Srinivasan	Theme Leader, ACEVS, UQ
Professor Jonathan Stone	Theme Leader, ACEVS, ANU
Professor Lawrence Cram	Deputy Vice-Chancellor, ANU

Meeting of the Advisory Board, February 2007

(L-R: standing) Mandyam Srinivasan, John Ross, Michael Arbib, Adnan Muhammad, Trevor Lamb, Hugh Taylor, Arthur Ho, Jonathan Stone
(L-R: Sitting) Robyn Wright, Anne Trimmer, Paul Martin, Peter McCluskey

Research Structure and Collaborations within the Centre



3 Research reports

The Centre's goals are:

1. to unravel the cellular basis of visual sensing and processing,
2. to reveal the algorithms that underlie the visual control of behaviour and perception, and
3. to discover the cellular mechanisms that make the eye and retina stable, and whose breakdown causes blindness.

Through our research we aim to achieve the following outcomes:

- Fundamental understanding of visual signalling and information processing.
- Breakthroughs in the detection, prevention, and treatment of visual impairment:
  - Detecting glaucoma and multiple sclerosis (MS)
  - Understanding, preventing, and treating retinitis pigmentosa (RP) and macular degeneration (AMD)
  - Preventing and treating myopia
- Novel strategies for machine vision and robotics.
- Collaborative synergies: bringing together major research teams in visual sciences.

The following pages present our reports on the Centre's research projects during 2007, arranged according to our three 'Themes'.

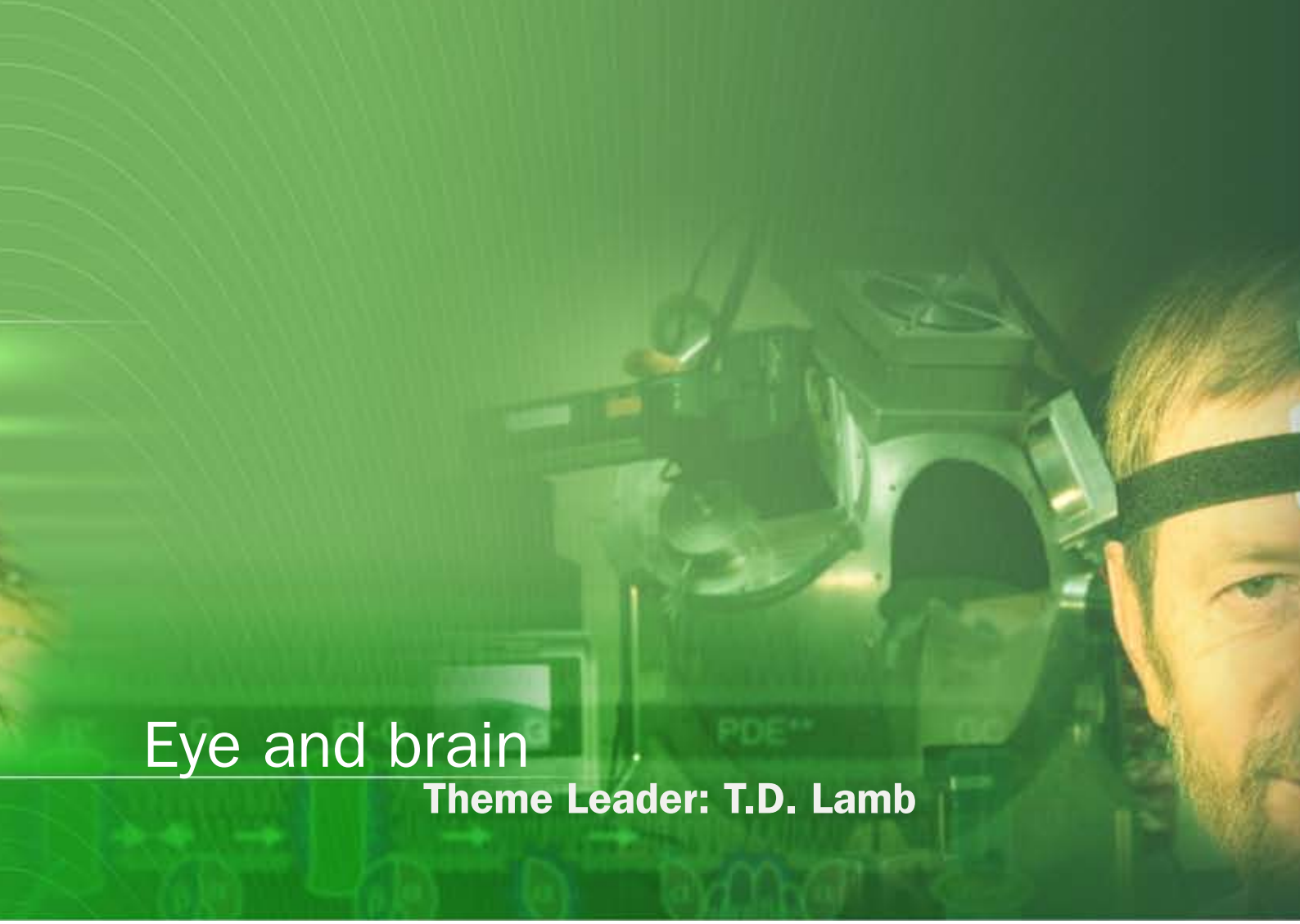
Informal gathering of Centre members

Theme 1
Vision for Living

Projects in Theme 1 are analysing the ways in which photoreceptors and other cells in the retina adapt to the ever-changing light environment, and the ways in which the retina and the brain process the information captured by the photoreceptors. Highlights of our research achievements include:

Photoreceptors and retinal processing

- Single-cell recordings from rod photoreceptors isolated from transgenic zebrafish have provided information about the shut-off steps involved in the light response.
- The responsiveness of rod bipolar cells in the living human eye has been monitored during the period of recovery following intense light exposures.
- The recovery of visual sensitivity of the overall human observer has been shown to be set at the level of the first synapse in the eye.
- The neural basis for the direction selectivity of retinal ganglion cells has been investigated.
- The anatomy of neurons conveying information outward from the brain to the retina has been mapped in the bird retina.



Eye and brain

Theme Leader: T.D. Lamb

Visual cortex and diagnostic technologies

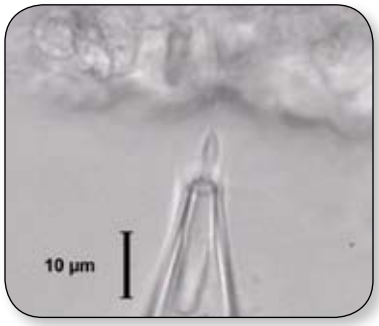
- Advances have been made in predicting retinal disease, using visual evoked potential recordings and pupillographic methods.
- Brain mechanisms underlying the discrimination of visual patterns and textures have been investigated.
- Advances have been made in the imaging and mapping of human visual cortex, using a combination of multifocal visual stimulation, functional MRI, and magneto-encephalography.
- The receptive-field arrangement, and the 'simple' versus 'complex' classification, of neurons in the visual cortex of the cat have been investigated, and classical concepts in the field have been overturned.
- The ability of the cat's visual cortex to rearrange its connectivity following damage has been investigated, and it has been found that considerable neuronal plasticity persists in the adult brain.

Trevor Lamb: Light adaptation and dark adaptation at the first stages of vision

Over the past year, our research has been aimed at determining the mechanisms of light adaptation and dark adaptation at the first stages of vision; i.e. at the level of the rod photoreceptors and the rod bipolar cells in the retina. We have used single-cell recording techniques with cells of wild-type mice and of transgenic zebrafish, and we have also investigated responses in the human retina by recording the electroretinogram (ERG).

Responses of individual rod photoreceptor cells

Two projects have been pursued by Fivos Vogalis using "suction pipette" electrodes to record the electrical responses of individual photoreceptor cells. The first project undertaken by Fivos has established the response properties of wild-type mouse rods over a very wide range of stimulus conditions. He has recorded responses to stimuli ranging from extremely dim flashes (delivering on average only about one photon) up to flashes delivering more than 1 million photons, and he has characterized the recovery phase over this range. The second project used transgenic zebrafish provided by colleagues in Japan, and has enabled Fivos to characterise the alteration in response properties in rods that exogenously express the shut-off protein (GRK7) normally expressed in cone photoreceptors. The responses of the rods of the transgenic animals are less sensitive and they display unusual kinetics in the late stages of recovery from bright flashes. These experiments are helping to explain the mechanisms by which rod photoreceptors recover from light, and are also helping to explain the differences between rods and cones.



Zebrafish rod in suction pipette

Dark adaptation of human rod bipolar cells

In an extension of recent research in the laboratory, Allison Cameron has examined changes in the kinetics of human rod bipolar cell responses during recovery from intense bleaching exposures. These experiments were prompted by our discovery of discrepancies in recovery during dark adaptation, from what would be expected on the classical hypothesis that the visual system experiences something equivalent to a fading light during post-bleach recovery. Allison has discovered consistent differences between the recovery of sensitivity and the recovery of response kinetics recorded from rod bipolar cells in the period of dark adaptation following exposure of the eye to very intense illumination. These experiments are indicating that measurements of response kinetics provide a good measure of the

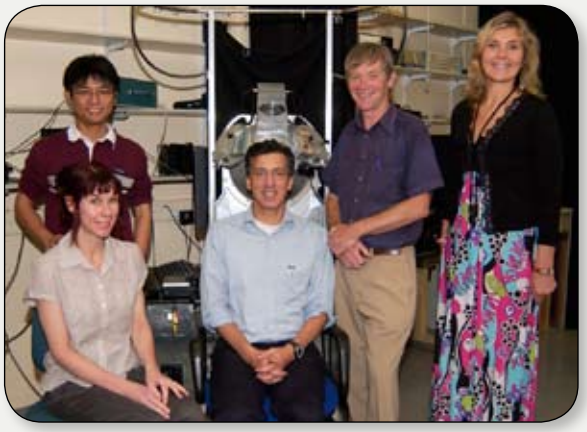
fading of "equivalent background", and that measurements of sensitivity may additionally be affected by other phenomena (such as a possible direct effect of bleach-released retinoid). Hence it appears that, in order to assess the recovery of the retina in the living human eye, it is not sufficient just to measure response sensitivity but it is additionally necessary to measure the time course of the response to light.

ERG signals being recorded from Allison's eye

Dark adaptation of the overall human visual system

Rasa Ruseckaite has been investigating the dark adaptation recovery of the same human subjects whose ERG recoveries have been measured by Allison. Bleaching exposures are delivered to the subject's eye in exactly the same apparatus as used for the ERG experiments, but the subject's psychophysical threshold is measured in a separate ganzfeld that is capable of presenting calibrated flashes at extremely low intensity (as required to measure the subject's absolute threshold). To validate the technique Rasa first measured visual thresholds at a range of stimulus durations and stimulus areas. She found that the time-course of post-bleach recovery was very similar for ganzfeld stimuli and for stimuli of small areas. The former are required in the ERG measurements but the latter are easier for a subject to use when estimating threshold. The recoveries of psychophysical threshold exhibit a very close relationship to the recoveries of rod bipolar cell responsiveness measured using the ERG b-wave. Thus, both sets of recovery exhibit an 'S2' phase of recovery, with a constant slope of log equivalent background against time, and the dependence of recovery time on bleach is very similar in the two cases. Therefore it seems that the phenomenon that determines the recovery of visual sensitivity for an intact human observer is present at the first synapse in the retina.

Prof Trevor Lamb (Chief Investigator)
Dr Allison Cameron (Postdoctoral Fellow)
Dr Rasa Ruseckaite (Postdoctoral Fellow)
Dr Fivos Vogalis (Research Fellow)



(L to R) Liang Miao, Allison Cameron, Trevor Lamb, Jaakko Jarvinen, Fivos Vogalis, and Rasa Ruseckaite

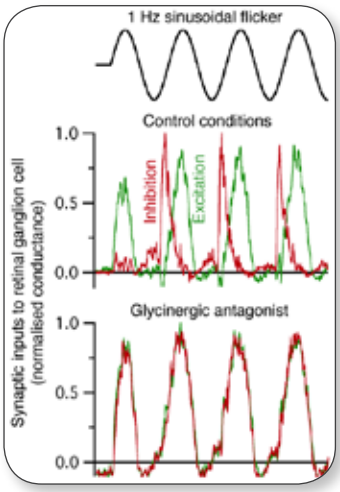
David Vaney: Information processing in the retina

David Vaney

Temporal dynamics of retinal ganglion cells

There are two types of direction-selective ganglion cells (DSGCs) in the retina. It is thought that the On-Off DSGC signals local image motion whereas the On DSGC signals global retinal slip. Correspondingly, the On DSGC has a larger receptive field and is narrowly tuned to slow image velocities, whereas the On-Off DSGC responds to a broad range of image velocities. Ben Sivyer, Rowland Taylor and David Vaney are investigating the synaptic mechanisms underlying the differences in speed tuning by recording the light-evoked excitatory and inhibitory currents in DSGCs of the rabbit retina.

The excitatory input is attenuated at fast speeds in the On DSGC whereas it remains unchanged in the On-Off DSGC. The On DSGC receives sustained excitatory and transient inhibitory inputs, and their relative timing shapes the temporal tuning of the spike responses. Pharmacological experiments revealed that a glycinergic circuit creates this temporal offset by sharpening the inhibitory input. The On-Off DSGC responds more transiently than the On DSGC because it receives both transient excitatory and sustained inhibitory inputs whose timing is opposite to that of the inputs to the On DSGC.



The results suggest that the transient bipolar cell providing the excitatory input to the On-Off DSGC may drive an amacrine cell that inhibits the On DSGC, whereas the sustained bipolar cell providing the excitatory input to the On DSGC may drive an amacrine cell that inhibits the On-Off DSGC. This simple circuit could underlie the speed-tuning differences between the two types of DSGCs.

Nitrergic neurons in the bird retina

Nitric oxide is a modulator of neuronal function in the retina and other parts of the CNS. Anatomical studies by Martin Wilson, Nathan Hart and Nicholas Nacsa have shown that the nitrergic neurons in the bird retina have a striking regional distribution.

In the dorsal chick retina, the ganglion cell layer contains a population of heavily stained cell bodies that are regularly distributed whereas, in the ventral retina, these cells are more lightly stained. The efferent fibres, together with their large presynaptic swellings and postsynaptic target amacrine cells (TACs), were strongly stained in the ventral retina but were absent elsewhere. Also restricted to the ventral retina is an amacrine cell whose large cell body is located at the margin of the inner plexiform and inner nuclear layers. This unusual cell type has thick primary dendrites that ramify near the edge

of the plexiform layer. In addition to spine-bearing dendrites, these neurons give rise to much thinner intra-retinal axons that branch several times. It is not clear why these neurons should be restricted to the ventral retina but their distribution is not exactly identical to that of the TACs.

Photoreceptors: Chromatic and spatial sensitivity

Although Misha Vorobyev has been based at the University of Queensland, half of his salary was jointly funded by the ANU and UQ nodes of ACEVS in 2006 and 2007. Misha and his PhD student Leigh Fischer used computational methods to investigate the role of waveguide effects in shaping the spectral sensitivity of human cones, and this has provided better agreement with psychophysical data than previous estimates based on geometric optics. Currently they are extending this modelling to the optics of fiddler crab compound eyes, using anatomical data obtained by Jochen Zeil's laboratory.

Further insights into colour coding in the primate retina have been provided by an analytical investigation of how the pattern of input from red and green cones to the surround of midget ganglion cells shapes the receptive-field properties. The findings from this study showed that the sensitivity to chromatic gratings would be improved significantly by non-random connections of the cones.

Understanding the roles of different types of cones in vision is powerfully informed by comparative studies on different vertebrates. Misha Vorobyev and ARC Postdoctoral Fellow Uli Siebeck have used behavioural methods to show that high-resolution vision in damsel reef fish is mediated only by long-wavelength cones and not by short-wavelength cones, analogous to the situation in the human retina.

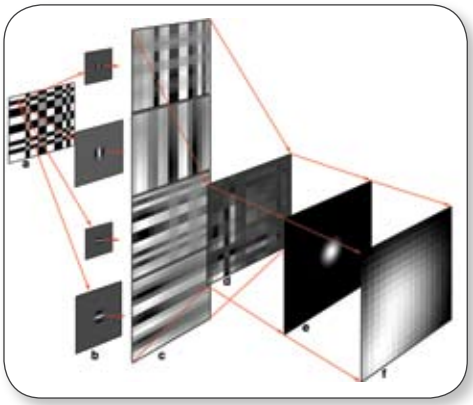
Misha Vorobyev will leave UQ in early 2008 to take up a position at the University of Auckland. Uli Siebeck will take Misha's place in the UQ Node and this will provide the opportunity to further strengthen the links with the other visual neuroethologists in the ANU Node.

Back row (L to R) Refik Kanjhan, Benjamin Sivyer
Middle rom (L to R) Misha Vorobyev, David Vaney, Nicholas Nacsa
Front row (L to R) Rowland Taylor, Ulrike Siebert

Prof David Vaney (Chief Investigator)
Prof Martin Wilson (Visiting Fellow)
Dr Misha Vorobyev (Associate Investigator)
Mr Nicholas Nacsa (Research Assistant)
Mr Benjamin Sivyer (PhD student)
Dr Ulrike Siebert (Research Fellow from 2008)

Ted Maddess: Applications of multifocal methods to vision in disease and health

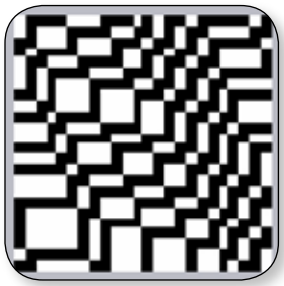
Predicting AMD and glaucoma using multifocal VEPs and pupillography



Our PDF, Dr Suzanne Petratchkov, completed a study of AMD and normal subjects using multifocal VEPs and pupillography. The analysis of the mfVEP data shows an intriguing capacity to predict disease in the supposedly normal fellow eyes of AMD patients. Dr Petratchkov moved to an NHMRC funded position to do similar research into multiple sclerosis in August 2007.

