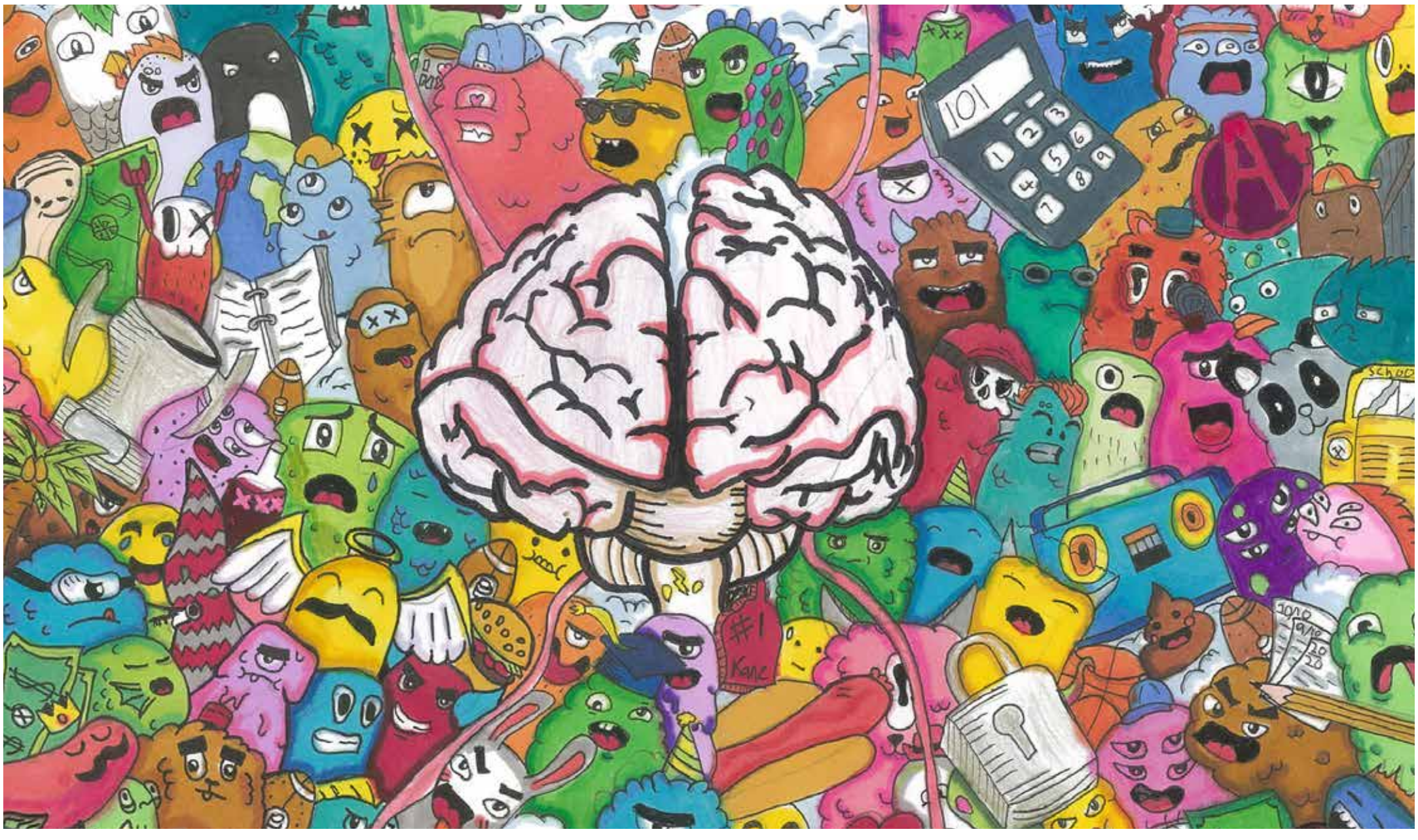
How the Brain Interacts with the World



A journey of brain discovery through science and art

ARC Centre of Excellence for Integrative Brain Function

Australian Research Council
Centre of Excellence for
Integrative Brain Function

The Australian Research Council Centre of Excellence for Integrative Brain Function was established in 2014 through the Australian Research Council's Centres of Excellence program.

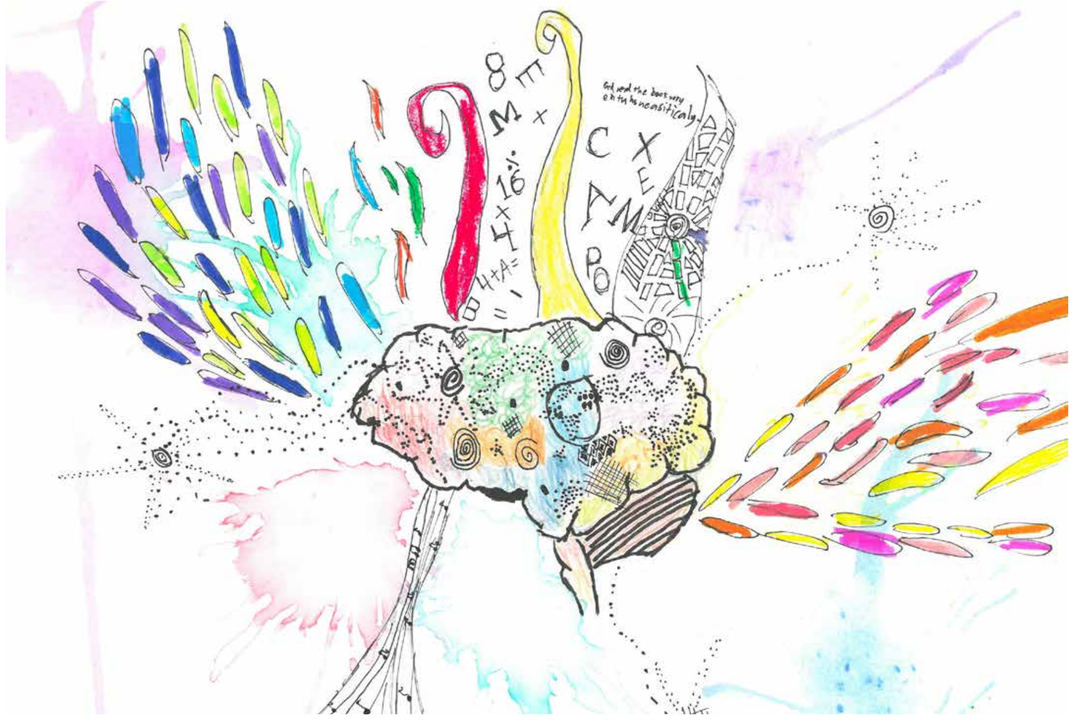
Researchers, students, and collaborators of the Centre have focussed their energy on studying the brain and how it interacts with the world around us.