In related projects Corinne Carle investigated the sensitivity and specificity for glaucoma of multifocal pupillographic stimuli that had 40 stimulus regions per eye rather than the 24 we had used previously. The new higher resolution stimuli provided sensitivity and specificity for glaucoma around 90% for a test with 4 minutes recording time to assess both eyes concurrently. The study was predicated on an earlier one by Therese Jo and Yikwen Lo who investigated stimuli with 40 or 60 regions in normal subjects. Our Research officer, and now MPhil student, Maria Kolic, completed several studies funded by Seeing Machines.

Texture vision



Our work on texture vision continued on three fronts. With Prof. Yoshinori Nagai we examined small neural oscillator networks as biologically inspired texture discrimination systems. Our PhD student Ryan Taylor leads the second front where he examined the ability of various entropy measures to mimic human texture discrimination performance. Interestingly the entropy measures that performed most like humans were computed on all combinations of pixels in small horizontal domains within textures. The third element of this work is a developing project that has been progressed with NICTA on stochastic texture patterns. The work is progressing following the appointment of Dr Marconi Barbosa and a PhD student, Novi Quadrianto, to the project in the last few months.

With the approval of further funds for an eyetracking device we were able to purchase visual stimulus hardware for fMRI. That equipment has now been installed at the Canberra Hospital (TCH) and all the necessary ethical approvals have been obtained both with the ANU and ACT Health. A further delay was introduced by senior staff changes and building works at TCH.

ARC Centre of Excellence in Vision Science

A new Department of Ophthalmology at The Canberra Hospital was started following lobbying from ACEVS members. Rohan Essex and Kate Reid will run the new Department along with two new registrars, and after consultation with Dr Maddess regarding the purchase of mutually advantageous equipment they have donated a fundus camera to Dr Maddess.

Research activity plan for next 12 months

A multifocal project on diabetic retinopathy (DR) that was to be carried out by Dr Petratchkov is being done by Dr Andrew Bell. Dr Bell was appointed to the position for the duration of the PDF and he has made good progress. A new appointment to follow up on those projects will be made in 2008. Work with Seeing Machines on glaucoma will continue, providing benchmarks are met. A project with Antonio Robles-Kelly of NICTA on correlative multifocal functional testing of the visual field and multi-spectral retinal imaging has been expedited with the donation of a fundus camera by TCH, and will now likely go ahead with help from Andrew Bell. Work with NICTA looks like expanding as they are about to commit about $300k pa to the texture work. We will attempt multifocal experiments with texture stimuli and with additional RSBS support this will encompass limited clinical experiments of texture discrimination by persons with neurodegenerative diseases. Another project examining eye movements in response to texture stimuli will commence with Ryan Taylor and, assuming funds can be found, we will commence fMRI studies of texture vision in 2008.

Dr Ted Maddess (Chief Investigator)
Dr Andrew Bell (Postdoctoral Fellow)
Dr Suzanne Petratchkov (Postdoctoral Fellow)
Mr Ryan Taylor (PhD Student)
Ms Maria Kolic (Postgraduate Student)
Ms Corinne Carle (Honours Student)

Back row (L to R) Andrew Bell, Ted Maddess
Front row (L to R) Ryan Taylor, Suzanne Petratchkov, Corinne Carle, Maria Kolic

Andrew James: Multimodal-multifocal analysis of the hierarchy of human visual cortical areas

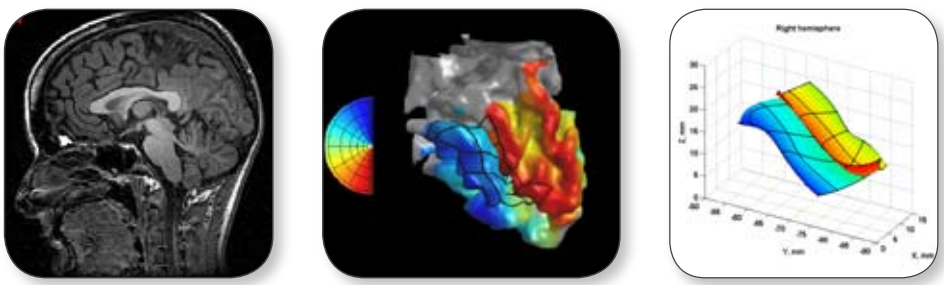
How does the human brain so rapidly and robustly create a generally reliable percept of a visual scene from the noisy and ambiguous signals that are transmitted from the eyes? The conception driving our research is that the visual cortex implements an inferential system, in which a hierarchy of cortical areas enables the fitting of lower level specific data with ongoing models of the external world.

To study the two-way flows of information within this hierarchy, we are seeking ways to reliably map evoked potentials and magnetic fields back to underlying cortical currents within multiple visual areas. This is done by deriving the geometry of visual field representations for each subject as maps on a folded cortical sheet in 3D using a multifocal fMRI mapping technique we have previously developed. These maps are then combined with sets of evoked potentials and magnetic fields derived from spatially matched multifocal stimulus designs, allowing decomposition into components generated by multiple visual areas. Due to the variation in the geometry of cortical areas between subjects, this form of analysis is necessarily done independently for each subject and the results will then be comparable at the level of cortical currents.

A spin-off of this research has been the development of increasingly powerful algorithms that are being applied to visual field mapping for the diagnosis of disorders of the visual system in a clinical setting.

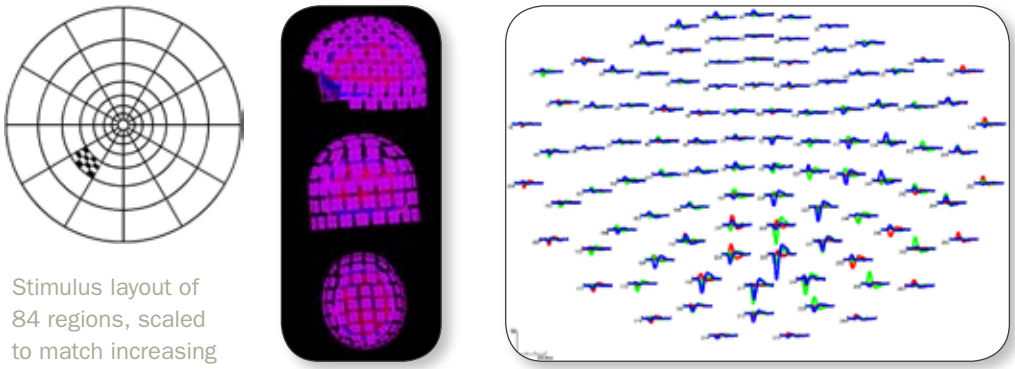
Imaging of human calcarine sulcus by multifocal functional MRI

The 3D geometry of retinotopic maps in the visual cortex of a human subject is typically derived by the laborious process of segmenting a high-resolution anatomical MRI scan to find the folded cortical sheet defined by the white-matter/grey-matter border, and then co-registering a lower resolution functional map of the visual field representation. We have developed a method that derives the visual field representation as a folded 3D surface within the cortex based solely on functional data from our previously developed multifocal fMRI mapping technique. This method produces estimates of location and direction of current dipoles that can be used for the decomposition of multifocal MEG/EEG responses, while eliminating the most time-consuming step of previous methods.



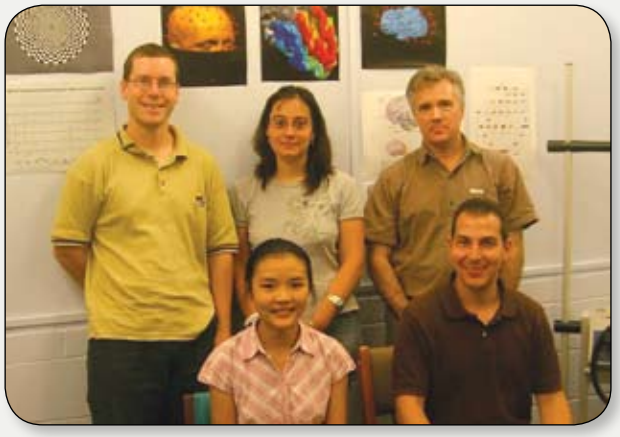
High-resolution anatomical scan (left). From this the 3D cortical surface of the occipital lobe can be derived (middle), and colour-coded with a map of left-visual field (right). Primary visual area V1 occurs in and around the calcarine sulcus. The location and shape of the mapping in 3D can now also be derived directly from the multifocal functional data

Pattern-pulse multifocal MEG mapping of human visual cortex using the general linear model



Stimulus layout of 84 regions, scaled to match increasing cortical magnification of central visual field (left). Layout of 102 sensor elements around the head, each recording three channels of response (middle). The three fitted waveforms at each of 102 sensor locations, estimating response to presentation at the single focal visual field location indicated (right). Such maps are obtained for each of the 84 stimulus regions, in four minutes of recording

The cortical responses to focal visual field stimulation have been mapped to unprecedented spatial resolution using a multifocal design with 84 cortically scaled stimulus regions. The magnetic fields generated by evoked currents within the cortical sheet were recorded with the 306 channel Neuromag magnetoencephalography (MEG) device at the site of partner investigator Simo Vanni at the Helsinki University of Technology. Decomposition of the compound response into elementary waveforms representing individual stimulus presentations was done with a novel method, fitting the general linear model with optimised temporal weighting. Waveforms are modelled as linear combinations of a set of empirically derived temporal basis functions and this allows channels with a strong response to define a filter that prevents weaker channels from being lost in noise.



Back row (L to R) Ben Doolan, Cecile Bordier, Andrew James
Front row (L to R) Xin-Lin Goh, Samuel Inverso

Dr Andrew James (Chief Investigator)
Dr Cecile Bordier (Postdoctoral Fellow)
Ms Xin-Lin Goh (PhD student)
Mr Samuel Inverso (PhD student)

Bogdan Dreher: Organization and reorganization of mammalian visual cortex

In 2007 we continued our research aimed at improving our understanding of the neuronal mechanisms underlying the receptive field organization of cells in the mammalian visual cortex (V1). As in the past, our approach consisted of recording (in anaesthetized mammals) and quantifying responses of single cortical neurons to visual stimuli. Apart from studying the receptive field properties of cells in the primary visual cortices of normal adult mammals, we continued to examine the effects of circumscribed retinal lesions in adolescent mammals on the reorganization of topographic representation of the retina in the primary visual cortex of adult mammals.

Contrast dependence of centre and surround integration in striate cortex of the cat

Receptive fields of all neurons in mammalian primary visual cortices have 'classical receptive fields' (CRFs). That is, the regions in visual space, stimulation of which with appropriate visual stimuli, result in generation of action potentials. In addition, most neurons in primary visual cortices contain 'silent' surround regions, stimulation of which per se do not result in generation of action potentials. Stimulation of silent surrounds however has strong (usually suppressive and orientation dependent) effects on the magnitude of responses to stimuli presented in the CRFs (Fig 1). We have found that when optimally oriented sine-wave drifting grating patches extended into distant, rather than proximal, parts of the silent surround regions, about 40% of V1 neurons exhibited a 'counter-suppression', that is, a reduction in the magnitude of suppression. Overall, the magnitude of suppression when the silent surround was stimulated tended to increase with increase in stimulus contrast, while the magnitude of counter-suppression tended to increase with decrease in stimulus contrast. Thus, the surround modulations that were unequivocally suppressive at high contrast were less suppressive or even facilitatory at low contrasts. This inverse relation between the contrast and the relative magnitudes of suppression and counter–suppression allow improvement of 'recognition' (high- contrasts) or 'detection' (low- contrasts) of visual objects in constantly changing visual conditions.

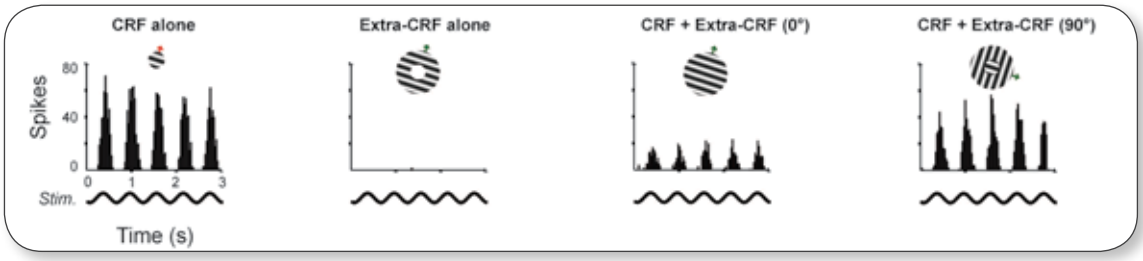


Figure 1. The peristimulus time histograms of spike responses of a simple neuron recorded from a cat's striate cortex. Typically, the magnitude of response to patches of gratings restricted to the CRF is reduced, in a stimulus orientation dependent manner, when patches extend into the silent suppressive surround

Reorganization of primary visual cortex following circumscribed monocular retinal lesions

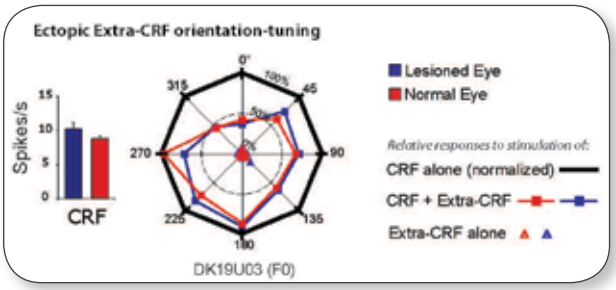
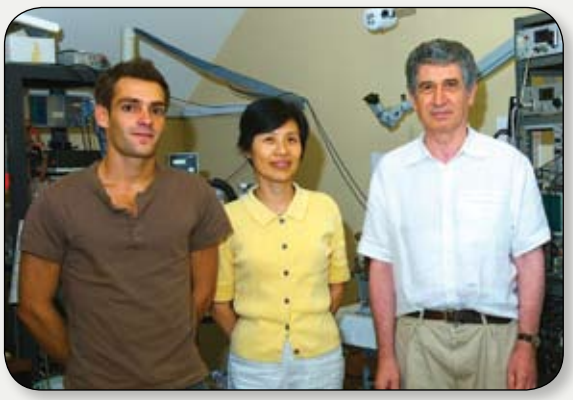


Figure 2. The relative strength and orientation tuning of silent suppressive surround of a typical cell recorded from the LPZ in the striate cortex of an adult cat with circumscribed monocular lesion. The effects were almost identical irrespective of the eye through which the patches of gratings were presented

It is well established that circumscribed monocular retinal lesions in adult or adolescent cats result in substantial reorganization of circuitry in primary visual cortex. This means that when stimulated via the lesioned eye, neurons in the cortical lesion projection zone (LPZ) have new 'ectopic' CRFs located in the region of normal retina in close proximity of the lesion. In the past, we have documented the fact that in both the striate (cytoarchitectonic area 17, area V1) and parastriate (cytoarchitectonic area 18, area V2) many of the receptive field properties (e.g. size, orientation and direction selectivities, velocity preferences, etc) of the CRFs of the ectopic receptive fields are often indistinguishable from those seen when visual stimuli are presented via the non-lesioned eye. Recently, using luminance-contrast sinusoidally modulated grating patches rather than single elongated bars, we compared quantitatively not only the receptive field properties of CRFs but also the magnitude of suppression (or facilitation) and orientation tuning of combined CRF and silent surround stimulation of binocular cells recorded from the LPZs and para-LPZ regions in the striate cortices of adult cats which had undergone circumscribed monocular retinal lesions when they were 8 weeks old. For most LPZ and para-LPZ neurons tested, the 'surround-orientation-tuning' was virtually identical for stimuli presented through either eye (lesioned and non-lesioned; Fig. 2), although for a substantial proportion of these cells the relative strength of surround modulation varied between each eye. Only small proportions of neurons exhibited substantial interocular differences in surround-orientation-tuning. These findings demonstrate that not only CRF characteristics, but also CRF/surround interactions are generally well matched between the two eyes. Furthermore, this property is maintained despite the presence of a monocular lesion of the retina, suggesting a major reorganisation of the cortical network following retinal lesions.

Professor Bogdan Dreher (Chief Investigator)
Dr Chun Wang (Senior Research Fellow)
Dr Wioletta Waleszczyk (Visiting Scholar)
Mr Cedric Bardy (PhD student)
Mr Yoshua Young (PhD student)



(L to R) Cedric Bardy, Chun Wang, Bogdan Dreher

Theme 2
Vision for Action and Robotics

Nature has equipped animals and humans with vision systems *par excellence*. This is readily apparent to anyone observing a fly orchestrating a flawless landing on the rim of a teacup, a bee returning unerringly to its hive after finding food several kilometres away, or a cricketer executing a brilliant running catch in the outfield. Man-made machines and robots continue to perform such tasks with far less finesse. Our challenge, therefore, is to better understand how the eye and brain solve complex visuomotor tasks, and to ask if they can be used to design novel strategies for machines that see, perceive, steer and navigate.

In relation to equipment and technology, the ANU node, which has already set up a fully functional optical recording system for visualizing cortical activity in cat brains, has now commenced a new initiative to develop a bionic eye, and is using novel electronic technology to identify individual honeybees as they enter or leave their hive. In addition to establishing a strong outreach program with Questacon at the National Science Museum, the ANU is now using their earthquake simulator to study how our perception of movement is shaped by the interactions between our visual and vestibular senses. The UQ node has a fully functional, state-of-the-art All Weather Bee Flight Facility to study visually mediated behaviour under controlled conditions all year round, and also has access to a 17 Tesla MRI machine for imaging brain structure.

Theme Leader: M. Srinivasan

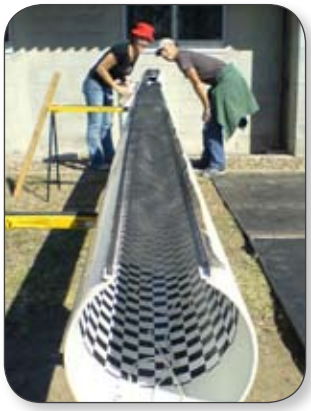
In relation to research, 2007 has provided a spectrum of fresh insights that span a broad range of creatures and scientific questions. We now have a better understanding of how fiddler crabs might perceive colour, of how bees find their way home from distant food sites, and of how they enhance foraging efficiency by combining information on target identity, location and time of day. We are looking at how wasps establish a "homing corridor" and how flying insects deal with headwinds and crosswinds. We also understand how eye movements affect our perception of motion, and how we perceive transparency through disparate motion cues. After extensive development and testing of algorithms in the laboratory, our biologically-inspired robots have moved outdoors and are taking to the air. All of this work is helping us elucidate the common fundamental bauplan that underlies the design of the visual systems of many members of the animal kingdom including ourselves. Indeed, we have found that even bees are right-eyed, like most humans.

Mandyam Srinivasan: Vision and navigation in flying insects, with applications to robotics

Introduction

Many flying insects display remarkable visual agility and impressive navigational skills, despite carrying relatively small brains and simple nervous systems. We are using the honeybee as a model to elucidate the principles by which visual information is used to stabilize flight and guide navigation. Another goal of our research is to explore whether some of the findings can be used to devise novel, biologically inspired strategies for the guidance of autonomous aerial vehicles.

2007 has been a busy and eventful year, with the move of five members of our laboratory to the University of Queensland's Queensland Brain Institute. Although this relocation has produced some predictable and unavoidable down time in our research, the new laboratories are now running, new ACEVS-funded staff members have been appointed, and the newly constructed, rooftop All Weather Bee Flight Facility is now fully operational. Our progress in 2007 is outlined below.



Carla Evangelista and Peter Kraft working with a polarized-light tunnel

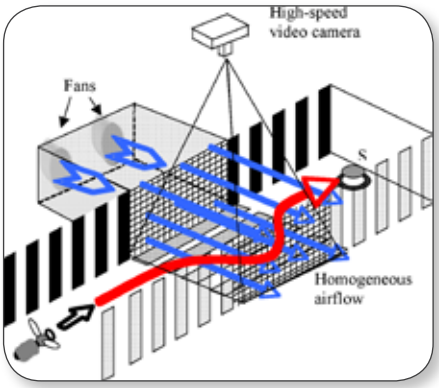
Critically testing the role of the polarization compass in honeybee navigation

Although several studies have examined how honeybees gauge the distance that they have flown to reach a food source, we know relatively little about how the information on the distance and the direction of flight are combined to pinpoint the location of the target. This year, we have addressed this question through two studies. In the first study, we have obtained the first real evidence that bees use polarized-light information to gauge their flight direction whilst navigating to a food source. In the second study, we found that bees may possess two different odometers – a "community" odometer that is used to provide information to nestmates via the dance, and a "personal" odometer that is used by an experienced individual to return to a previously visited food source.

Control of speed and height, and compensation for wind

Although there are a few studies of the influence of wind on insect flight in the literature, relatively little is known about whether, and to what extent, flying insects compensate for wind. This year we investigated the control of altitude, by video-filming bees using high-speed stereo cameras during flight in a wind tunnel. We found that the height of flight is modulated systematically by airspeed and that bees fly lower when they experience a stronger headwind. Presumably, this reduces exposure to headwind, and therefore the energy required for the journey. In another study we examined how bees react to crosswind, by using a specially designed crosswind tunnel. Our results indicate that bees actively compensate for crosswind, using specific visual cues. They also reveal that crosswind compensation is a learned, context-triggered motor behaviour.

Biologically inspired machine vision and robotics



Apparatus for investigating flight in crosswind

In 2007 we have continued to design and test two types of biologically inspired vision sensors for autonomous visual guidance of aircraft. One sensor uses optic flow information from images captured by a specially shaped reflective surface that reduces the velocity of the image of the ground during fast, low altitude terrain flying and eliminates perspective distortion. This vision sensor has now been augmented with gyros, and de-rotation algorithms have been developed to remove the components of optic flow that are due to yaw, roll and pitch. As a result we are now able to estimate height accurately and reliably. The system is currently being tested outdoors using a model aircraft.

Another sensor uses panoramic stereovision for visual guidance. This sensor incorporates a single video camera together with a set of specially shaped reflective surfaces to enable the detection of objects and obstacles in the environment, and estimation of their range through stereo. The advantage of this device over systems that use optic flow information is that it does not rely on the movement the aircraft. The performance of the system has been evaluated in the laboratory, and is now being assessed outdoors using a fixed-wing model aircraft.

(a) Raw image from test gantry; (b) Optic flow pattern generated by complex egomotion comprising translation and yaw; (c) de-rotated flow pattern

Prof Mandyam Srinivasan (Chief Investigator)
Mr Dean Soccol (Research Assistant)
Mr Saul Thurrowgood (Research Assistant)
Ms Emily Baird (PhD Student)
Mr Allen Cheung (PhD Student)
Ms Pinar Letzkus (PhD Student)
Mr Partha Bhagavatula (PhD Student)

(L to R) Carla Evangelista, Mandyam Srinivasan, Partha Bhagavatula, Saul Thurrowgood, Dean Soccol, Allen Cheung, Peter Kraft and Emily Baird in the Biorobotics Laboratory

Mark Edwards: Processing of motion information by the human visual system

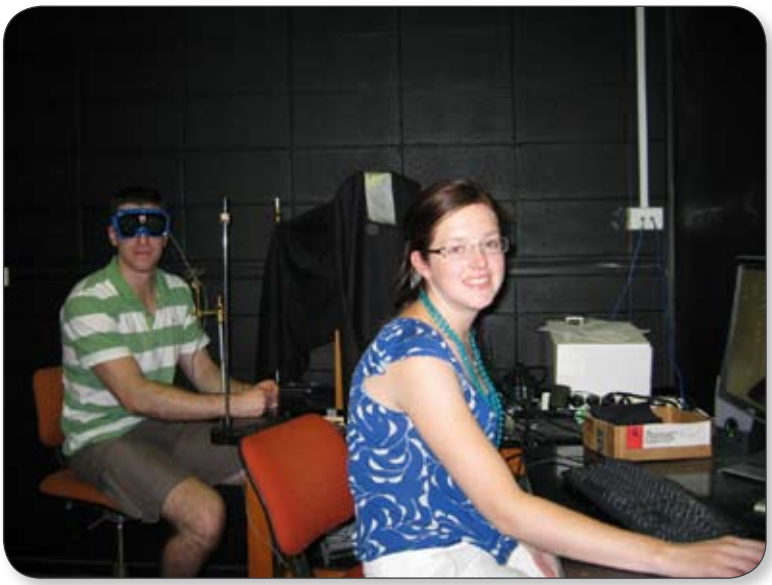
Visual information is processed via a number of parallel pathways, with cells in these pathways being specialised for extracting particular aspects of the visual scene. Each of these pathways contains distinct processing stages that transform the information being represented. Research in our laboratory investigates the interaction between these pathways at the various stages with particular focus on the processing of motion information.

Optic-flow processing

Optic-flow patterns are the pattern of image motion on the retina produced when we move through our environment. Forward motion produces a radially expanding pattern and backward motion a contracting one. We have shown that people are more sensitive to large-field radially contracting patterns than they are to expanding ones. This finding cannot be the result of biases in visual stimulation from the environment and given that we travel forwards more than we travel backwards, any asymmetries in sensitivities resulting from this selective stimulation would result in the opposite pattern of results. We have proposed that the reason for the greater sensitivity to contracting patterns is due to the use of optic-flow information in maintaining balance, and the functional requirements of this task. Specifically, given that our feet project forwards, we can sway forward further than we can backwards before falling over and hence it is important to stop backward sway (producing contracting optic-flow patterns) earlier than forward sway (expanding patterns). Given that the vestibular system is also involved in maintaining balance, we are currently investigating the possibility that vestibular signals may affect sensitivity to optic-flow patterns. That is, optic-flow thresholds may be lower when the optic-flow and vestibular inputs are consistent, e.g. the person is presented with an expanding pattern while they are moving forward, compared to when they are inconsistent, e.g. expanding pattern while moving backwards. We are conducting these experiments with Questacon – using their earthquake-simulation room.

Motion transparency

Motion transparency occurs when there are multiple motion signals in the same region, e.g. when driving in the rain, you see the radial optic-flow motion of objects and the vertical motion of the rain coming down. Our experiments on this topic have focused on how many signals a person can simultaneously perceive, i.e. the transparency limit, and how the different signals are represented by the population activity of cells within the visual system. We have established that the transparency limit is two, if the motion signals differ only in terms of their direction, and that it can be increased to three if the signals also differ in speed or depth. We have linked this limit to the processing characteristics of the global-motion level in the visual system and by using adaptation techniques have shown that, contrary to the current prevailing theory, transparency is perceived only when the different motion signals result in distinct response peaks in the population activity. Current focus is on determining whether the limit of three is specific to the transparency system or whether it is a generic limit within the motion system. The results of experiments using spatially non-overlapping (non-transparent) stimuli indicate that it is a generic limit.



Antony Gates and Olivia Metcalf are running experiment on investigating depth perception

Integration of motion signals

The cells that initially extract motion have small receptive fields, which means that they cannot accurately determine the true direction of motion of objects. In order to extract the veridical motion of objects, the visual system has to combine the outputs of many of these local-motion units. Together with Dr Shin'ya Nishida and Prof. David Badcock, we have looked at the way the visual system pools these signals. We have shown that two strategies are employed. However, the strategy that is employed depends upon the type of information available at the local-motion level. These findings have reconciled a debate that has existed for some time in the field.

Dr Mark Edwards (Chief Investigator)
Dr Kunjam Vallam (Postdoctoral Fellow)
Mr John Greenwood (PhD Student)
Mr Antony Gates (PhD Student)

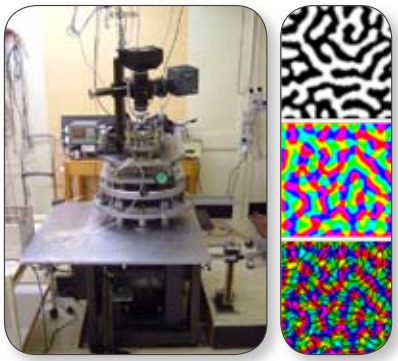
(L to R) John Greenwood, Mark Edwards, Kunjam Vallam

Michael Ibbotson: Brain and perception

The research in my laboratory investigates how signals in single visually active nerve cells (neurons) can be put together with signals from other neurons to generate complex behaviours and perception. The laboratory uses a wide range of approaches that include single cell recording from cats, monkeys and honeybees. The cat and monkey research is conducted at the ANU while the monkey research is done in collaboration with an ACEVS Partner Investigator in the USA (Prof Mike Mustari). A major theme of my laboratory is to develop mathematical models that explain the link between single cells and behaviour. In addition to recording from single neurons, we record simultaneously from very large regions of the visual cortex using optical imaging techniques. The acquisition of this technique through ACEVS funding has allowed us to learn a great deal about how the visual cortex is functionally organised.

Cortical maps

One of the new initiatives in 2007 was to record functional maps of cortical organisation using optical imaging. The optical imaging system, which allows us to literally film the brains of domestic cats while they respond to selected visual stimuli, is shown in the Figure. We present various types of visual stimuli to anaesthetised cats and record the activity-driven changes of blood flow in the brain. Basically, when active the brain blushes, much as a person's cheeks do when embarrassed. We can measure the amount of activity by filming the amount of brain-blushing.



Optical recording system and activity maps from the cat cortex

The Figure shows the optical recording set-up and some maps of ocular dominance (top right), orientation preference (middle right), and combined maps where multiple stimulus parameters were changed (bottom right). Once the maps have been generated, it is then possible to target specific locations in the cortical map. For example, we can select a region of the brain that responds only to rightward motion of vertical bars at a particular spatial frequency through only the left eye. The ability to choose where we record has allowed us to collect data from specific cell types. This is a radical departure from all previous research in this field, where it has only been possible to record randomly from unknown cell types. The advantages of optical recording combined with subsequent single cell recording is that we can now build up highly specific data banks on particular cell types, thus greatly improving the ability to investigate single cell properties in the cortex.

Bionic eye

The second major new initiative in the laboratory this year was to become involved in the Australian effort to develop a bionic eye. The bionic eye project will attempt to produce a microchip that can be implanted into the eye of a visually impaired individual to return partial sight. This technology is possible because much of the neural tissue in the eye remains functional when disease kills the photoreceptors. Therefore if we replace photoreceptors with light-sensitive microchips we should be

able to electrically stimulate the underlying retinal tissue and produce viable visual perceptions. My laboratory's role in this project is to implant the microchips into animal models and use optical imaging to assess what types of signals make it to the brain. Based on our data it will be possible to modify the chips to improve the transfer of information from the eye to the brain.

Monkey research

We have made substantial progress in the monkey projects in 2007. The importance of this research is that we are able to record from alert, normally behaving monkeys. As a result it is possible to measure single cell activity during complex behavioural tasks such as moving the eyes between visual targets. The project has shown that every time a monkey moves its eyes the processing capacity of the visual system is modified in a highly predictable manner. Quite literally, moving the eyes to a new visual location alters the way in which the visual system functions. Before and during eye movements the visual system is shut down. However, after the eyes have locked onto their new target the visual system becomes hyperactive, producing responses up to 4-5 times larger than under control conditions. This observation matches the well-known observation that when someone is interested in something they move their eyes more often. The reason for this increase in eye movements appears to be related to the need to increase processing capacity. The implication of this discovery is profound, as a very large portion of the visual brain is involved in coordinating vision with eye movements, and fully understanding visual-motor coordination will assist in understanding visual perception.

Insect research

Over a period of several years we have run behavioural and physiological experiments with honeybees in collaboration with Professor Srinivasan. We have now reached a stage where we can match certain behaviours to specific identifiable clusters of neurons in the bee brain. Thus we are able to say with great certainty that particular identifiable neurons drive specific behaviours, e.g. initiating landing responses on vertical surfaces. Such detailed knowledge of the brain is not currently possible in vertebrates, so its achievement in the honeybee brain is significant.

Back row (L to R) Joshua van Kleef, Michael Ibbotson, Nathan Crowder, Norbert Boeddeker
Front row (L to R) Sophie Wilson, Terri Warner, Madeleine Scott

Dr Michael Ibbotson (Chief Investigator)
Dr Shaun Cloherty (Postdoctoral Fellow)
Dr Norbert Boeddeker (Postdoctoral Fellow)
Ms Sophie Wilson (Research Assistant)
Mr Joshua van Kleef (Research Assistant)

Shaowu Zhang: Visual cognition in honeybee navigation

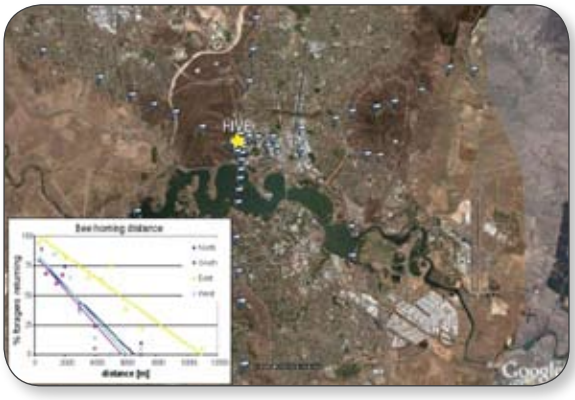
One of the most pressing and intriguing challenges of visual neuroscience is to gain a better understanding of the cues and strategies that natural vision systems exploit to solve complex visuomotor tasks. Research in our laboratory is aimed at examining visual cognition in relation to honeybee navigation at the behavioural level, along with the underlying neuronal mechanisms. The objectives for 2007 were to address the following questions:

Circadian timed episodic-like memory – a bee knows what to do when, and also where

This study investigated how the colour, shape and location of patterns could be memorized within a time frame. Bees were trained to visit two Y-mazes, one of which (Maze B) presented yellow vertical (rewarded) *versus* horizontal (non-rewarded) gratings in the morning, while another (Maze A) presented blue horizontal (rewarded) *versus* vertical (non-rewarded) gratings in the afternoon. The bees could perform well in the learning tests and various transfer tests, namely when (i) the colour cues of the visual patterns were removed at Maze A and Maze B; (ii) the location cue (a) and shape (b) or colour cues (c) were removed at a novel Maze C. The results reveal that the honeybee can recall the memory of the correct visual patterns by using spatial and/or temporal information.

The role of the celestial and terrestrial cues in honeybee navigation

The ability of honeybees (*Apis melifera*) to locate their nest site following artificial displacement was investigated by using the Radio Frequency Identification (RFiD) technique. Bees tagged with RFiD chips were released at various spots in the area surrounding the hive at distances of less than 2km, 2km, 3km, 4km, 5km, 7km and 11km in various directions. The proportion of bees returning to the hive and the average return time were recorded by the RFiD system. The results revealed: i) honeybees are able to return to the hive after displacement to a location where they most likely had never been. It is likely that they conduct a systematic search until familiar landmarks are encountered. ii) The return rate and the maximum limit of the homing distance was different for different directions. Bees returned from distances of up to 11km in the north-east direction, and from 6-7km in the remaining directions, with the proportion of bees returning declining with increased distance of the release site from the nest; iii) The sun compass and the major geographical landmarks of Canberra, such as Lake Burley Griffin and the view of Black Mountain facilitate the return of bees from north-eastern release sites.