In addition to scientific research, Centre members engaged with the community to share knowledge with a wider audience. Research findings were translated from scientific articles into plain language summaries, some of which you will find throughout this booklet, to ensure the research was accessible by all.

Targeted events were held to raise awareness of discoveries in brain research and to encourage the next generation to enquire and be curious about the human brain and how it functions. Each year as part of Brain Awareness Week the Centre held an art competition for primary school students around Australia. The competition was designed to encourage students to explore the brain through artistic expression, and to help teach why it's important to understand how our brains interact with the world around us.

More than 250 schools across all Australian states and territories engaged with the art competition and a total of over 4,000 student artworks were submitted. Throughout the book you will find a selection of the amazing artwork that was entered into the competition.

We hope you enjoy viewing the inspiring artwork and reading about the brain research achievements of the Centre.



Artwork: Ghil age 8, 2017

The ARC Centre of Excellence for Integrative Brain Function has achieved so much in seven years. I well remember having the privilege, as Chair of the Advisory Board, of visiting many of the research nodes at the outset, along with the Director Professor Gary Egan. We met brilliant researchers, and the next generation in training, and witnessed their ground-breaking research.

It was exciting and enriching but illustrated to us the potential of the Centre to facilitate more strategic collaboration between the teams. The chapters here show how successful that approach has proved to be.

At a time when humankind is facing so many challenges and opportunities, it is vital that we understand better how our brains shape our behaviour. Australia has a proud tradition as one of the leaders of brain research worldwide and our Centre is helping to add another chapter to that story.

We also set out to enrich the neuroscience discipline in Australia in ways beyond our integrated program of research. These ways included championing diversity and inclusion, supporting researchers early in their careers via mentoring, workshops and retreats, and encouraging science communication via initiatives such as the "In a Nutshell" series. We also reached out to the community to 'demystify' brain research by way of well subscribed public events and engaged with young people through an art-meets-science competition in schools.

The Centre is justifiably proud of our achievements. We leave a legacy on which our researchers and others can build, not only in terms of scientific discoveries but also the culture we have championed.

I trust that you will enjoy this book in which we share our stories with you.

Professor Lyn Beazley AO

I use my brain to be me.

Words and artwork, Dean, age 9, 2017

Artwork: Lucas, age 9, 2021

Visual processing relies on a balance between selectivity and invariance

The human brain has the remarkable ability to recognise specific objects, even when those objects change in appearance. For example, we can tell that a hand is a hand regardless of its colour, size, location or orientation.

When processing visual information, brain cells respond to specific features that are important to an object's identity – that is, they display feature selectivity. At the same time, the cells ignore features that are not important – they are invariant to feature manipulation. Combining selectivity and invariance is crucial for visual processing, but how the brain does this was not well understood.

To answer this question, a team of Brain Function CoE researchers, led by Ali Almasi from the National Vision Research Institute of Australia and Hamish Meffin from the University of Melbourne, studied cells in the primary visual cortex (V1). This region of the brain is responsible for the first stage of visual processing in the cortex.

The researchers measured how the activity of cells in the V1 changed when the cells received visual information about 'white noise' – random combinations of black and white pixels arranged in a square grid.

Because the images of white noise are random, patterns can emerge in the pixels – such as horizontal or vertical stripes. The researchers used the brain activity data to map how the cells responded to different combinations of patterns.

The researchers built a computer model to estimate the cells' selectivity and invariance to particular features of the different patterns, such as their orientation, frequency and phase. For a striped pattern, these features would describe whether the stripes were horizontal or vertical, how tightly spaced they were, and whether the pattern started with a black stripe or a white one.

The model revealed that most cells had a high degree of selectivity and a low degree of invariance for both orientation and frequency. However, the cells varied in their response to phase – some cells were highly selective, whereas others were completely invariant.

These findings show that even at a stage of visual processing as early as V1, the brain forms an elaborate set of sensitivities to generic features. These form the basis of more sophisticated processing in other visual areas of the brain.

Article: Based on Almasi, A., Meffin, H., Cloherty, S.L., Wong, Y., Yunzab, M., & Ibbotson, M. R. (2020). Mechanisms of feature selectivity and invariance in primary visual cortex. Cerebral Cortex, bhaa102. doi: 10.1093/cercor/bhaa102

Artwork: Micah, age 10, 2021

Improving the resolution of restored vision

Several diseases of the retina – the area at the back of your eyeball where light-sensitive cells are found – can lead to partial or even total blindness. In retinitis pigmentosa and age-related macular degeneration, for example, retinal cells are slowly damaged or lost over time. As a result, the cells become less able to absorb light and convert it to biological signals for the brain to process.

Retinal prostheses have restored some vision in people with retinal diseases by electrically stimulating the surviving cells, enabling them to send visual signals to the brain. However, the restored vision often has a low resolution, so it's not sharp enough for important tasks such as recognising faces.

Ideally, each retinal cell would be stimulated individually, which means that improved vision would require a prosthesis with many electrodes that are as close in size to the cells as possible. Precise patterns of electrical stimulation waveforms have also been shown to provide clearer vision.