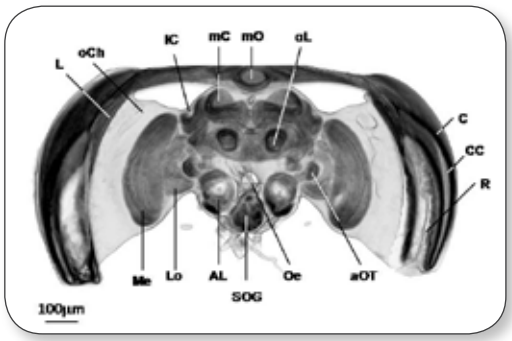
Map showing release sites at various distances and directions around the bee hive

Number-based visual generalisation in the honeybee

In investigations of the flexibility and reliability of the navigation system of the honeybee using a delayed match-to-sample protocol, we found that bees continue performing well even after the sample and choice patterns are changed. Our latest experiments revealed that honeybees could be trained to make generalisations about the number of elements in a visual pattern, and distinguish between arrays composed of two and three elements. Having controlled for lower-order cues such as area and edge length, we believe that bees were using the number of elements in each pattern as a cue on which to base their decisions.

Optical imaging approach and structure-functional anatomical research

We continued optical imaging experiments to study the neural representations for various visual objects in the optic lobe of the honeybee. We have also commenced structure-functional anatomical research by using classic histological techniques, as well as a new X-ray micro-Computed Tomography (X-ray mCT) technique in collaboration with Prof. Willi Ribi from the University of Liechtenstein. This technique offers a significant improvement in resolution, time, and expense, for the quantitative three-dimensional analysis of developing bee brain centres.



X-ray µCT of the honey bee head, frontal view. (The neuropil of the brain stains dark. AL antennal lobe, aOT anterior optic tubercle (Kenyons's optic body) C cornea, CC crystalline cone area, lC left lateral calyx, αL αlobe, L lamina, Lo lobula, mC left median Calyx, Me medulla, mO median ocellus, oCh outer chiasma, Oe oesophagus, R retina, SOG suboesophageal ganglion. Scale bar 100 µm)

Dr Shaowu Zhang (Chief Investigator)
Dr Shunpeng Wang (Postdoctoral Fellow)
Ms Waltraud Pix (Research Assistant)
Ms Hong Zhu (Research Assistant)
Dr Aung Si (Research Assistant)
Mr Mario Pahl (Visiting Scholar)
Ms Jialin Mi (Visiting Scholar)

Back row (L to R) Emily Baird, Willi Ribi, Cathy Stewart-Morre, Hong Zhu, Jialin Mi, Mark Snowball
Front row (L to R) Shunpeng Wang, Mario Pahl, Shaowu Zhang, Waltraud Pix, Aung Si

Jochen Zeil: Visual ecology and neuroethology

Our research is concerned with visual information processing under the natural, real-life conditions in which the eyes and brains of animals have evolved. We analyse behaviour in natural habitats using imaging and robotics techniques, including synchronized high-speed stereo cameras, panoramic and spectrographic imagers and a mobile robotic gantry, to reconstruct what animals see when moving about and making decisions. We combine these methods with molecular genetics, in-vivo optics and electrophysiological investigations, to characterize the responses of photoreceptors and neurons to biologically relevant events.

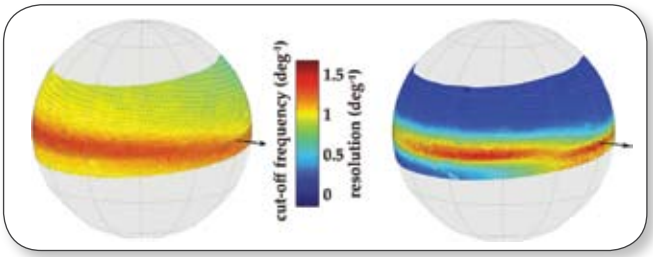
Fiddler crabs: dichromats of the third kind?

Fiddler crabs are very colourful animals, and over the last two years we have shown – for the first time for any invertebrate - that they use colour vision for species recognition, for individual recognition and for mate choice (Detto et al. 2006, Proc Roy Soc Lond B 273, 1661–1666; Detto (2007) Proc Roy Soc Lond B 274, 2785-2790). To understand the neural basis of colour vision in these crabs, Ali Alkaladi in collaboration with Ryszard and Joanna Maleszka (RSBS, ANU) has used *in-situ* hybridization experiments with two recently identified fiddler crab opsin gene sequences (provided by Prof Samir Deeb, University of Washington, USA) to map the distribution of opsin gene expression across the eyes of crabs. The results so far indicate that colour processing in these crabs is likely to be very unusual indeed. Most photoreceptors express both opsin genes, with the exception of those in the frontal and in the ventral retina, which are used in the processing of social information and where certain classes of photoreceptors express either one or the other opsin. Debjani Das, a visiting scholar, intends to use fluorescent probes that we hope will improve the specificity and contrast of our *in-situ* preparations. These findings are confirmed by an analysis of the sampling array of fiddler crab eyes, which Jochen Smolka carried out to show that optical and anatomical sampling in the frontal retina is optimized for the detection of short-wavelength light. Since the true spectral sensitivities of crab photoreceptors depend in addition to the absorption characteristics of the visual pigment on a series of colour filters, Jochen Smolka is currently confirming our findings by electrophysiological recordings from crab photoreceptors. Misha Vorobyev and his student Leigh Fischer have begun developing a numerical model for crab photoreceptors that will help us explain their unusual banding patterns of orthogonal microvilli directions which Ali Alkaladi has discovered in an electronmicroscopical study.

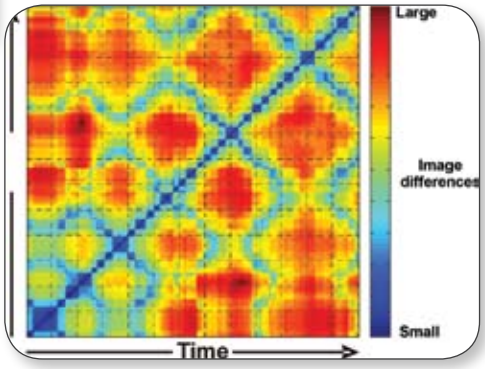
Acquiring and using views for homing

Homing insects are guided by visual memories of the goal environment. They acquire these visual representations during highly structured and elaborate learning flights on departure. The organization of these learning flights is surprisingly similar across different species of wasps and bees, indicating that they reflect fundamental requirements of view-based navigation. Using high-speed stereo cameras Norbert Boeddeker, Jan Hemmi, Wolfgang Stürzl and Jochen Zeil have now shown that ground-nesting wasps employ a saccadic gaze strategy during both learning and homing, in which gaze is stabilized along consecutive segments of linear flight. To understand what wasps are looking for during their learning flights and how they use what they see during learning to guide their return we have used

a robotic gantry to move a panoramic imaging device along the flight paths of learning and homing wasps. We then determined how image differences develop throughout a learning flight, and identified which views guide the insect's return. We discovered that learning wasps move in such a way as to acquire a series of boundary snapshots that define a V-shaped flight corridor leading to the nest. When they encounter these boundary views upon homing, they move away from the left or the right boundary towards the centre line of the V-shaped flight corridor. Ajay Narendra has joined the group to investigate the role of image motion as a cue to landmark distance during view-based homing.



The distribution of optical and anatomical resolving power varies dramatically across the fiddler crab compound eye (from Jochen Smolka)



The image differences experienced by a ground-nesting wasp in the course of her learning flight on departure from the nest

Dr Jochen Zeil (Chief Investigator)
Dr Jan Hemmi (Associate Investigator)
Dr Norbert Boeddeker (Associate Investigator)
Dr Misha Vorobyev (Associate Investigator)
Prof Johannes Zanker (Partner Investigator)
Prof Martin Egelhaaf (Partner Investigator)
Mr Ali Alkaladi (PhD Student)
Mr Jochen Smolka (PhD Student)
Ms Wiebke Ebeling (PhD Student)
Mr Sam Reid (PhD Student)

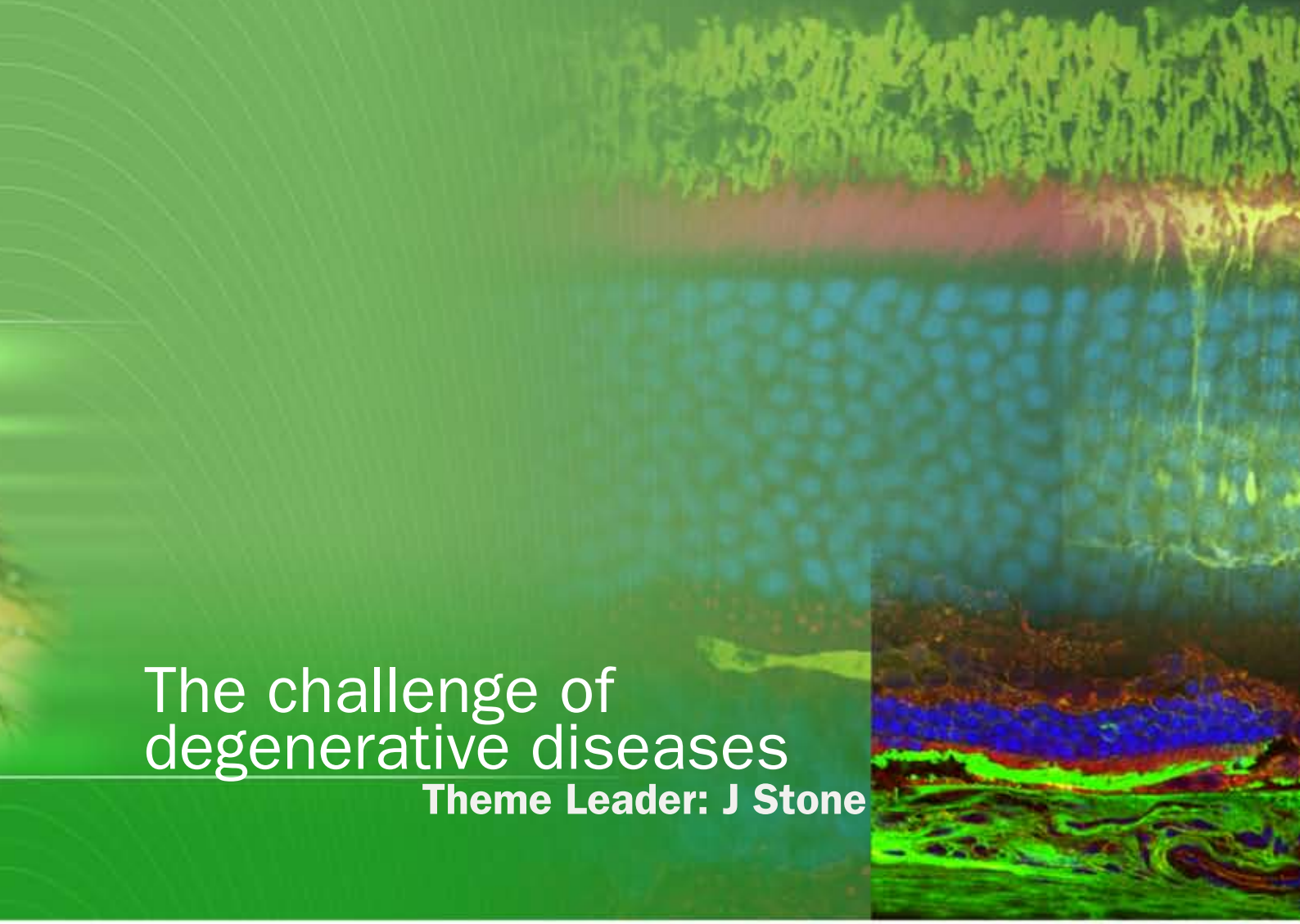
Back row (L to R) Ali Al-Kaladi, Norbert Boedekker, Martin How, Brigit Greiner, Jan Hemmi, Richard Peters
Middle row (L to R) Jochen Smolka, Andreas Pfeil, Waltraud Pix, Cathie Stewart-Moore, Wiebke Ebeling
Front row (L to R) Nicole Carey, Sam Reid, Jochen Zeil, Mark Snowbal

Theme 3
Vision for Life

All projects in this Theme made strong progress in 2007. The highlights of this progress include:

The demonstration of functional recovery in cones, in a model of retinal dystrophy in which (as in most clinical cases) the mutation responsible is in a rod-specific protein. This finding shows a close functional dependence of cones on rods, but also show that recovery is possible, in the present model with management of light experience. This is an important step towards clinical trials of light management in retinal dystrophy, which will commence in 2008.

The demonstration that age-related macular degeneration – the sudden breakdown in older people of the critical macular region of the retina – is preceded by, and may be caused by, a panretinal degeneration which affects cones as well as rods. These observations are novel, and point to life-long management of retinal stress as an important way of delaying/preventing macular degeneration.



The challenge of degenerative diseases

Theme Leader: J Stone

The continued analysis of the epidemiology of myopia, has led to clinical trials in cooperation with institutions in Singapore. This epidemiological work is backed by molecular analysis of the control of eye growth, and the clinical trials are the important and essential step to practical testing of knowledge gained.

Demonstration of the complexity of the retina's response to hyperoxia: All degenerating retinas become hyperoxic, a direct result of the depletion and dysfunction of photoreceptors. Understanding of the retina's response to hyperoxia is a key to the cell biology of degenerating retina, and to the development of optimal therapeutic management of the retinal dystrophies.

Late in the year, Prof Stone convened a specialist meeting on translational aspects of our work on retinal degenerations. The ACCORD (Australiasian Consortium for the Care of Retinal Dystrophies) was attended by all Theme 3 CIs, and by a number of Australasian scientists funded to work on retinal dystrophies, and produced several highlights in work on retinal dystrophies.

Jonathan Stone: Oxygen-induced gene expression; and effects of hyperoxia on the ERG

Oxygen induced gene expression

One paper has been submitted, and one is in preparation, describing the outcome of this work, and further studies are under way. The paper in preparation describes the outcome of a micro-array study of the impact of oxygen on gene expression in the C57BL/6 mouse retina. The paper submitted focuses on one of the oxygen-regulated genes, Oxr1, showing a biphasic regulation of its expression. Subsequent study will follow several individual genes. The work is documenting for the first time the complexity of the retina's response to hyperoxic challenge. Our most recent experiments will compare hyperoxia-induced gene expression between vulnerable and resistant areas of the same mouse retina.

Identifying genes regulating photoreceptor vulnerability to oxygen

This work has moved to its second stage - genome wide scans based on DNA collected from the N1 generation of mice bred from oxygen resistant (Balb/C) and vulnerable (C57BL/6) strains. This will achieve chromosomal localisation, and will be a major step to the goal of identifying, for the first time the genes which regulate photoreceptor vulnerability to oxygen.

Mitochondrial locations and their relation to oxygen

A structural study was completed and published in 2007, which carefully mapped the locations of mitochondria in the adult retina. Striking relationships were detected – for example mitochondria were noted in the axon terminals of photoreceptors in vascularized retinas, but not avascular retinas. Taken together, the several findings in this study indicate that mitochondria migrate along oxygen gradients to their adult positions, as close as possible to sources of oxygen, the blood vessels. In photoreceptors, the effect is that mitochondria are sequestered to the extreme poles of the cell, and the mitochondrial genome is separated from the nuclear genome. This is a previously unrecognised aspect of photoreceptor biology, which may contribute to the relative fragility of photoreceptors, which are the most degeneration–prone of all retinal cells.

Mitochondrial damage in retinal degenerations

Work led by an earlier PhD student Arturo Bravo-Nuevo was published, demonstrating for the first time the involvement of mitochondria in the degeneration of photoreceptors. The work, which involved detection of deletions of the mitochondrial genome, showed for the first time the early involvement of mitochondrial damage in photoreceptor degeneration in the normal retina, and in the spontaneously degenerative RCS rat.

Effects of oxygen on the ERG: closing in on an enigma

We have confirmed by direct experiment the ability of oxygen to both enhance and degrade the electroretinogram, working in both mouse and rat models. Understanding these seemingly conflicting observations may be clinically important, as the literature on hyperoxia and the retina provides two contrasting accounts of how high levels of oxygen affect retinal stability. On the one hand, there are persistent reports that hyperbaric oxygen therapy in humans can enhance the ERG and visual performance in humans undergoing retinal degeneration; while our own work (the oxygen toxicity hypothesis) has demonstrated the photoreceptor-specific toxic effects of hyperoxia. The resolution of this discrepancy may lie in the kinetics of gene expression when the retina is affected by hyperoxia. Long-term exposure is toxic to photoreceptors, but short term (hours to 3 days) exposure upregulates a group of genes, such as Oxr1, which have a short-term protective effect. Clarification of these kinetics will be an important step for the management of oxygen levels to enhance photoreceptor survival.