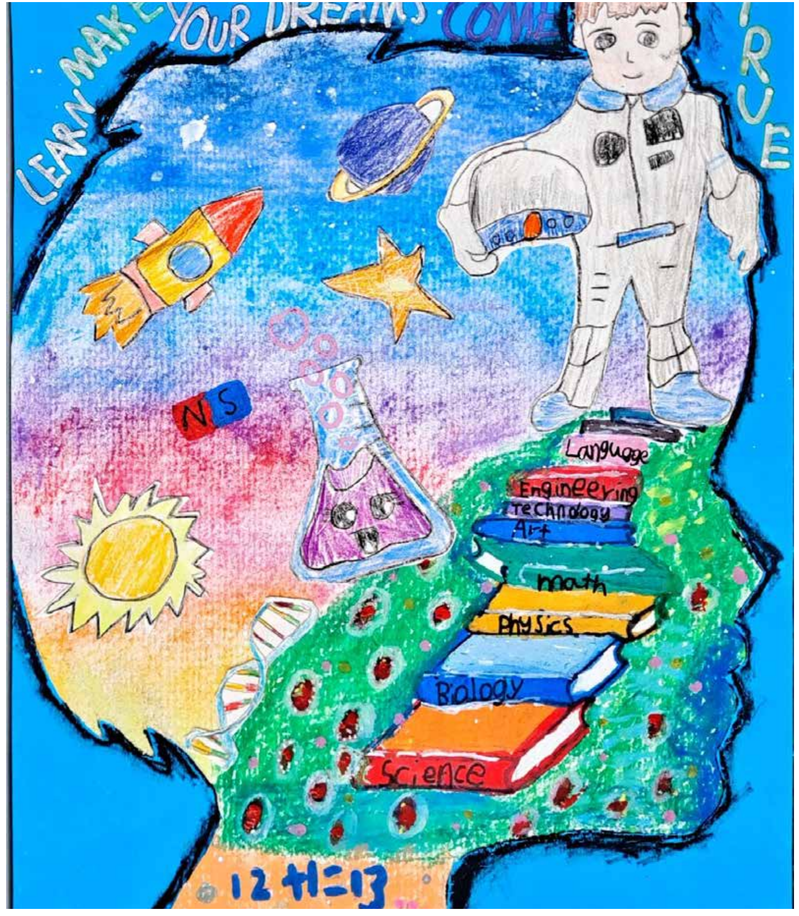
To increase the resolution of retinal prostheses, Brain Function CoE investigators from the University of Melbourne studied the best way to stimulate retinal cells. The team, led by postdoctoral researcher Wei Tong in Michael Ibbotson's laboratory, used a diamond-based electrode array, which has more electrodes than existing prostheses.

The researchers stimulated retinal cells in rats with or without retinal disease, varying the duration of the electrical pulse from one-thirtieth of a millisecond up to 50 milliseconds. They also compared the effect of different 'return' locations. Returns are pieces of wire that stop the electrical current, limiting the area stimulated by each electrode. The returns were positioned either close to the electrode (local return) or further away from it (distant return).

The researchers found that the most effective strategy for directly stimulating a specific region of the retina used short electrical pulses – as brief as one-tenth of a millisecond – in combination with a local return.

The stimulation strategy developed in this study will be used in the 'Diamond Eye', a diamond-based retinal prosthesis that is expected to undergo clinical trials in the next few years.

Article: Based on Tong, W., Stamp, M., Apollo, N.V., Ganesan, K., Meffin, H., Prawer, S., Garrett, D. J., Ibbotson, M. R. (2019). Improved visual acuity using a retinal implant and an optimized stimulation strategy. Journal of Neural Engineering. doi: 10.1088/1741-2552/ab5299



Artwork: Billie, age 6, 2021

Article: Based on Townsend, R. G., Solomon, S. S., Chen, S. C., Pietersen, A. N., Martin, P. R., Solomon, S. G., & Gong, P. (2015). Emergence of complex wave patterns in primate cerebral cortex. The Journal of Neuroscience, 35(11), 4657-4662.

Your unconscious brain is working harder than you think

Brain states such as sleep and anaesthesia are characterised by slow changes in brain electrical activity. These slow waves were thought to indicate low levels of activity, like the slow rise and fall of the ocean on a calm day.

Now Brain Function CoE investigators Pulin Gong and Paul Martin, and colleagues at University of Sydney and University College London, have shown that even unconscious brains may be very active indeed.

When they measured the fine detail of electrical activity of the brain's visual centres in anaesthetised monkeys, they found the slow waves actually hide a previously unidentified class of brain electrical activity: a rich variety of micro-patterns, just 4 mm across, that evolve continuously in space and time.

"These micro-patterns were not at all like a calm sea," says Martin. "In fact the pictures we got were more like a series of tropical storms." According to Martin, the micro-patterns morph and move rapidly, at rates similar to those seen in electrical activity associated with conscious processing of vision, touch and hearing, and physical activity, not with anaesthesia or sleep.

To make sense of the patterns, physicists in the team applied methods for analysing turbulent flow in gas and fluids. When you experience air turbulence on a bumpy flight it can feel that the bumps are random. In fact, there are hidden patterns in turbulence, and physics has special mathematical tools to analyse them.

"We modified the equations and applied them to the micro-patterns, and the fit was excellent," says lead author Rory Townsend, a Brain Function CoE graduate student.

The team speculate that information may be encoded in the micro-patterns, communicated by their movement, and processed when they interact. "These micro-patterns were not at all like a calm sea," says Martin. "In fact the pictures we got were more like a series of tropical storms." According to Martin, the micro-patterns morph and move rapidly, at rates similar to those seen in electrical activity associated with conscious processing of vision, touch and hearing, and physical activity, not with anaesthesia or sleep.

Artwork: Mia, age 7, 2016

A new maestro in the brain's orchestra

Electrical activity in the brain contains rhythmic oscillations at different frequencies ranging from 0.01 Hz to 600 Hz. Like musical notes in a symphony, these electrical rhythms are the result of precisely timed, coordinated activity. They are generated by thousands of brain cells of different type arranged as ensembles.