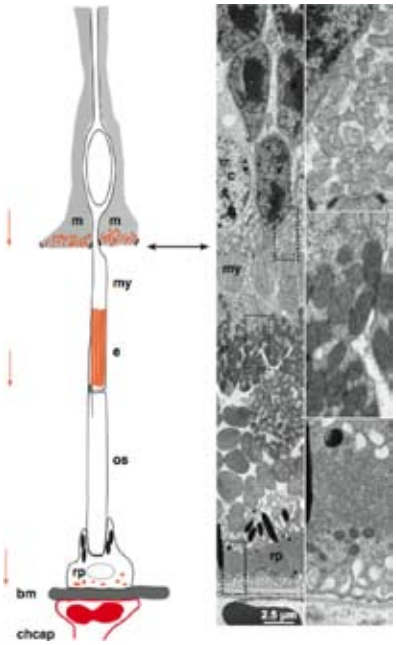


Diagram and electron micrographs showing the distribution of mitochondria in the adult photoreceptor, and associated cells. Mitochondria (orange) are highly polarised in the photoreceptor, with a major concentration in the ellipsoid (ed) of the inner segment, where mitochondria abut the cilium, at the base of the outer segment (os), In cells of the retinal pigment epithelium (rp) mitochondria concentrate at the outer aspect of the cell, against Bruch's membrane (bm). In Müller cells (m) too, mitochondria concentrate at the outer end of the cell, at the level of the outer limiting membrane (double headed arrows). Thus, mitochondria appear attracted to the aspect of each cell type closest to their source of oxygen, the choriocapillaris (chcap)

Professor Jonathan Stone (Chief Investigator)
Dr Krisztina Valter (Chief Investigator)
Ms Yuan Zhu (PhD student)
Mr Riccardo Natoli (PhD student)

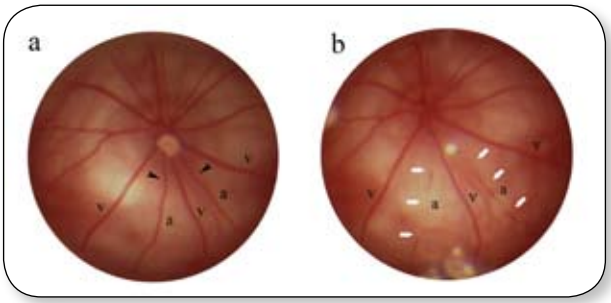
Back row (L to R) Yuan Zhu, Sivaraman Purushothuman, Vicki Chrysostomou, Riccardo Natoli
Front row (L to R) Sally Stowe, Jonathan Stone, Diana Kirk

Dao-Yi Yu and Steve Cringle: Oxidative stress in degenerating retina

Our role in the ACEVS research program focuses on the direct measurement of the role of oxygen and tissue ischemia in the normal and diseased retina. We previously demonstrated an altered intraretinal oxygen environment in several models of outer retinal degeneration in the rat, including the P23H rat provided by Professor Stone's group. We also demonstrated the critical nature of the intraretinal oxygen environment in the primate fovea, an area of great significance to future studies of relevance to age related degeneration of this, our most critical region of retina. These studies have highlighted the possibility of therapeutic approaches aimed at correcting intraretinal oxygen levels by manipulation of the external oxygen environment, modulation of metabolic requirements, or modulation of ocular blood flow. In 2007 our ACEVS related research has resulted in publications on the intraretinal oxygen environment in an ischemic retina and how oxygen levels are improved by supplemental oxygen therapy, the survival and function of ganglion cell axons with raised intraocular pressure, and the effects of light exposure on retinal vessels during fluorescein angiography.

Intraretinal oxygen levels during retinal ischemia

We studied the intraretinal oxygen distribution in rats before and after laser occlusion of the retinal circulation. This model represents the most dramatic form of retinal ischemia, a common blinding condition. We demonstrated that much of the inner retina becomes hypoxic and that even with supplemental oxygen therapy it was not generally possible to avoid some degree of intraretinal hypoxia. This result was rather surprising and highlights the dramatic increase in inner retinal oxygen uptake as more oxygen is made available.



Fundus photographs of the rat retina before (a) and after (b) laser occlusion of a pair of retinal arteries

Axonal transport under conditions of elevated intraocular pressure (IOP)

The ganglion cell axons carry the visual signal from the retina to the brain. In glaucoma, these axons are damaged, leading to visual field loss and ultimately blindness. The axons must accommodate several different environments, and they seem to be particularly vulnerable at the point where they leave the eye and form the optic nerve. Internal transport of nutrients along the axon is essential for healthy function, and this can be studied using fluorescent tracers. We were able to demonstrate in a pig model of high IOP that even moderate elevation of IOP significantly decreases axonal transport in the region of the optic nerve head. This model provides a means of studying potentially protective agents to lessen the neuronal death in such conditions.

Vasoactive effects of light and sodium fluorescein

Fluorescein angiography is a common procedure in clinical ophthalmology, providing useful data on tissue perfusion, leakage, and vessel calibre in a range of retinal diseases. A bolus of sodium fluorescein is injected into the brachial vein and the arrival at the retina is monitored by fundus photography. We used an isolated retinal artery preparation in which vessel diameter can be accurately measured, and examined the influence of clinically relevant doses of fluorescein. It was demonstrated that fluorescein has a significant contractile effect on pig retinal arteries, and that this effect was enhanced further by bright light exposure. This finding suggests that vessel diameter may be affected in fluorescein angiography where both high light levels and high concentrations of fluorescein are used, providing a potentially false impression of the actual state of retinal perfusion.

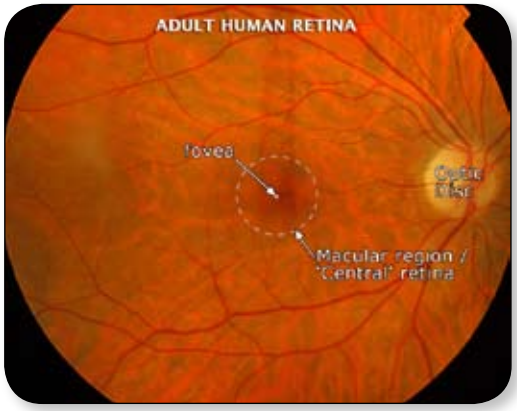
Future studies will begin to focus more on the human retina using a newly developed perfusion technique employing post-mortem eyes. We plan to address major questions related to the structural properties of the vascular structures of the human eye and to study both vascular and retinal changes with age.

Research team:

Prof Dao-Yi Yu (Chief Investigator)
Assoc Prof Stephen Cringle (Chief Investigator)
Dr Er-Ning Su (Research Fellow)
Dr Paula Yu (Research Associate)
Dr Chandra Balaratnasingam (PhD Student)

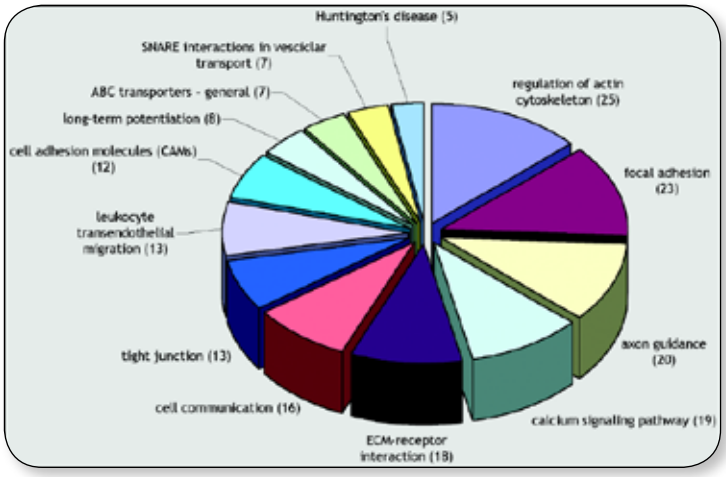
Jan Provis: Retinal development and ageing

Human visual acuity is second only to some of the highly adapted birds of prey, like the eagle, *Aquila audax*. This ability to resolve very fine detail is due to specialization of the central region of the retina – the *macula lutea*, or 'macula' in primates – including a striking formation known as the *fovea centralis* ('fovea'). Individuals without this specialization (*foveal hypoplasia*) have poor vision. But which of the several features of central retinal specialization are the key determinants of high visual acuity? And, are these adaptations the explanation for the vulnerability of this part of the retina to the principal cause of untreatable visual loss in the elderly, age-related macular degeneration (AMD)?



A view of the interior of an adult human eye. The macula and the fovea are indicated. This part of the retina is responsible for all of our useful vision

Some species of fish, reptiles and birds have foveae, but amongst mammals, they occur only in simian primates. These foveae take slightly different forms in the different species, and have varying degrees of associated specializations. For example, primate foveae are associated with an avascular area and specialization of the photoreceptor layer, including peak cone photoreceptor density. Bird retinas have no vessels and there are varying degrees of adaptation of the photoreceptor layer. The Retinal Development and Ageing Laboratory is investigating the morphology and development of foveae in several species, including humans, to understand how the macula becomes specialized for high acuity functions, and the significance of the fovea.



A pie chart showing the functional categories of genes that are differentially regulated in the developing human macula

During 2007 we completed experimental work aimed at identifying genes that are differentially expressed in the central / macular region of developing human retina. PhD candidate, Peter Kozulin hybridized RNA extracted from specific regions of developing human retinas to GeneChip® microarrays. Each array is made up of 55,000 probes, including all identified human genes, most of which are identified by more than one oligonucleotide sequence; binding of RNA product

indicates expression of that particular gene in the RNA sample. Peter analysed gene expression in five human foetal retinas at similar stages of development and, using proprietary software, classified the differentially expressed genes into known gene ontologies. An overview of the data obtained comparing gene expression in the developing macular region with a location on the nasal side of the optic disc is shown in the pie chart. Of particular interest are genes with a known involvement in vascular guidance, a majority of which are classified with those involved in 'axonal guidance'. A further aim is to identify the cellular expression of particular genes of interest, which are likely to have roles in determining the key characteristics of the macular region.

An investigation of adult human retina, looking at indicators of incipient degeneration in cone photoreceptors was completed in 2007 and a manuscript has been submitted for publication. The data show that incipient cone pathology is common in normal adult retinas, including the retina of a 22 year old donor, as well as in histologically normal regions of retinas affected by AMD. These findings will form the basis of an investigation of cone function in age-cohorts of human subjects, commencing in 2008.

Honours student Angeliza Querubin, under the supervision of Jan Provis and Keely Bumsted O'Brien, completed the first known map of photoreceptor topography in the pigeon retina. The pigeon retina is of interest because, like humans, it has a cone-rich, rod-free, fovea. Because the eye develops *in ovo* it is relativiely easy to access and manupulate. We propose, therefore, to study early development of the pigeon retina, and in particular the fovea, to identify genes that specify the location of the fovea, and the cone fate of photoreceptors that differentiate at that location. Angeliza was awarded the 'best basic science student poster' at the Australasian Ophthalmic and Vision Sciences meeting in December for her work on the pigeon photoreceptor distribution.

Dr Jan Provis (Chief Investigator)
Dr Keely Bumsted O'Brien (Associate Investigator)
Mr Riccardo Natoli (Research Assistant)
Mr Peter Kozulin (PhD Student)
Ms Angeliza Querubin (Honours Student)

(L to R) Jan Provis, Riccardo Natoli, Angeliza Querubin, Peter Kozulin

Krisztina Valter: Photoreceptor damage and repair

Photoreceptor damage and recovery

Exposure to excessive light has been known to cause photoreceptor death. When retinas are exposed to bright light for 24 h, photoreceptor damage is apparent within a few hours. The exact mechanisms behind the light-induced changes are unknown, although roles for free radicals and disruption of cell metabolism have been suggested. We are investigating the effect of light on the photoreceptor's powerhouse, the mitochondrion. Mitochondria are responsible for oxidative metabolism, and are also the site of free radical production, and are known to include molecules that can either initiate or prevent cell death. Mitochondria are especially important in relation to the photoreceptors, since these cells contain the highest concentration of mitochondria of all cells in the body.

Mitochondrial DNA deletion resulting in disruption of genes responsible for oxidative metabolism occurs within 1 hour of the commencement of light stress. This leads to an increase in the production of free radicals and subsequently, upregulation of genes initiating cell death. As more mitochondria are affected, the cells begin to show signs of damage. If the stress is not alleviated, a sudden, large amount of cell loss ensues.

Studies in my laboratory have shown that after 24 hours light exposure, the resulting damage to the retina is not uniform. Typically we noted a 'hot spot' of damage just above the optic nerve head, where loss of the entire photoreceptor population and disruption of the inner retina and Bruch's membrane was evident. Matt Rutar obtained first class honours in 2007 for his work that examined the possibility of recovery of the retina after animals were returned to low light level. His work demonstrated that areas with less severe disruptions showed a remarkable improvement, while areas with more serious damage showed no recovery. Moreover, severely damaged areas seemed to engulf tissue from the neighbouring retinal areas as time passed, increasing the area of severe damage. This sort of spread of retinal damage is seen in Age-related Macular Degeneration. The methodical description of such structural and biological changes will be important, to assess the best timing for and the value of therapeutic interventions.

The benefits of saffron

My collaborator, Prof Silvia Bisti has shown that use of saffron, a known antioxidant, protects photoreceptors from the direct effects of bright light. Juliet Fisher and Christina Salmon were key players in helping me to examine the mechanisms of the effects of saffron on the retina. In 2007 we demonstrated that damage in 'hot spots' is ameliorated in animals pre-treated with saffron, such that the destabilization of the retina does not occur.

We also investigated the effects of saffron in genetic models of retinal degeneration. We have shown a slowing of early photoreceptor cell loss, typical to these degenerations in two rodent models (P23H, RCS).

670nm light therapy

With my colleague, Prof Janis Eells, we are looking at the possible therapeutic effects of 670nm light exposure, on the slowing of retinal degeneration. Prof Eells and colleagues demonstrated that light at 670nm wavelength is absorbed by cytochrome oxidase, a rate limiting metabolic enzyme in the mitochondria. Exposure to light of this wavelength has also been reported to protect cells from the effects of metabolic toxins, and to increase the level and efficacy of cell metabolism, thereby leading to cell protection and survival. Under our supervision Diana Kirk, PhD student, is assessing the effect of the 670nm light treatment on the developing degenerative models. In 2007 she demonstrated that light treatment successfully decreased photoreceptor cell loss.

Rats are fed saffron by infusing it into their favourite treats, potato or rice chips

Light management

It has been shown that in some forms of retinitis pigmentosa, the photoreceptors are highly sensitive to light levels. Thus even low, physiological levels of light can increase the loss of cells and render the surviving cells non-functional. Vicki Chrysostomou, PhD student, has examined the damage and recovery of photoreceptors after acute light stress in the adult P23H-3 transgenic rat model. She demonstrated that light restriction following stress allowed the recovery of the photoreceptors both functionally and structurally in both the rods and cones. To establish the benefits of light management in the developing retina as well as to assess its chronic effects I used young P23H-3 rats and followed their functional and structural changes at different light levels for 1 year. I was able to demonstrate that

- Light restriction from birth slowed the progression of degeneration
- Light restriction started at a mature age, after constant light stress during development, showed a remarkable protection of the retina, allowing measurable retinal function even at 1 year of age, while in animals not restricted from light, function was lost by about 6 months of age.

Dr Krisztina Valter (Chief Investigator)
Prof Jonathan Stone (Chief Investigator)
Prof Silvia Bisti (Partner Investigator)
Ms Juliet Fisher (Laboratory Manager)
Ms Vicki Chrysostomou (PhD student)
Ms Diana K. Kirk (PhD student)
Mr Matt Rutar (Honours student)
Ms Christina Salmon (Technical Officer)

(L to R) Vicki Chrysostomou, Diana Kirk, Christina Salmon, Juliet Fisher, Krisztina Valter

Ian Morgan: Molecular pathways for the control of eye growth

Ian Morgan

Research highlights

The four main themes of our research in 2007 were the role of dopamine in control of eye growth, molecular changes in growth control pathways, clinical trials on the prevention of myopia, and further studies of risk factors in the development of human myopia. All of these research themes have an emphasis on factors that prevent axial elongation, and therefore have the potential to be used to prevent or limit the development of myopia.

Dopamine in the control of eye growth

Dopamine, a retinal transmitter, was the first postulated eye growth control molecule, on the basis of quite indirect evidence. It was believed to act as an inhibitor of eye growth. We have now provided the first direct evidence that dopamine release is reduced in the development of form-deprivation myopia. However, analysis of the other eye growth control paradigms has shown that dopamine release is reduced in two other paradigms, although in one, eye growth is increased, while in the other, eye growth is decreased. This evidence suggests that dopamine release is controlled by spatial and temporal characteristics of the visual input in these paradigms, but that it is not a universal eye growth control molecule, as was originally postulated. The importance of reductions in dopamine release in paradigms in which eye growth is increased, and the role of dopamine in limiting eye growth in these paradigms require further investigation.

Molecular changes in the control of eye growth

Our studies on four potential eye growth control molecules (ZENK, pre-proglucagon, α-βcrystallin and Pax6) have shown that ZENK and pre-proglucagon are involved in the very early stages of the development of myopia, but that α-βcrystallin and Pax6 are not. Using ZENK as a marker of the state of retinal circuits, we have shown that within one hour of initiating increased eye growth, levels of ZENK and pre-proglucagon are reduced, and retinal circuits have been profoundly affected, such that they show markedly increased sensitivity to the molecules atropine and ADTN. Both these molecules have potential as clinical tools in the management of myopic progression. Consistent with this idea, if slowed eye growth is triggered by the removal of diffusers, then the expression of ZENK and pre-proglucagon increases. However, in the most clinically relevant paradigm, the fitting of positive lenses to reduce eye growth, no such molecular changes are observed. Later in the development of experimental myopia, there are changes in the expression of α-βcrystallin and Pax6 which suggest that these molecules are markers of the development of chorio-retinal pathological changes within highly myopic eyes, which are the most serious problems associated with myopia. Further studies will be carried out in this area to explore whether changes in these molecules can be used monitor the effectivness of potential treatments for high myopic pathology.

Risk factors for myopia

Further analysis of risk factors for myopia in the Sydney Myopia Study and the recent NHMRC-funded Sydney Adolescent Vascular and Eye Study has shown that nearwork (such as reading and writing) does not appear to be a major driver of the development of myopia, despite the continuing evidence that intensive schooling is associated with higher levels of myopia. In contrast, increased time spent outside in bright sunlight appears to protect from the development of myopia. This does not explain the association of myopia with schooling, because there is no systematic relationship between increased schooling and less time spent outdoors. Our finding of the importance of time spent outdoors, not necessarily on sport, has already been adopted in Singapore as the basis for their new myopia prevention strategy, although interventions based on it have not yet been tested in a randomised clinical trial (RCT). Understanding the link to myopia remains a major challenge for future research. Future research will develop an animal model of the effects of time spent outdoors, to test the possibility that the effect is mediated by increased release of dopamine in bright light.