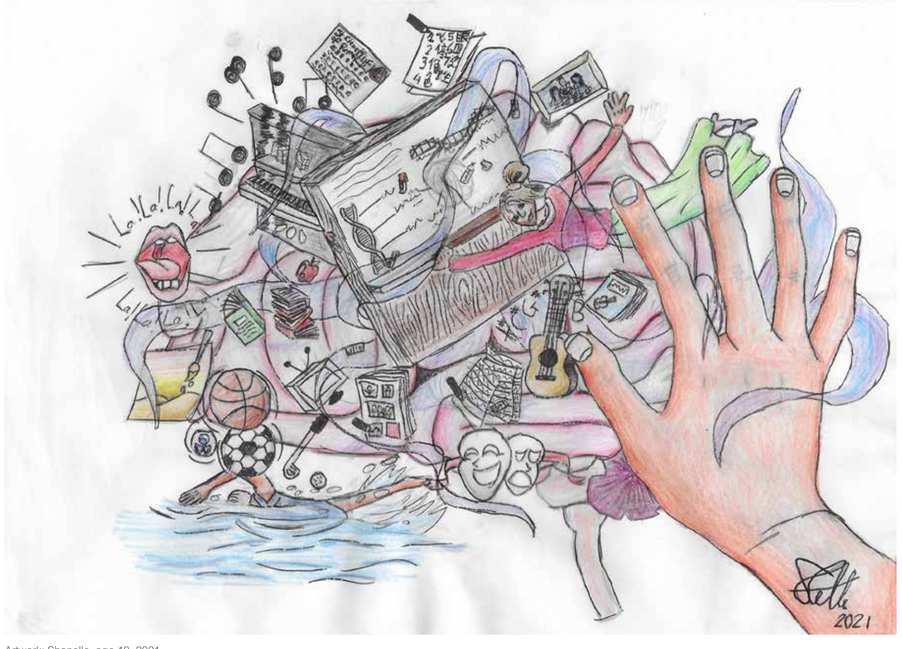
Oscillations with different frequencies have different functions depending on the brain region and behavioural state. In the temporal lobe, oscillations called sharp waves and ripples (SWs) occur during sleep to help consolidate memories. SWs are one of the most synchronized brain rhythms, and understanding these rhythms at the cellular level could help to explain how they contribute to memory function and disorders such as epilepsy.

To investigate the origin and generation of SWs, Brain Function CoE researchers examined networks of brain cells in the temporal lobes of rodents. The research was led by Madhusoothanan Perumal in Pankaj Sah's group at the Queensland Brain Institute.

Using recordings of the electrical activity in different types of brain cells during SWs, the researchers discovered that SWs are initiated by a rare type of brain cell known as a chandelier neuron. These neurons form extensive connections within local regions of the brain. The recordings showed that chandelier neurons orchestrate other cells and their circuits at precise times to generate SWs.

To understand how oscillations are produced at specific frequencies, the researchers built a computational model of a neural network containing microcircuits controlled by chandelier neurons. Simulations using the model generated SWs. They also revealed that interactions between microcircuits and the distribution of connections between neurons in the network produced the distinctive frequencies of SWs.

Article: Based on Perumal, M. B., Latimer, B., Xu, L., Stratton, P., Nair, S., & Sah, P. (2021). Microcircuit mechanisms for the generation of sharp-wave ripples in the basolateral amygdala: A role for chandelier interneurons. Cell Reports, 35(6), 109106. doi: 10.1016/j.celrep.2021.109106



Artwork: Shanelle, age 10, 2021

Movies offer new tool for studying adaptive brain function

Our brains constantly adapt in response to our surroundings. We take in sensory information about the environment and use it to make predictions about the world. This process is refined with each new piece of information and experience.

Many areas of the brain coordinate their activity to enable adaptive behaviour. But capturing the brain activity involved in each step – from perception to evaluation to action – is challenging.

New research reveals that movies can be used to study how patterns of brain activity change in response to external stimuli. The research team included Brain Function CoE investigators Johan van der Meer from QIMR Berghofer Medical Research Institute and Michael Breakspear from the University of Newcastle.

The researchers used a 20-minute movie called 'The Butterfly Circus' as the external stimuli. This allowed them to expose participants to the same simulated real-world experiences at specific times. For example, the movie featured actors using positive and negative facial expressions and included scenes that were designed to evoke particular emotions.

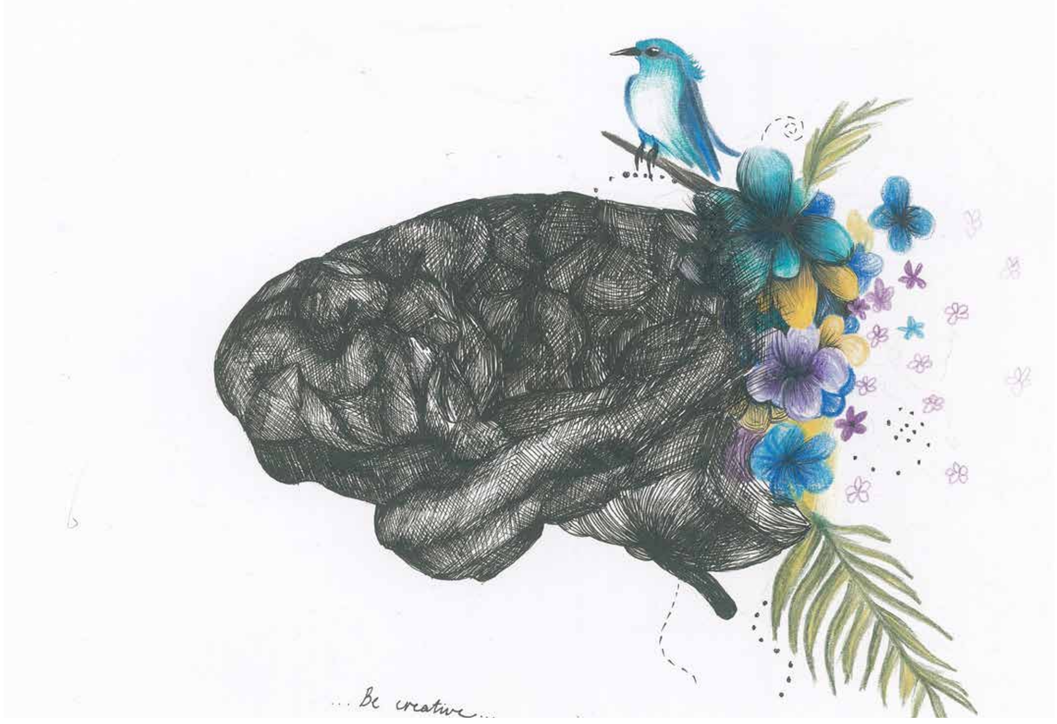
As participants viewed the movie, their brain activity was recorded using functional magnetic resonance imaging (fMRI). It was also recorded before the movie, while they rested with their eyes closed. Afterwards, the participants completed a questionnaire about how much they enjoyed the movie, whether they were bored, and how emotional it made them feel.

By comparing fMRI recordings using statistical techniques, the researchers could study how patterns of brain activity change in response to complex external stimuli.

They found that brain activity at rest switched between two relatively indistinct states. During movie viewing, however, brain activity switched between multiple distinct states that aligned with specific features of the movie. The patterns of brain activity were more consistent between participants when they viewed the movie, compared with when they rested. Differences in the patterns between participants reflected individuals' engagement in the movie.

These findings show that movies can be used in research as a structured, contextually rich simulation of the real world. Movies also give researchers a reliable and reproducible way to study the brain's response to stimuli that are similar to those we process in everyday life. This approach complements traditional research methods that capture brain responses using repetitions of a single external stimulus.

Article: Based on van der Meer, J. N., Breakspear, M., Chang, L. J., Sonkusare, S., & Cocchi, L. (2020). Movie viewing elicits rich and reliable brain state dynamics. Nature Communications, 11(1), 5004. doi: 10.1038/s41467-020-18717-w



Be creative....

Words and artwork, Tahlia, age 11, 2016

Artwork: Rhea, age 6, 2019

The fractal properties of brain activity are part of a bigger picture

The brain processes information by sending electrical signals between cells. The patterns of electrical activity – also called spike patterns – change depending on the type of brain cells involved and what function the brain is performing at the time.

It is now known that the spike patterns of individual cells can have a fractal quality – that is, they have similar properties whether you zoom in to look at a specific detail or zoom out to look at a much larger scale. Fractal patterns are common in nature – just think of the patterns in snowflakes, clouds, or Romanesco broccoli – and recent discoveries show that they might also be an important part of brain activity.

To understand why fractal-like patterns are important, Brain Function CoE researchers, led by Pulin Gong and Paul Martin at the University of Sydney, analysed cells in the early visual system – the parts of the brain involved in processing visual information.

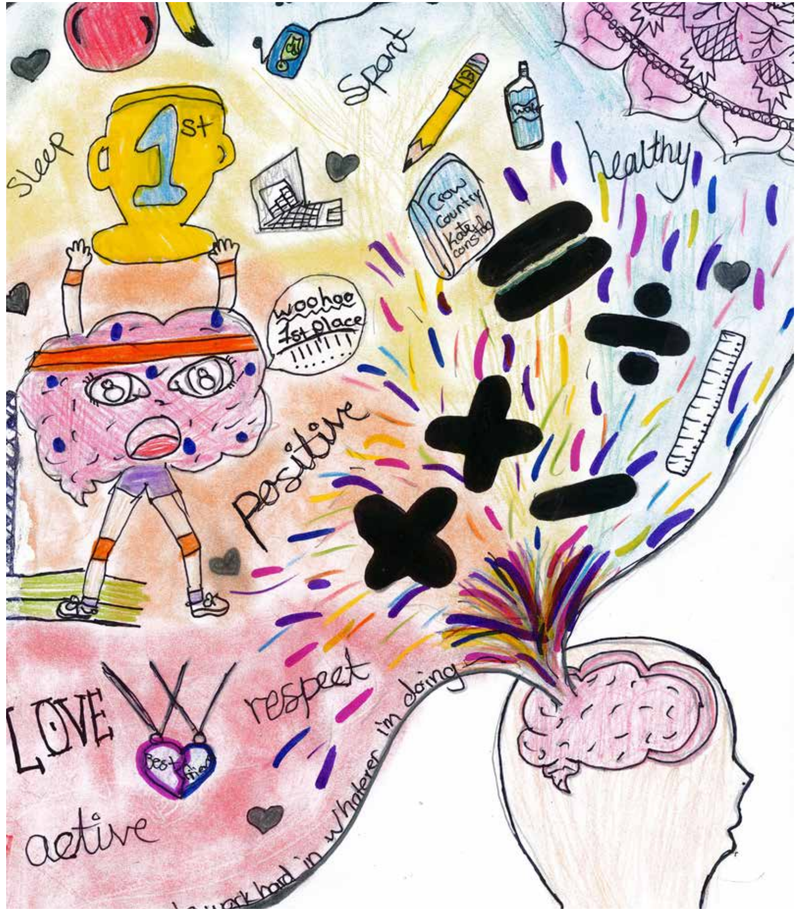
They measured the spike patterns of single cells from two vision-related areas of the brain in marmoset monkeys: the lateral geniculate nucleus (LGN) and the medial temporal visual cortex (MT). Then, they analysed the patterns using methods that they had developed to detect the statistical fingerprints of fractal activity.

The LGN is made up of three cell types. M-cells are involved in perceiving movement and depth. P-cells have a role in sharp vision. There are different kinds of K-cells; some respond to flashing or moving stimuli, possibly helping us to respond rapidly to nearby threats.

The researchers' analysis showed that K-cells had more fractal-like spike patterns than P-cells or M-cells. And the spike patterns of MT cells were even more fractal-like than those of K-cells.