Clinical trials on the prevention of myopia

Our previous laboratory work indicated that fitting positive lenses had the potential to slow the worsening of clinical myopia, and perhaps to prevent the development of new cases of myopia. A series of clinical interventions carried out in Sydney gave promising results. A randomised clinical trial (RCT) involving 100 progressing myopes is now underway in collaboration with the Singapore Eye Research Institute, which is funding the study. Results are expected towards the end of 2008. Our epidemiological work has indicated that exposure to sunlight might also have a role in preventing the development of myopia. A larger randomised clinical trial with four arms, carried out on around 1200 students in schools in Guangzhou, will test the effectiveness of both positive lenses and promotion of time spent outdoors. This study is carried out in collaboration with, and funded by the Key National Laboratory in Ophthalmology in Guangzhou, China. Results of this trial will not be available until mid 2010.

Dr Ian Morgan (Chief Investigator)
Dr Regan Ashby (Postdoctoral Fellow)
Ms Siobhan McCarthy (PhD Student)

(L to R) Regan Ashby, Ian Morgan, Siobhan McCarthy

4 Publications

Journal articles

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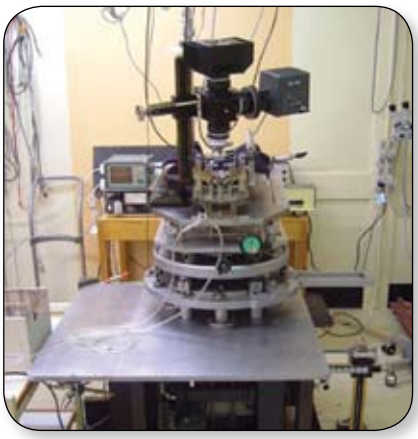
5 Leveraged Research

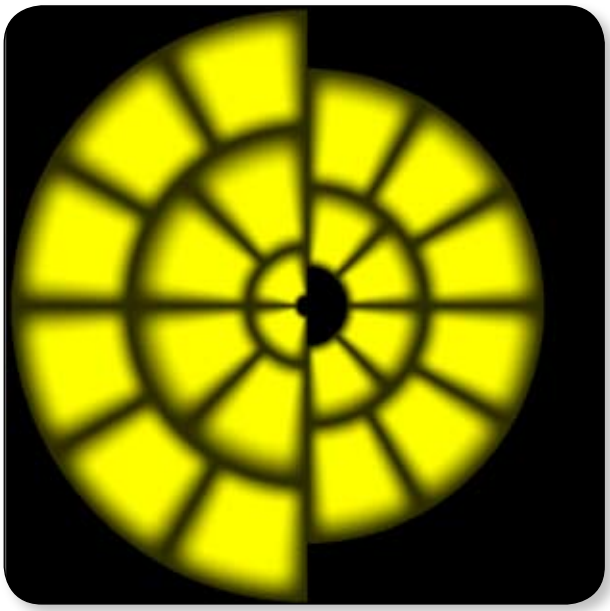
In addition to "core" Centre research, that has been directly funded by our ARC Centre of Excellence grant and for which project reports are presented above in section 3, the Centre has been very actively engaged in leveraging additional funding, and in extending Australia's research in the broad area of vision science, through new initiatives that have been made possible only through the existence of our Centre. Examples of such leveraged research initiatives are outlined below, followed by a list of outcomes (research grants awarded, etc.) that have been spawned by the Centre.

Leveraged research initiatives

- The purchase by the Centre of a state-of-the-art Optical Coherence Tomograph (OCT, $107k), enabled Drs Maddess and James to leverage $1.2m in Centre-related research support from Seeing Machines Ltd in 2006-07, and additionally enabled them to leverage an NHMRC Development Grant of $113k to assist with large scale clinical experiments on glaucoma.
- The Centre's purchase of a 32-channel EEG/ERP recording system ($43k) has allowed Dr Maddess' group to conduct their core research projects on multifocal analysis of macular degeneration and diabetic retinopathy. But in addition, our Partner Investigator, Seeing Machines Ltd, supplied the dichoptic stimulus generator, which meant that parallel multifocal pupillography experiments could also be done on the same subjects. The freeing-up of an older EEG system meant that Dr Maddess was able to leverage two other projects: an NHMRC-funded set of large scale clinical experiments on multiple sclerosis ($143k), and similar experiments on Parkinson's disease funded by the RSBS Biotechnology Research Fund ($166k).
- The Centre's purchase of a cortical optical imaging system ($110k) has enabled Dr Ibbotson to leverage two new initiatives: (1) a collaborative research project with NICTA, aimed towards the development of a Bionic Eye, and (2) a planned collaboration with Dr Geoff Goodhill (UQ) to work on cortical development, with major medical implications.
- Centre funding led to an increased level of work on Dr Ibbotson's cat cortex projects through an increase in critical mass. This provided preliminary data that enabled Dr Ibbotson and Professor Dreher to apply successfully to the NHMRC for a project on integration of feedforward and feedback signals ($282k).
- Using Centre funding for the study of insect odometry, Dr Ibbotson has built a small but coherent critical mass of insect physiologists (3 students and 3 post-docs over 2 years). This had a major impact on winning a US Air Force grant on visual orientation in flying insects ($340k).



Construction of new beehouse at the University of Queensland node



A representation of a newly patented ensemble of stimuli arising from the multifocal pupillographic perimeter project with Seeing Machines

- As a result of his relocation from our ANU node to our University of Queensland node Professor Mandyam Srinivasan leveraged a substantial increase in infrastructure support from UQ. This included construction of new beehouse at a cost of $2.3m, and renovation of a flight tunnel; in addition Professor Srinivasan has been given around 250 sq metres of laboratory space, of which about half is devoted to Centre projects.
- Professor Srinivasan's progress in visually guided insect flight and its applications to robotics, which has been supported by the Centre, has leveraged both a Queensland Smart State Premier's Fellowship for Professor Srinivasan (2008-2012, $1.25m), and a U.S. Asian Office of Aerospace Research and Development grant for research on target tracking and interception by aggressive honeybees ($140k).
- The Centre's support for Professor Lamb's research on photoreceptors allowed him to extend a pilot study on the evolutionary origin of photoreceptors to encompass the writing of a review on the evolution of the vertebrate eye (Lamb, Collin & Pugh, 2007, in section 4, Publications). The testing of the predictions of that model are outside the scope of the research plan set out in the Centre's application for funding and will be conducted as a non-Centre project.
- The Centre's support for Dr Morgan's research on prevention of myopia with brief periods of imposed myopic defocus has leveraged funding for translational research in two clinical trials. The first involves brief periods

of monocularly-imposed myopic defocus and is funded by the Singapore Eye Research Institute (S$10k). The second involves brief periods of binocular myopic defocus under teacher supervision in schools, and is funded by the Department of Preventive Ophthalmology, Zhongshan Ophthalmic Centre, Guangzhou, China, in collaboration with the Department of Education, Guangzhou City (estimated cost $80k). The Centre's support for analysis of the control of eye growth by Dr Morgan, particularly work on the control of retinal dopamine release by light in relation to the prevention of myopia associated with time spent outdoors, contributed to a successful NHMRC grant application ($1.2 million over 3 years) for a follow-up study of the initial cohort of the Sydney Myopia Study.

- The Centre's support for analysis of the control of eye growth by Dr Morgan has also stimulated a forthcoming 10-month sabbatical visit by Professor William Stell, of the University of Calgary, to investigate interactions between the dopaminergic and nitrergic systems in the control of eye growth in the chicken retina. This visit is directly supported by a grant to Professor Stell from the Alberta Heritage Foundation for Medical Research (C$21k), and the research will also be supported in part by a National Science and Engineering Research Council of Canada Discovery grant to Professor Stell (2007-2012, C$28k per annum). It is envisaged that this will be an on-going collaboration on growth control pathways.
- The Centre's support for Dr Zhang's research has leveraged several studies on honeybees in China (at Zhe-Jiang University, at the Chinese Academy of Science, and at Yunnan Agricultural University) and in Europe (University of Würzburg, and University of Liechtenstein).

Leveraged outputs

Patent application

Maddess T & James AC, "Method and apparatus for sensory field assessment", Australian patent application (No. 2007906174).

Leveraged research grants

Dreher B, Ibbotson MR, Wang C, Solomon S & James A, "Integration of information by cells in mammalian visual cortices: role of feedforward and feedback inputs", NHMRC Project grant 457525, 2006-2009, $282,250.

Maddess T, James AC, Goh XL, Kolic M, Carle CF, Centre-related research support, Seeing Machines Ltd, 2006-2007, $1.2m.

Maddess T, James AC, Goh XL, Kolic M, "Binocular objective visual field testing using pupillography", NHMRC Development Grant, 2007, $113,000.

Maddess T, James AC & Lueck CJ, "Rapid, cost-effective, diagnosis and monitoring of multiple sclerosis by novel multifocal evoked potential methods", NHMRC Development Grant, 2007-2008, $143,000.

Maddess T, James AC, Voicu C, Caetano T, Barbosa M, "Neurodegenerative diseases and vision", RSBS Biotechnology Research Fund, 2007-2008, $166,000.

Mitchell P, Smith W, Rose KA, Wang JJ, Flood V & Morgan IG, "Sydney Adolescent Vascular and Eye Study (SAVES)", NHMRC Project Grant 512530, 2008-2010, $1,234,788.

Srinivasan MV, "From small brains to novel aerospace technology", Queensland Smart State Premier's Fellowship, 2008-2012, $1.25m (analogous to an ARC Federation Fellowship, with similar funding rules).

Srinivasan MV, "Target tracking and interception by aggressive honeybees", U.S. Asian Office of Aerospace Research and Development, 2007-2008, $140,000.

Stange G, Dacke M, Warrant E & Ibbotson M, "Nocturnal visual orientation in flying insects: a benchmark for the design of vision-based sensors in micro-aerial vehicles", US Air Force grant, 2007-2010, $340,000.

Stell WK, Alberta Heritage Foundation for Medical Research, 2008, C$21,400.

Leveraged clinical trials

Clinical trial registered as "Pilot study to assess the efficacy of short exposure to defocus to slow the progression of myopia in children", ClinicalTrials.gov Identifier NCT00400140. Funded by the Singapore Eye Research Institute, S$10,000.

An application for registration as a clinical trial has been submitted to ClinicalTrials.gov under the title "A randomised controlled trial of prevention of juvenile-onset myopia in Chinese children". Funding from the Department of Preventive Ophthalmology, Zhongshan Ophthalmic Center, Guangzhou, China, in collaboration with the Department of Education, Guangzhou City; estimated cost $80,000.

6 Invitations to International Conferences

During 2007 the Centre's Chief investigators were invited to address many international conferences. In addition they participated on the organising committees of a number of major international conferences.

Dr Michael Ibbotson

- Dr Ibbotson was invited to deliver a Plenary Lecture to the The Australia-United States bilateral Emerging Technologies Conference, DSTO, 2007 to speak about "*Emerging Technologies in Neuroscience – Defence and National Security Implications"*
- He was an invited symposium speaker at the 7th IBRO World Congress of Neuroscience, Melbourne, 2007, "*Visual movement detection in the cortex*".

Professor Trevor Lamb

- Professor Lamb was invited to deliver a lecture "*From photopigment spectral sensitivities to colour matching functions, and back*" at the Summer Colour Conference, 1-2 February 2007, at the National Vision Research Institute, Melbourne, Australia.
- Professor Lamb was invited to deliver the Plenary Lecture, entitled "*Human rods, cones, and bipolar cells: their responses, adaptation, and role in vision*", at the 2007 FASEB Summer Research Conference, "Biology and Chemistry of Vision", 16-21 June 2007, Snowmass Village, Colorado, USA.

Dr Ted Maddess

- Dr Maddess was an invited Symposium Speaker on "*Multifocal pupillographic visual field measurement*" at the 2007 Australasian Ophthalmology and Vision Science Meeting, Canberra.
- Dr Maddess was on the organising Committee of the 2007 Australasian Ophthalmic and Vision Sciences meeting, Canberra.
- Dr Maddess was a program Committee member for the 2007 SPIE, BioMEMS and nanotechnology II meeting, Canberra.

Dr Ian Morgan

- Symposium speaker (Myopia), Asia-ARVO, Singapore, March 2007, "*Is dopamine an important regulator of eye growth in both animals and humans*".
- Symposium speaker (International Epidemiology), Asia-ARVO, Singapore, March 2007, "*Race and ethnicity in the development of myopia*".
- Symposium speaker, 10th Anniversary Celebrations of the Department of Ophthalmology, Zhongshan Ophthalmic Centre, Guangzhou, September 2007, "*A three-phase model of refractive development in children*".
- Symposium speaker, International Conference on Refractive and Oculomotor Disorders, Helmholtz Research Institute of Eye Diseases, Moscow, September 2007, "*The use of plus lenses to control myopic progression – from the lab to the clinic*".

- Symposium speaker, Australasian Ophthalmic and Visual Science Meeting, Canberra, December 2007, "*Environmental effects on the development of myopia*".
- Chair of Organising Committee, Australasian Ophthalmic and Visual Sciences Meeting, Canberra, December 2007.
- Symposium organiser, "*Myopia: Prevalence, causes and prevention*", Australian Ophthalmic and Vision Science Meeting, Canberra, December 2007.

Dr Jan Provis

- Dr Provis was invited to address the Fall Vision Meeting of the Optical Society of America, Berkeley CA, September 16-19.

Professor Mandyam Srinivasan

- University Lecture, Cornell University, 4 October 2007
- Symposium speaker in the international Symposium on Development and Evolution of Higher Cognition in Animals, Australian Academy of Science, Canberra, 4 May 2007, *"Perception, learning and 'cognition' in honeybees"*
- Symposium speaker, Symposium on Higher Cognition in Animals, Forum for European-Australian Science and Technology Cooperation (FEAST), Berrima, 6-8 May 2007, "*The Non-cognate bee. Invited presentation*".
- Plenary Lecture, 7th IBRO World Congress of Neuroscience, Melbourne, 12-17 July 2007, "Small Brains, Smart Minds: Vision, navigation and 'cognition' in honeybees, and applications to robotics".
- Invited presentation, International Conference on Flying Insects and Robots, Monte Verita, Ascona, Switzerland, 12-17 August, 2007, "*Visual guidance of flight in flying insects*".
- Co-organizer, *International Conference on Flying Insects and Robots*, Monte Verita, Ascona, Switzerland, August 12-17, together with Prof. Dario Floreano, EPF Lausanne, Switzerland .
- Plenary Lecture, 12th International Commercialization of Micro and Nano Systems Conference, Melbourne, 2-5 September 2007, "*Bug-Eyed Science*".
- Co-organizer, *Ninth Australasian Conference on Robotics and Automation,* Brisbane, 10-12 December 2007, together with Dr Matthew Dunbabin, CSIRO.

Dr Krisztina Valter

- Dr Valter was a member of the Organising Committee of the Australasian Ophthalmic and Visual Sciences Meeting, Canberra, Australia. December 2007
- Dr Valter gave an invited lecture at the Foundation Meeting of the Australasian Consortium for the Care of Retinal Dystrophies, Canberra, Australia. December 2007

Professor David Vaney

- Prof Vaney was invited to give a Plenary Lecture at the Inaugural European Retina Meeting, Frankfurt, 4-6 October 2007.
- Prof Vaney chaired the Organising Committee of Vision Down Under 2007, which was a Satellite Meeting of the 7th IBRO Congress of Neuroscience, held near Cairns QLD from 19-22 July 2007. VDU 2007 was the largest gathering of visual neuroscientists ever held in Australia, attracting 250 registrants including 100 from overseas.
- Prof Vaney and Prof Srinivasan chaired the Symposium on "Minds with an eye for movement: visual motion processing in simple and complex brains" at the 7th IBRO World Congress of Neuroscience, Melbourne, Australia, 12-17 July 2007.

Professor Dao-Yi Yu

- Professor Yu was a keynote speaker at an international ophthalmology congress in China. Yu D-Y, Cringle SJ, Su E-N, Balaratnasingam C, Morgan WH, X Sun, W-Y Guo and Yu PK (2007) Function, structure and metabolism of retinal ganglion cells, Chongxi, China.

Dr Jochen Zeil

- Dr Zeil was an invited lecturer and field work organiser at the 2007 IBRO Advanced School of Neuroscience "Neuroethology" in Argentina, Buenos Aires, 12-29 November 2007
- Dr Zeil was invited as Symposium speaker at the 8th International Congress of Neuroethology, Vancouver, Canada, July in the symposium "*Eye and head movements: functional and evolutionary aspects*": Zeil J, Boeddeker N, Hemmi JM (2007) Vision and the Organization of Behaviour.
- Dr Zeil was an invited speaker at the International Symposium on Flying Insects and Robots. Monte Verita, Ascona Switzerland, August. Zeil J, Boeddeker N, Gilbert C, Carey N (2007) Stealthy target tracking in satellite flies.
- Dr Zeil together with Drs Hemmi, Narendra, and Peters organized the Annual Easter Conference of the Australasian Society for the Study of Animal Behaviour (ASSAB) at the ANU, Canberra, Australia.

7 International visitors

The following leading international scientists visited the Centre's Chief Investigators in 2007 for collaborative research and /or to deliver lectures.

- Professor S Bisti, Universita di L'Aquila, Italy
- Professor B Chauhan, Dalhousie University, Nova Scotia, Canada
- Professor J Eells, University of Wisconsin, Milwaukee, USA
- Professor M Giurfa, University of Toulouse, France
- Professor A Hendrickson, University of Washington, USA
- Professor J Hildebrand, University of Arizona, USA
- Professor I Meinertzhagen, Dalhousie University, Canada
- Professor Y Nagai, Kokushikan University, Japan
- Professor D Osorio, University of Sussex, UK
- Professor R Payne, University of Maryland, USA
- Professor W Ribi, University of Liechtenstein, Liechtenstein
- Professor W Sponsel, University of Texas, San Antonio, USA
- Professor J Shi, Fudan University, China
- Professor WK Stell, University of Calgary, Canada
- Professor E Warrant, University of Lund, Sweden
- Emeritus Professor A Watanabe, National Institute for Physiological Sciences, Japan
- Professor R Weiler, University of Oldenburg, Oldenburg, Germany
- Professor T Wiesel, Nobel Laureate and Secretary General, Human Frontiers Science Program
- Professor D Williams, University of California, San Diego, USA
- Dr E Baird, University of Bielefeld, Germany
- Dr K Bumsted O'Brien, University of Auckland NZ
- Dr J Carroll, Medical College of Wisconsin, USA
- Dr M Dacke, University of Lund, Sweden
- Dr S Dakin, University College London, UK
- Dr T Delbruck, ETH Zürich, Switzerland
- Dr B Greiner, Dalhousie University Halifax, Canada
- Dr W Hong, Kunming Institute of Zoology, China
- Dr S Nishida, NTT Basic Research Laboratories, Japan.
- Dr S Pandav, Advanced Eye Center, Postgraduate Institute of Medical Education and Research, India
- Dr R Taylor, Oregon Health & Science University, Portland OR, USA
- Dr M van Wyk, Max Planck Institute for Brain Research, Frankfurt, Germany
- Dr C Voicu, University of Otago, New Zealand
- Dr B Webb, University of Edinburgh, Scotland
- Dr E Yang, National Taiwan University, Taiwan

8 Collaborations

The Centre's researchers actively collaborate with leading national and international scientists in the field of vision science. Examples of such collaborative research activities in 2007 are listed below:

Professor Bogdan Dreher

- A/Prof TR Vidyasagar & Professor PR Martin, University of Melbourne, Australia, *Laminar distribution of different functional classes of neurons in the dorsal lateral geniculate nucleus and cortical interactions between afferent channels in macaque visual system.*
- Professor MB Calford, University of Newcastle, Australia. *Reorganization of primary visual cortex following circumscribed retinal lesions.*
- Professor K Obermayer, Berlin University of Technology & Humboldt University of Berlin, Germany. *Modelling of neuronal mechanisms underlying reorganization of primary visual cortex following circumscribed retinal lesions.*

Dr Mark Edwards

- Dr S Nishida, NTT Basic Research Laboratories, Japan and Professor David Badcock, University of Western Australia, Australia. *Processing stages in human motion extraction*.
- Dr S Kohlhagen, National Science & Technology Centre, Canberra, Australia. *Interaction of vestibular and optic-flow processing*.

Dr Michael Ibbotson

- Professor M Mustari, Emory University, USA. *Primate Research*
- Dr G Goodhill, University of Queensland, Australia. *Cortical development*

Dr Andrew James

- Dr S Vanni, Helsinki University of Technology, Finland. *Advanced imaging techniques for human cortex.*
- Dr M Dojat, INSERM, U836 & Joseph Fourier University, France. *fMRI mapping of human visual cortex.*
- Drs A Klistorner & SL Graham, University of Sydney, Australia. *Multifocal visual evoked potential mapping of human visual fields.*

Professor Trevor Lamb

- Professor EN Pugh Jr, University of Pennsylvania, USA and Professor SP Collin, University of Queensland, Australia. *Evolution of the vertebrate eye.*
- Dr M Pianta, University of Melbourne, Australia. *Measurement of human psychophysical dark adaptation in the scotopic visual system.*
- Professor Y Fukada, Tokyo University, Japan and Professor S Kawamura, Osaka University, Japan. *Involvement of GRKs in shut-off of the rod's response to light.*

Dr Ted Maddess

- Dr T Caetano & Dr M Barbosa, NICTA, Australia. *Stochastic methods for generation of texture patterns with constrained statistics.*
- Dr R Essex, Canberra Hospital and Dr I Dunlop, Canberra Eye Hospital, Australia. *Development of a pulliographic visual field analyser.*
- Dr K Rose, University of Sydney, Australia. *The Sydney myopia study.*
- Dr CJ Lueck & Dr G Danta, Canberra Hospital, Australia. *Multifocal methods in multiple sclerosis.*
- Dr Y Rosli, University of Kebangsaan Malaysia. *A multifocal VEP and pupillographic investigation of macular degeneration.*
- Professor Y Nagai, Kokushikan University, Japan; Professor JD Victor & Dr MM Conte, Weill Medical College, Cornell University, USA. *Studies of the visual sense of structure using deterministic isotrigon texture patterns.*
- Dr EC Yang, National Taiwan University, Taiwan. *Rapid assessment of texture vision of bees.*

Dr Ian Morgan

- Dr K Rose & Professor P Mitchell, University of Sydney, Australia. *Risk factors for myopia in children.*
- Professor L Ellwein, National Eye Institute and World Health Organisation, USA. *What is the natural end-point for refractive development in children and further analysis of the Refractive Error Study in Children data.*
- Dr K Schmid, Queensland University of Technology, Australia. *Dopamine release in response to image contrast.*
- Professor M He, Zhongshan Ophthalmic Institute, Sun Yat-sen University, China. *Clinical trial of imposed myopic defocus in preventing myopia and analysis of data from the Guangzou Twin Eye Study.*
- Professor SM Saw, National University of Singapore, Singapore. *Risk factors for myopia in children – comparative analysis of data from Sydney and Singapore.*
- Dr WH Chua and Professor D Tan, Singapore Eye Research Institute, Singapore. *Clinical trial of imposed myopic defocus in the prevention of myopia.*
- Dr M Boelen, LaTrobe University, Australia. *Role of dopamine receptor adaptation in the retinal dark-light switch and the control of eye growth.*
- Dr P Megaw, James Cook University, Australia. *Dopamine release in the control of eye growth.*

Dr Jan Provis

- Professor A Hendrickson, University of Washington, USA. *Development of human retina.*
- Dr K Bumsted-O'Brien, University of Auckland, New Zealand. *Patterning in the developing retina – siting the fovea.*
- Dr M Madigan, University of Sydney, Australia. *Gene expression in central vs peripheral retina; Ageing of the human retina and AMD; Regression of the hyaloid vasculature – a proteomic analysis of human fetal vitreous.*
- Dr J Sebag, University of Southern California, USA and Professor Lloyd Paul Aiello, Harvard University, USA. *Regression of the hyaloid vasculature – a proteomic analysis of human fetal vitreous.*

Professor Mandyam Srinivasan

- Dr E Baird, University of Bielefeld, Germany. *Control of altitude and flight speed in honeybees.*
- Dr M Dacke, University of Lund, Sweden. *Polarization vision and path integration in honeybees.*
- Professor D Floreano, EPF Lausanne, Switzerland. *Biologically inspired robotics.*
- Professor R Chellappa, University of Maryland, USA. *Biologically inspired machine vision.*
- Dr W Ribi, University of Liechtenstein, Liechtenstein. *Neuroanatomy of learning and memory in honeybees.*
- Dr W Stürzl, Technical University of Munich, Germany. *Wide-angle imaging systems.*

Professor Jonathan Stone

- Professor J Heckenlively, University of Michigan, USA. *Inherited retinal dystrophies.*
- Professor S Bisti, Universita di L'Aquila, Italy. *Anti-oxidant dietary in the mitigations of retinal dystrophies.*
- Professor J Eells, University of Wisconsin, Milwaukee, USA. *Near-Infrared radiation in the mitigation of retinal dystrophies.*
- Professor J Mitrofanis, Australian National University and University of Sydney, Australia. *Impact of cerebral haemorrhage on synaptic density in surrounding tissue.*

Dr Krisztina Valter

- Prof S Bisti, Universita di L'Aquila, Italy. *The effects of the antioxidant saffron on the mammalian retina.*
- Prof J Eells, University of Wisconsin, Milwaukee, USA. *Protective and therapeautic effects of near-infrared light on the mammalian retina.*

Professor David Vaney

- Dr WR Taylor, Oregon Health & Science University, USA. *Information processing in the retina.*
- Dr M van Wyk, Max Planck Institute for Brain Research, Germany. *Local-edge-detector retinal ganglion cells.*

- Prof R Weiler, University of Oldenburg, Germany. *Gap junctions in the retina.*
- Prof M Wilson, University of California, Davis, USA. *Nitrergic neurons in the bird retina.*

Professor Dao-Yi Yu and Dr Stephen Cringle

- Dr G Zinser, Heidelberg Engineering, Germany. *Laser based measurements of retinal blood flow in health and disease.*
- Professor T Gardner, Penn State College of Medicine, USA. *Retinal vascular permeability.*
- Professor M Humayun, Doheny Eye Institute, USA. *A new device for retinal oxygenation.*

Dr Jochen Zeil

- Dr K Cheng, Macquarie University, Australia. *Information content of panoramic images.*
- Dr A Cheung, University of Queensland, Australia. *Information content of panoramic images.*
- Professor S Deeb, University of Washington, USA. *Fiddler crab opsin genes.*
- Dr B Greiner, Dalhousie University, Canada. *Photoreceptor specializations in ants.*
- Dr R Maleszka, Australian National University, Australia. *Fiddler crab opsin genes.*
- Dr W Stürzl, Technical University Munich, Germany. *View-based homing in insects.*

Dr Shaowu Zhang

- Professor J Tautz, Würzburg University, Germany. *Honeybee navigation.*
- Professors H Gross and J Tautz, Biozentrum, Würzburg University, Germany. *Number-based visual generalisation in the honeybee.*
- Professors S Su and S Chen, Zhe-Jiang University, China. *i) Non-destructive genotyping and genetic variation of fanning in a honey bee colony. ii) East meets west: Asiatic honeybees can understand the dances of European honeybees.*
- Professors R Chen & L Liu, Institute of Biophysics, Chinese Academy of Sciences, China. *Function of non-coding genes in honeybees.*
- Professor F Liu, Xishuangbanna, Tropical Botanical Garden, Chinese Academy of Sciences, China. *Giant honeybee migration routes in the tropical Asian rain forest.*
- Professor K Tan, Yunnan Agricultural University, China. *The role of dorsal ram of compound eye in honeybee navigation.*
- Professor W Ribi, University of Liechtenstein, Liechtenstein. *Investigation of learning and memory in the honeybee.*

9 Research commercialisation

TrueField Analyzer – Objective perimetry made easy

In 2007, Drs Ted Maddess and Andrew James, two of the Centre's Chief Investigators, devoted extensive time for the development of a new diagnostic device with the Centre's commercial partner Seeing Machines. This device, the TrueField Analyzer now has FDA approval and has been demonstrated at the two leading international ophthalmology conferences during 2007. The device is based on the methodology for the multifocal mapping of visual fields developed over the years by the Centre's Chief Investigators.

TrueField Analyzer

The TrueField Analyzer heralds a new era in visual field testing. It combines objectivity with "non-contact" ease of use, making it easy for technicians and patients, and gives clinicians objectivity in assessing their patient's condition. The device brings together advanced multifocal stimulus and analysis methods with real-time computer vision pupil monitoring to realize the dream of objective pupil perimetry. The device compares a subject's performance against a normative database and generates bilateral visual field test results. In addition, relative size of direct and consensual responses can indicate a range of neurological issues that warrant further investigation.

For more information about the device please visit www.TrueField-Analyzer.com. More information about our commercial partner, Seeing Machines, can be obtained from their website www.seeingmachines.com.

Optical detection system

Last year Professor Srinivasan and his team, comprising Mr Dean Soccol and Mr Saul Thurrowgood, filed an Australian provisional patent application for their novel "Optical detection system". This year they have filed an International (PCT) patent application to protect this intellectual property internationally. The "Optical detection system" has potential for use in multiple applications such as in Unmanned Aerial Vehicles (UAVs); in industry for the measurement of the volume of materials being transported on a conveyor belt, and use of such measurements to control the feed rate from the conveyor; and in road profile measuring, road quality assessment and in automatically controlling the profile of a road surface as it is being constructed. A second provisional patent application has been filed for a further modification of the system that involves the use of two reflective surfaces (rather than one) and which provides the same information without any need for motion. Some progress has been made in finding a suitable partner for commercialising this innovative system.

A specially shaped mirror – a key element of the optical detection system

10 Education and training

Summer Research Scholars program

The ANU node of the Centre runs a Summer Research Scholar Program designed for talented students considering undertaking postgraduate research in the future. The program is an excellent opportunity to work with distinguished researchers, utilising facilities and materials not readily available elsewhere. The Centre's Chief Investigators, Dr Ted Maddess, Dr Ian Morgan, Dr Krisztina Valter, and Professor Trevor Lamb were among those who supervised several summer scholars in 2007.

Honours students

The following seven students completed their Honours degree in 2007 working with Centre Chief Investigators:

STUDENT	SUPERVISOR	NODE
Phillip Romo	Jan Provis	ANU
Matthew Rutar	Krisztina Valter	ANU
Angeliza Querubin	Krisztina Valter & Jan Provis	ANU
Kanupriya Kalia	Mark Edwards	ANU
Brand Steyn	Mark Edwards	ANU
Madeleine Scott	Michael Ibbotson	ANU
Corinne Carle	Ted Maddess	ANU

New graduate students

The following four new PhD/Masters students joined the Centre in 2007.

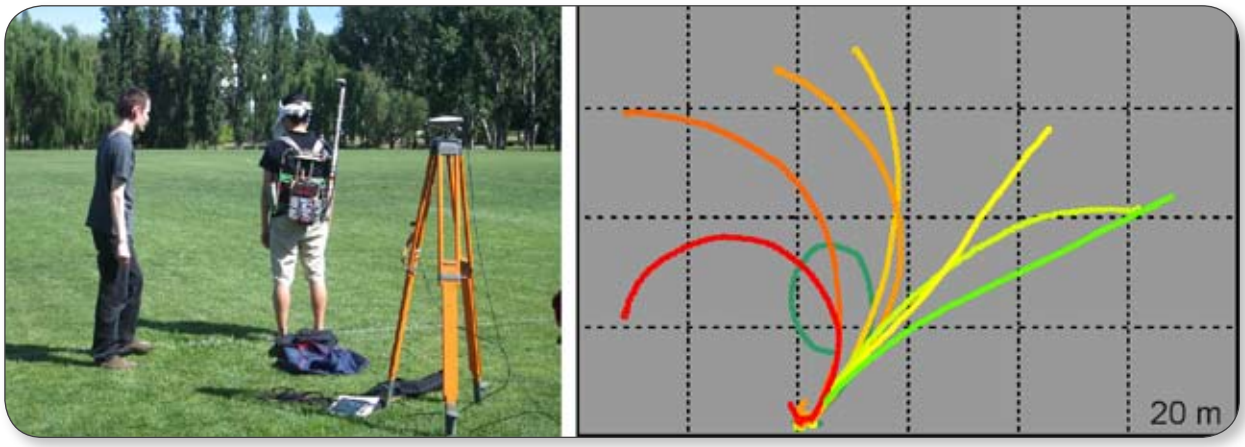
STUDENT	DEGREE	SUPERVISOR	NODE
Antony Gates	PhD	Mark Edwards	ANU
Hung Yu-Shan	PhD	Michael Ibbotson	ANU
Samuel Reid	PhD	Jochen Zeil	ANU
Maria Kolic	MPhil	Ted Maddess	ANU

Sixth ACEVS-CVS Summer School on Animal Navigation

One of the Centre's Chief Investigators, Dr Zeil, organised the Sixth ACEVS-CVS Summer School on Animal Navigation. The idea is "*to introduce students from Australia and New Zealand to a fascinating and rapidly developing multi-disciplinary research field*." The school is aimed at 3rd year, honours and PhD students of biology, psychology and robotics. A number of other staff members of the Centre including Drs Zhang, Narendra, Cheung and Boeddeker participated in the delivery of this course. In 2007 the school covered the following topics:

- Zeil: View-based Homing
- Zhang: The role of learning & memory in honeybee navigation
- Boeddeker: Gaze, flight control & optic flow processing in insects
- Vickerstaff: Path integration I: Principles & models
- Cheung: Path integration II: Errors & limitations
- Narendra: Path integration and landmark guidance in ants
- Barron: The honeybee dance language
- Cheng: Representation of space
- Nordstroem & Brinkworth: Target tracking and pursuit
- Garratt & Chahl: Autonomous flight
- McCarthy & Barnes: Robot navigation: The use of optic flow
- Zimmer: Robot navigation: Control architectures

The Summer School runs for one week and aims to create a discussion atmosphere that involves both students and lecturers. This year there were a total of 25 participants, including students from Adelaide, Brisbane and ADFA. With the help of Matt Garratt's differential GPS system we also conducted a human navigation experiment on the *Ability to Walk Straight*.



The portable differential GPS system (owned and adapted by Matt Garratt, ADFA, Canberra) and the recorded paths of 8 blind-folded people asked to walk straight for 100 steps (photograph by Mario Pahl).

11 Outreach

Can you believe your eyes?

L-R: Em Blamey (Questacon), Stuart Kohlhagen (Questacon), Mark Edwards (ACEVS) with the visual illusions exhibit installed at Questacon

This is a new visual illusion exhibit that was unveiled at Questacon in August 2007. This exhibit is a joint initiative between the ARC Centre of Excellence in Vision Science and Questacon, Australia's National Science and Technology Centre. The display explains aspects of how the brain processes visual information by showing and explaining a number of visual illusions. The illusions used in this exhibit have been selected and developed to reflect some of the hot research topics in vision science that this Centre of Excellence has been formed to advance. The main thrust behind the development of this exhibit is to promote vision science to the general public and particularly to school students through fun and entertainment. Questacon is visited by more than 400,000 people, including over 100,000 students in organised school groups, from all over Australia, each year. The Centre highly regards its collaboration with Questacon and will continue to support new initiatives of mutual interests. Currently two of the Centre's Chief Investigators, Dr Mark Edwards and Prof Mandyam Srinivasan are working with the development team at Questacon to develop another vision exhibit focussing on perception.