"Fractal brain activity is more flexible than constant brain activity, especially in an unpredictable environment", explains Pulin Gong. The researchers believe that the fractal quality of spike patterns may enable brain activity to change efficiently in response to irregular threats in the animal's environment, such as the sudden appearance of predators.

Article: Based on Munn, B., Zeater, N., Pietersen, A. N., Solomon, S. G., Cheong, S. K., Paul R. Martin, P. R., & Gong, P. (2020). Fractal spike dynamics and neuronal coupling in the primate visual system. Journal of Physiology 598(8), 1551–1571. doi: 10.1113/JP278935



Artwork: Jayde, age 11, 2017

Better multitasking takes practice

Although multitasking might make us feel more productive, it comes at a cost. Often, performing tasks together takes longer than tackling them individually.

Multitasking requires the brain to send and receive information across different brain regions known as the frontal-parietal network. This slows down the brain's response time.

Practicing individual tasks can help us to multitask more quickly. Practicing causes changes in the connections across the frontal-parietal network.

New research from the Brain Function CoE shows that these changes extend deeper into the brain than previously thought.

Kelly Garner and Paul Dux from the University of Queensland, along with Marta Garrido from the University of Melbourne, recruited 100 people to take part in a multitasking experiment. Each participant's brain activity was recorded while they completed a single task or multitasked. Then, half of the participants spent a week practicing multitasking. At the end of that week, all participants were tested again on their ability to perform the tasks one at a time or at the same time.

The results showed that the participants had longer reaction times when they performed tasks together than when they performed them separately. Participants who practiced multitasking performed faster and better than those who didn't practice.

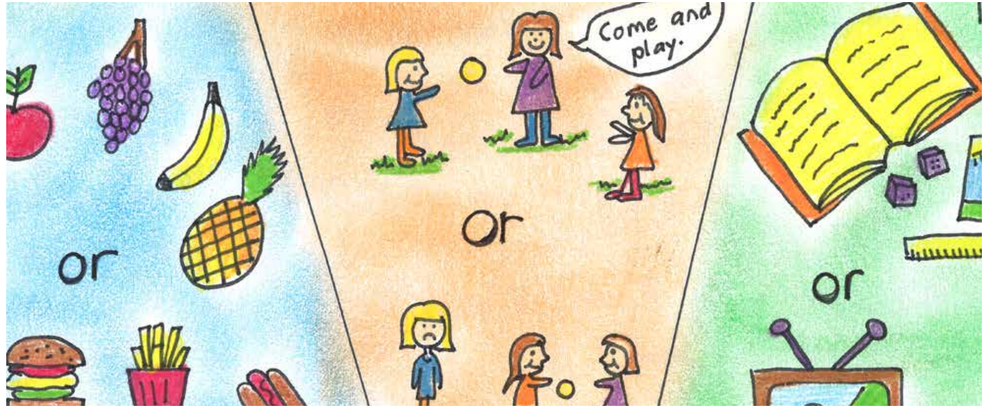
The researchers then pinpointed which parts of the brain were most active during multitasking. They found that in addition to the frontal-parietal network, the putamen – part of a region deep in the centre of the brain called the striatum – was active. The putamen is involved in different types of learning.

The researchers found that there was more communication between the putamen and the frontal-parietal network when multitasking than when carrying out single tasks.

The higher rate of information transfer between these brain regions during multitasking may explain why reaction times increase. The researchers suggest that when a task has been learned, or practiced, there is a change in how information is transferred to the putamen.

Article: Based on Garner, K. G., Garrido, M. I., & Dux, P. E. (2020). Cognitive capacity limits are remediated by practice-induced plasticity between the putamen and pre-supplementary motor area. eNeuro, ENEURO.0139-20.2020. doi: 10.1523/ENEURO.0139-20.2020

Artwork: Claudia, age 9, 2021



Attention and decision-making are closely related

We constantly adapt our behaviour in response to our surroundings. In each situation, we decide on the appropriate response by processing sensory information – such as what we see or hear around us. Processing irrelevant or distracting stimuli may lead to errors, so it is essential that the brain pays attention to relevant stimuli only and disregards other sensory input.

For example, when deciding whether to cross a busy road, we pay attention to traffic signals and cars to our left or right. But we disregard the movement of pedestrians or objects around us. We continue to process this sensory input until we have enough relevant information to make a decision.

Most neuroscience research on attention and decision-making has examined these two processes independently. Little was known about whether, or how, they interact.

To find out, Brain Function CoE investigators Dragan Rangelov and Jason Mattingley from the University of Queensland designed an experiment that required people to pay attention and make decisions at the same time.

Participants performed a simple visual task as their brain activity was monitored using electroencephalography. They viewed a computer screen showing two fields of moving dots – the target and the distractor. The two fields overlapped, were coloured differently, and moved in different directions. The participants were asked to focus their attention on the target field and to report what direction it moved in.

In principle, participants could first identify the target by its colour, and then decide what direction it moves in. In this case, the movement of the distractor should not influence the participants' decision.

Contrary to this expectation, the results showed that the movement of the distractor influenced the participants' decisions about the target motion. It also affected their associated brain activity.

This means that even when the participants paid attention only to the target, their brains still processed some information about the distractor. It also suggests that paying attention to relevant stimuli and deciding on the appropriate response happen at the same time.

In contrast to previous research, which assumed that attention and decision-making are relatively independent, the results of this study show that they are closely related.

Article: Based on Rangelov, D., & Mattingley, J. B. (2020). Evidence accumulation during perceptual decision-making is sensitive to the dynamics of attentional selection. NeuroImage, 117093. doi: 10.1016/j.neuroimage.2020.117093

Memories

I look into the back of my mind
And I see so many stories, so many pictures.

I see memories that make me angry,
memories that make me sad
memories that make me ashamed
memories that make me mad.

But beyond the sadness there are the happy
memories, full of giggles, fun, love and smiles.

Sometimes we forget how lucky we are,
we focus too much on the pain.
But the happy memories are stronger
and they will forever remain.