Small brains, smart minds

Prof Srinivasan delivering public lecture at Questacon

Professor Srinivasan, a Chief Investigator and a Theme Leader in the Centre, delivered a public lecture entitled, "Small brains, smart minds" at Questacon. In his lecture Professor Srinivasan described his research aimed at understanding the mechanisms underlying visual perception, navigation, learning, memory and 'cognition' behaviour in honeybees. He explored opportunities for incorporating insect-inspired principles into the design of autonomous robots. The lecture initiated a lot of interest in people who attended the lecture that was obvious from an extended question and answer session following the lecture. The Centre and Questacon are planning to continue this initiative with a public lecture series at Questacon, where researchers from the Centre will deliver lectures describing their latest research in vision science.

Other outreach activities

Centre staff actively participate in outreach activities. Some of these activities in 2007 are listed below:

Dr Michael Ibbotson
As the representative of the Australian Neuroscience Society, Dr Ibbotson set up a committee to organise the ACT element of the National Brain Bee competition. A competition was held at the ANU and the winner went to Melbourne during the IBRO congress to compete in the national finals.

Professor Trevor Lamb
Gave a presentation about the ARC Centre of Excellence in Vision Science at ANU open day.

Dr Ted Maddess
Hosted Year 11 students attending the National Summer Science Fair
Delivered a public lecture to ACT optometrists and ophthalmologists on glaucoma
Delivered a public lecture to ACT neurologists on multiple sclerosis

Dr Ian Morgan
President of the Australian Society for Vision Research

Dr Suzzane Petratchkov
Delivered a public lecture to the ACT Print Handicapped Society

Dr Jan Provis
Sat on the Scientific Advisory Committee for the Ophthalmic Research Institute of Australia. This committee is responsible for the assessment of research applications and distribution of $300-400K of research funds each year.

Prof Mandyam Srinivasan
Delivered a dinner lecture, *'Insect vision and navigation, and applications to robotics'* at National Youth Science Forum, Canberra.
Delivered a lecture, *'Honeybee Vision',* at Kenmore High School, Queensland
Delivered a lecture, *'How insects find their way',* at the Hut Environmental and Community Association Inc, Brisbane, Queensland
Member, Prime Minister's Science, Engineering and Innovation Council (PMSEIC), Oct 2006 - Sept 2007
Deputy Chair, PMSEIC working group on water for our cities, April - June 2007
Co-author, PMSEIC working group report on water for our cities, June 2007
Delivered a public lecture, small brains, smart minds: vision, navigation and cognition in honeybees, and applications to robotics, BrisScience, Brisbane City Hall, 27 August 2007

Dr Jonathan Stone
Founded the Australasian Consortium for the Care of Retinal Dystrophies (ACCORD) and organised its inaugural meeting on 4 December 2007. One of the purposes of ACCORD is to encourage the translation of research outcomes into treatment for retinal dystrophies, through appropriate clinical trials.

Dr Krisztina Valter
Hosted students from National Youth Science Forum, gave a lecture and organised practical activities

Prof David Vaney
President-elect of Australian Neuroscience Society
Member, Management Committee, Australian Course in Advanced Neuroscience

Dr Jochen Zeil
Dr Zeil and Martin How hosted two groups of students in the National Youth Science Forum

Dr Shaowu Zhang
Delivered a public lecture at the Canberra Society of Chinese Scholars (CSCS)

12 Performance measures and outcomes

Research Findings

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Number and quality of publications	**25** refereed journal articles Majority of publications in journal with impact factor > 2.5	**43** Journal articles, of which **23** articles in international refereed journal with impact factor >2.5 **6** Book chapters **109** Abstracts and conference proceedings (For details, see list of publications, section 4)
Number of patents	Filing an average of 1 p.a. after 1 year	**1** International patent application **2** Provisional patent applications
Invitations to address and participate in international conferences	**5** p.a.	**23** Invited lectures **10** Participations as conference organisers
Invitations to visit leading international laboratories	**5** p.a.	**17**
Number and nature of commentaries about Centre achievements	**5** p.a.	**27** Commentaries about Centre research and the work of its chief investigators

Research Training and Professional Education

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Number of postgraduates recruited	**8** p.a.	**4**
Number of postgraduates completions	**8** p.a. after first three years	To be reported after 3 years
Number of honours students	**8** p.a.	**8**
Number of professional courses	One each alternate year	**1**
Participation in professional courses	**5** CI/PI participation p.a.	**1**
Number and level of undergraduate and high school courses	**2** p.a. undergraduate summer schools, and **1** p.a. undergraduate course contribution	**1** summer school **1** summer scholar program **15** undergraduate course contributions

International, National and Regional Links and Networks

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Number of international visitors	**8** p.a.	**34**
Number of international and national workshops	At least 1 meeting, or satellite event, at a national or international meeting p.a., and 1 targeted workshop p.a.	**6** international **4** national
Number of visits to overseas laboratories	**10** p.a.	**17**

End User Links

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Number and nature of commercialisation activities	**2** interactions with commercial partners commenced p.a.	**1**
Number of government, industry and business briefings	**2** p.a.	**5**
Number of Centre associates trained/ing in technology transfer and commercialisation	Average 2 p.a.	**None**
Number and nature of public awareness programs	Average 3 p.a.	**4**

Organisational Support

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Annual cash contributions from Collaborating Institutions/Organisations	As listed in Table 1 of Schedule 3 of Collaborating Parties Agreement	All required contributions were received
Annual in-kind contributions from Collaborating Institutions/Organisations	As listed in Table 2 of Schedule 3 of Collaborating Parties Agreement	All required contributions were provided
Number of new Organisations recruited to or involved in the Centre	The Centre will initiate new linkages as research directions evolve.	New collaboration with NTT, Japan

Governance

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Breadth and experience of the members of the Advisory Board	Extensive international experience. Leadership in all research fields and end-user links, and in IP. Membership is listed in Application.	Extensive international experience. Leadership in all research fields and end-user links, and in IP. Membership is listed in Section 2.
Frequency and effectiveness of Advisory Board meetings	At least annual, with full input from and feedback to the Executive Committee.	**1** The Board meeting in 2007 provided both full input and feedback.
Quality of the Centre strategic plan	To be assessed by Advisory Board.	The Centre developed a detailed 2-year Research Plan for 2006-07, which was assessed and approved by the Advisory Board
Effectiveness of arrangements to manage Centre nodes	Continual monitoring by Research Director, and Executive Committee meetings at least twice p.a.	Management of the nodes has been continually monitored by the Chief Operations Officer and Research Director, and reviewed by the Executive Committee. There have been **2** formal meetings of the Executive Committee (and additional decisions taken by electronic communication).

National Benefit

PERFORMANCE MEASURE	TARGET	OUTCOME IN 2007
Case studies of economic, social, cultural environmental or other benefits	2	None at this stage.

13 Scientific Meetings

The Centre was closely involved with seven scientific meetings during the year.

Centre Retreat

The Centre held a very successful and enjoyable Centre Retreat from 9 – 11 February 2007 at Murramarang Resort near Batemans Bay, NSW, Australia, where members of the Centre were able to combine research presentations with discussions about future collaborations, in very pleasant surroundings. Over 50 members of the Centre attended this meeting and found it very useful in fostering scientific collaborations across four centre nodes and three research themes.

Young Visionaries

The Centre's PhD students and postdoctoral fellows organised a scientific retreat, Young Visionaries, from 8 -10 September 2007 at ANU Kioloa campus. The idea behind this meeting was to provide young vision scientists in the Centre with opportunities to discuss their research across themes and develop new collaborations. Drs Krisztina Valter and Jan Hemmi, senior members of the Centre, acted as mentors to over 20 students and postdoctoral fellows who attended this meeting.

Young Visionaries group at the meeting

Vision Down Under 2007

The Centre was the principal sponsor of the Vision Down Under 2007 conference held at Novotel Rockford Resort, Palm Cove, near Cairns, Australia, from 19-22 July 2007. The conference brought together 240 Australian and overseas vision scientists, and over 40 of the Centre's researchers presented their findings. The conference also incorporated Festschrifts for two of Australia's leading visual neuroscientists, including Professor Bogdan Dreher, a Chief Investigator in the Centre.

Participants at Vision Down Under 2007

Australasian Consortium for the Care of Retinal Dystrophies

The inaugural meeting of ACCORD, the Australasian Consortium for the Care of Retinal Dystrophies, was held on 4 December 2007 at the ANU's Research School of Biological Sciences. ACCORD is a group of scientists, clinicians and others committed to the understanding and treatment of retinal dystrophies. One of the purposes of ACCORD is to encourage the translation of research outcomes into treatment for retinal dystrophies, through appropriate clinical trials. Five of the Centre's members gave presentations in this meeting, which was also attended by members of the community (from Retina Australia) and research commercialisation professionals (from Eye Co Ltd). The meeting showed that Australasian researchers (including a number of the Centre's researchers) are making strong contributions in the areas of the cell biology and neurochemistry of photoreceptor stability and degeneration. It was also established that research commercialisation possibilities exist in the areas of light management, dietary supplementation, nanoparticle-borne anti-oxidants and neuropharmacological blocking of degeneration-related toxicity, and photobiomodulation. The members of ACCORD are actively exploring several of these possibilities.

Australasian Ophthalmic and Vision Science Meeting

Members of the Centre were the driving force behind the annual Australasian Ophthalmic and Vision Science meeting, held at the ANU's John Curtin School of Medical Research from 1-3 December 2007. Dr Ian Morgan (the President of the Australian Society for Vision Science), a Chief Investigator in the Centre, chaired the organising committee for this meeting. AOVS is Australia's principal vision research meeting, and brings together clinicians with scientists from a wide variety of disciplines, including optometry, visual neuroscience, psychology, robotics, etc.

Centre-Sponsored Symposium

Professors David Vaney and Mandyam Srinivasan organised and chaired the Centre-sponsored Symposium on "Minds with an eye for movement: visual motion processing in simple and complex brains", held at the IBRO World Congress of Neuroscience, Melbourne, 12-17 July 2007. The speakers included Centre Chief Investigator Michael Ibbotson, Centre Partner Investigator Dario Floreano, Richard Masland from Harvard University, and David O'Carroll from the University of Adelaide.

Australasian Society for the Study of Animal Behaviour Conference

In April, the Centre supported Australasian Society for the Study of Animal Behaviour Conference that was organised by Dr Jochen Zeil, a Centre Chief Investigator. The Centre provided travel support for invited speakers and travel scholarships to selected participating students.

14 Financials

The Centre's income and expenditure statement for 2007 is provided in the table below.

INCOME	
Accumulated funds from 2006	$1,917,761
ARC Centre grant	$2,335,228
Cash contributions by Nodes	
ANU	$412,500
UQ	$75,000
UWA	$38,750
USyd	$25,000
TOTAL INCOME	**$4,804,239**
EXPENDITURE	
Salaries	$1,730,740
Equipment	$538,494
Travel	$303,785
Other Expenditure	$345,026
TOTAL EXPENDITURE	**$2,918,045**
Accumulated funds	$1,886,194

Income and Expenditure Statement for 2007

15 Research staff

Chief investigators

Professor Trevor Lamb, The Australian National University
Professor Jonathan Stone, The Australian National University
Professor Bogdan Dreher, The University of Sydney
Professor Mandyam Srinivasan, The University of Queensland
Professor David Vaney, The University of Queensland
Professor Dao-Yi Yu, The University of Western Australia
Dr Stephen Cringle, The University of Western Australia
Dr Mark Edwards, The Australian National University
Dr Michael Ibbotson, The Australian National University
Dr Andrew James, The Australian National University
Dr Ted Maddess, The Australian National University
Dr Ian Morgan, The Australian National University
Dr Jan Provis, The Australian National University
Dr Krisztina Valter, The Australian National University
Dr Jochen Zeil, The Australian National University
Dr Shaowu Zhang, The Australian National University

Partner investigators

Professor Silvia Bisti, University of L'Aquila, Italy
Dr Peter Corke, CSIRO ICT Centre, Australia
Professor Martin Egelhaaf, University of Bielefeld, Germany
Professor Dario Floreano, EPFL Lausanne, Switzerland
Dr Russell Hamer, Smith-Kettlewell Eye Research Institute, USA
Mr Arthur Cheng, ObjectiVision, Australia
Professor Michael Mustari, Emory University , USA
Professor Yoshinori Nagai, Kokushikan University, Japan
Dr Simo Vanni, Helsinki University of Technology, Finland
Professor Johannes Zanker, Royal Holloway, University of London, UK
Dr Nick Cerneaz, Seeing Machines, Australia
Dr Christian Lueck, The Canberra Hospital, Australia

Associate investigators

Dr Norbert Boeddeker, The Australian National University, Australia
Dr Meeuwis Boelen, La Trobe Univeristy, Australia
Dr Keely Bumsted-O'Brien, The University of Auckland, New Zealand
Emeritus Professor William Burke, The University of Sydney, Australia

Dr Tiberio Caetano, NICTA, Australia
Dr Mary Conte, Weill Medical College of Cornell University, USA
Dr Jan Hemmi, The Australian National University, Australia
Emeritus Professor Adrian Horridge, The Australian National University, Australia
Dr Gregory Jackson, The University of Alabama at Birmingham, USA
Emeritus Professor Janus Kulikowski, The University of Manchester, UK
Professor Thomas Labhart, The University of Zurich, Switzerland
Dr Pamela Megaw, James Cook University, Australia
Dr Shin'ya Nishida, NTT, Japan
Dr Philip Penfold, Advanced Ocular Systems Limited, Australia
Professor Edward Pugh, Jr., University of Pennsylvania, USA
Dr Sebastien Rougeaux, Seeing Machines, Australia
Associate Professor Katrina Schmid, Queensland University of Technology, Australia
Professor Jonathan Victor, Weill Medical College of Cornell University, USA
Dr Misha Vorobyev, The University of Queensland, Australia
Dr Chun Wang, The University of Sydney, Australia
Dr Andreas Wenzel, University Hospital Zurich, Switzerland

Centre fellows

Dr Keely Bumsted-O'Brien, The University of Auckland, New Zealand
Dr Jan Hemmi, The Australian National University, Australia

Visiting fellows

Professor Martin Wilson, University of California, Davis, USA
Professor Willi Ribi, University of Liechtenstein, Liechtenstein

Postdoctoral and research fellows

Dr Andrew Bell, The Australian National University
Dr Cecile Bordier, The Australian National University
Dr Allison Cameron, The Australian National University
Dr Shaun Cloherty, The Australian National University
Dr Tanya Detto, The Australian National University
Dr Thomas Fitzgibbon, The University of Sydney
Dr Ajay Narendra, The Australian National University
Dr Suzanne Petratchkov, The Australian National University
Dr Rasa Ruseckaite, The Australian National University
Dr Er-Ning Su, The University of Western Australia
Dr Kunjam Vallam, The Australian National University
Dr Fivos Vogalis, The Australian National University
Dr Shunpeng Wang, The Australian National University
Dr Paula Yu, The University of Western Australia

Research assistants

Ms Juliet Fisher, The Australian National University
Ms Waltraud Pix, The Australian National University
Ms Joanna Maleszka, The Australian National University
Mr Nicholas Nacsa, The University of Queensland
Ms Christina Salmon, The Australian National University
Dr Aung Si, The Australian National University
Mr Dean Soccol, The University of Queensland
Mr Saul Thurrowgood, The University of Queensland
Mr Joshua van Kleef, The Australian National University
Ms Sophie Wilson, The Australian National University
Ms Hong Zhu, The Australian National University

PhD students

Mr Ali Alkaladi, The Australian National University
Mr Regan Ashby, The Australian National University
Ms Emily Baird, The Australian National University
Dr Chandra Balaratnasingam, The University of Western Australia
Mr Parthasarathy Bhagavatula, The Australian National University
Mr Allen Cheung, The Australian National University
Ms Vicki Chrysostomou, The Australian National University
Ms Wiebke Ebeling, The Australian National University
Mr Antony Gates, The Australian National University
Ms Xin-Lin Goh, The Australian National University
Mr John Greenwood, The Australian National University
Mr Samuel Inverso, The Australian National University
Ms Diana Kirk, The Australian National University
Mr Peter Kozulin, The Australian National University
Ms Pinar Letzkus, The Australian National University
Ms Siobhan McCarthy, The Australian National University
Mr Graeme Matich, The University of Western Australia
Mr Riccardo Natoli, The Australian National University
Mr Mario Pahl, The Australian National University
Mr Samuel Reid, The Australian National University
Mr Benjamin Sivyer, The University of Queensland
Mr Jochen Smolka, The Australian National University
Mr Ryan Taylor, The Australian National University
Ms Hung Yu-Shan, The Australian National University
Ms Yuan Zhu, The Australian National University

16 Contact Information

Chief Operations Officer

Adnan Syed Muhammad

ARC Centre of Excellence in Vision Science

The Australian National University
Level 3, Innovations Building
Cnr of Garran and Eggleston Roads
Acton, ACT 2601, Australia
P: +61 – (0)2 – 6125 5398
F: +61 – (0)2 – 6125 9532
E: Adnan.Muhammad@anu.edu.au
W: www.vision.edu.au

Research Director

Professor Trevor Lamb

The Australian National University
John Curtin School of Medical Research
Garran Road
Acton, ACT 2601, Australia
P: +61 – (0)2 – 6125 8929
E: Trevor.Lamb@anu.edu.au

USyd Node

Professor Bogdan Dreher

The University of Sydney
Visual Neuroscience
Department of Anatomy & Histology
F13 - Anderson Stuart Building
Sydney, NSW 2006, Australia
P: +61 – (0)2 – 9351 4194
E: bogdand@anatomy.usyd.edu.au

UWA Node

Professor Dao-Yi Yu

The University of Western Australia
Centre for Ophthalmology and Visual Science
35 Stirling Highway
Crawley, WA 6009, Australia
P: +61 – (0)8 – 9381 0723
E: dyyu@cyllene.uwa.edu.au

UQ Node

Professor David Vaney

The University of Queensland
Queensland Brain Insitute
Brisbane, QLD 4072, Australia
P: +61 – (0)7 – 3346 6334
E: d.vaney@uq.edu.au

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