Poem and artwork by Sofia, age 10, 2018

Artwork: Constance K, age 12, 2020

Lipid by-products linked to learning and memory formation

In response to learned fear, the concentration of saturated free fatty acids (FFAs) increases in certain parts of the brain. Brain Function CoE researchers made this discovery in the first brain-wide study of how FFA levels change in response to learning.

FFAs are derived from phospholipids in the brain. Unsaturated FFAs, such as arachidonic acid, have long been considered beneficial for learning and memory. But precisely how they and other FFAs contribute to these important processes was not known.

A research team led by Brain Function CoE researchers Frédéric Meunier and Pankaj Sah from the Queensland Brain Institute mapped the distribution of 18 saturated and unsaturated FFAs across the rat brain. The highest concentrations of FFAs were found in the amygdala, hippocampus and prefrontal cortex – which are involved in learning and memory. Saturated FFAs were more abundant than unsaturated FFAs across the brain.

To test how the concentration of FFAs changed during learning and memory formation, the researchers conducted an experiment involving auditory fear conditioning. This experiment teaches animals to associate a sound with an unpleasant sensation.

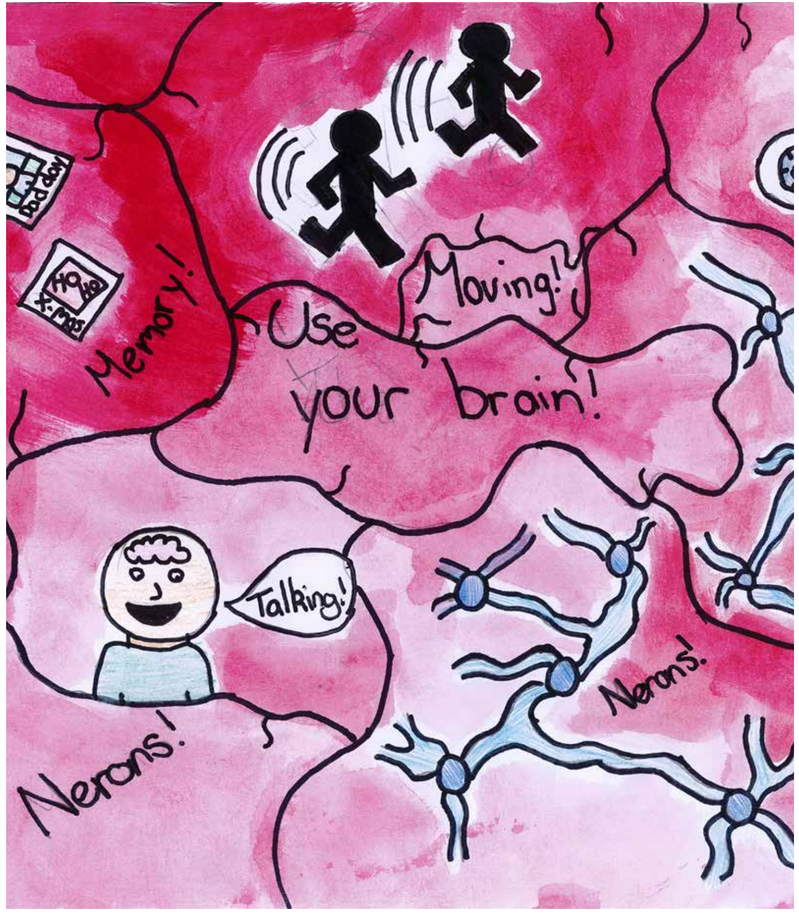
The researchers found that auditory fear conditioning led to an increase in saturated FFAs, mostly myristic and palmitic acids, in the same regions. It also led to a smaller increase in unsaturated FFAs like arachidonic acid. These changes were not seen when memory consolidation was chemically inhibited.

Studies of the brain often focus on the roles of proteins, genes and brain structures. The results of this study demonstrate the importance of studying the roles of phospholipids and FFAs as well.

Article: Based on Wallis, T.P., Venkatesh, B.G., Narayana, V.K., Kvaskoff, D., Ho, A., Sullivan, R.K., Windels, F., Sah, P., & Meunier, F.A. (2021). Saturated free fatty acids and association with memory formation. Nature Communications, 12, 3443. doi: 10.1038/s41467-021-23840-3

I use my brain to draw

Words and artwork, Amelia, age 11, 2017



Artwork: Georgia, age 11, 2017

Article: Based on Ward, P. G. D., Orchard, E. R., Oldham, S., Arnatkeviciute, A., Sforazzini, F., Fornito, A., Storey, E., Egan, G. F., & Jamadar, S. D. (2020). Individual differences in haemoglobin concentration influence BOLD fMRI functional connectivity and its correlation with cognition. Neuroimage, 221, 117196. doi: 10.1016/j.neuroimage.2020.117196

Haemoglobin levels affect the results of brain connectivity studies

The functional connectome is a map of all the connections used in the brain to communicate between cells. To determine the functional connectome and link it to brain activity, researchers often use functional magnetic resonance imaging (fMRI).

When brain cells become active, they need more oxygen. This increases blood flow to that part of the brain. It also changes the ratio of oxygenated to deoxygenated haemoglobin in the blood. The fMRI technique measures brain activity by detecting these changes.

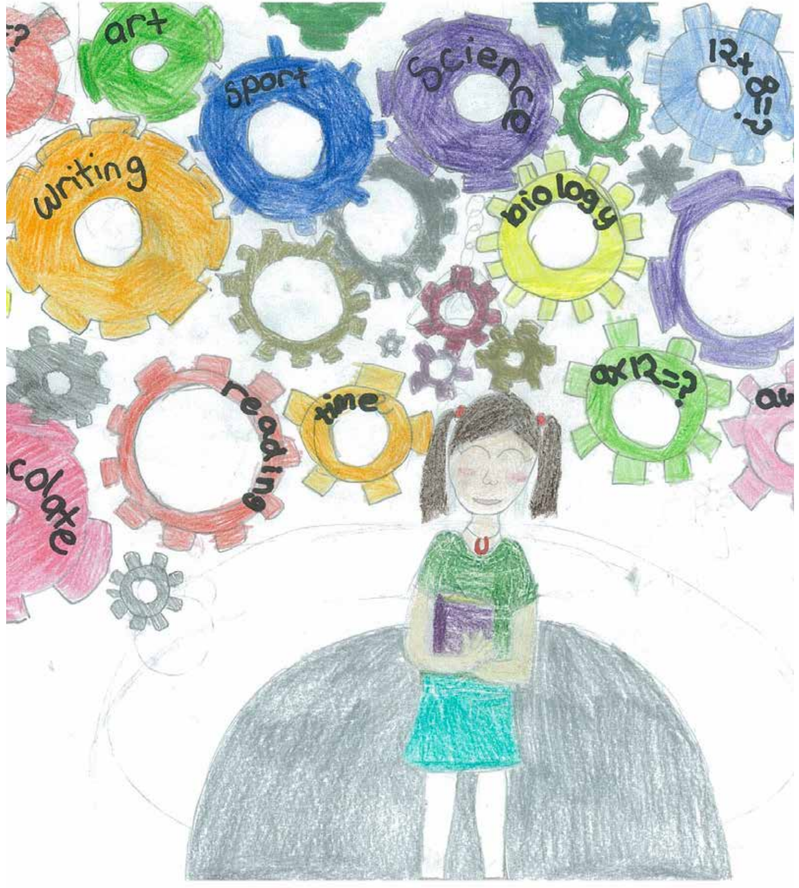
However, haemoglobin levels are influenced by many factors other than brain activity – such as a person's sex, age, race or stress levels. New research shows that these variations can affect fMRI-based studies of functional connectivity.

The team of researchers from Monash University, led by Brain Function CoE investigators Philip Ward and Sharna Jamadar, looked at individual differences in haemoglobin levels in a group of healthy older adults. The researchers split data from 518 participants into four groups: males and females with either a high or a low haemoglobin level. Then they compared the participants' fMRI measurements to see if group differences influenced how the functional connectome was determined.

In males, differences in haemoglobin levels affected how functional connectivity was measured across the whole brain. In females, however, the effect was weaker and more varied.

Compared with high-haemoglobin females, low-haemoglobin females had higher functional connectivity in regions of the brain at the rear of the cortex. But they had lower connectivity in regions in the middle of the brain.

These results show that if researchers do not control for the variability in people's haemoglobin in their analyses, they may come to the wrong conclusions when studying the functional connectome using fMRI.



Artwork: Ellisha, age 11, 2017

A potential disadvantage of fast brain processing

The brain processes sensory information by sending signals from region to region along a fixed pathway. In primates, for example, visual information from the retina normally travels along a brain pathway that stops at the primary visual cortex (V1) before proceeding to the amygdala.

But in some cases, the brain uses a shortcut. When primates look at face-like patterns, for example, the visual information reaches the amygdala before the V1.

These shortcuts allow the brain to process some types of information more quickly, which is important in situations where we need to avoid threats or make quick decisions.

A team of researchers led by Brain Function CoE Chief Investigator Marta Garrido from the University of Melbourne believes that these shortcuts might also be involved in some psychiatric disorders.

The researchers reviewed human and animal brain studies and found examples of shortcuts in audio and visual processing. The shortcuts enabled fast responses to imminent threats – such as freezing in place or escaping a potential predator.

But they found evidence that these shortcuts can affect the strength and quality of visual information, thereby changing our perception of the world around us. They also showed that the shortcuts can change how information is processed by other parts of the brain, such as those controlling attention and prediction.

The researchers believe that these effects of brain shortcuts could explain some of the changes in perception, attention and prediction that are seen in psychiatric disorders such as autism, attention-deficit hyperactivity disorder, anxiety and schizophrenia.

Article: Based on McFadyen, J., Dolan, R. J., & Garrido, M. I. (2020). The influence of subcortical shortcuts on disordered sensory and cognitive processing. Nature Reviews Neuroscience, doi: 10.1038/s41583-020-0287-1

Artwork: Jai, age 6, 2017

Primates form and use abstract rules

To perceive our surroundings and help us respond appropriately, our brains use abstract rules and categories to classify objects and events based on past experience.

For example, imagine arriving in a new city for the first time. Maybe you want to find something to eat, take a bus somewhere else, or explore. Using abstract rules, your brain can efficiently classify and group novel objects into behaviourally relevant categories to help you satisfy your current or future needs.

Without these rules, the brain would need to analyse every piece of information and compare it to every other piece of information that it has stored. Apart from taking a huge amount of brain power, this would make it impossible to ever react quickly to anything.

Abstract rules and categories give structure to our perception and thinking. They underpin many of our behaviours, such as planning, social interaction, reasoning and flexibility in adapting to new situations. Difficulties in creating these rules and using them properly have been linked to neuropsychological disorders such as autism spectrum disorder and schizophrenia.

When and how abstract rules emerge in the brain are therefore a topic of extensive research and debate. There is growing evidence that the prefrontal cortex has an important role in humans and non-human primates. However, damage to this region of the brain does not necessarily impair rule-dependent behaviour.

In a recent article in Nature Reviews Neuroscience, Brain Function CoE researcher Farshad Mansouri and colleagues propose a framework for how abstract rules are formed and used in the primate brain.

They describe different types of rules, such as object matching versus non-matching, colour matching versus shape matching, and matching the number of items. For each type, they review evidence from human and animal studies to determine similarities and differences between species.

Based on this knowledge, the authors propose that abstract rules emerge from a dynamic, multi-stage process involving different brain mechanisms and memory. In this process, the prefrontal cortex is involved in forming, storing, retrieving and updating rules. In stable environments, the rules are reinforced, and little prefrontal cortex involvement is required. In new or changing environments, however, the rules are continually formed and updated. This requires more cognitive resources and the contribution of the prefrontal cortex.

This framework helps to explain the role of the prefrontal cortex in the emergence and implementation of abstract rules for controlling primate behaviour.

Article: Based on Mansouri, F. A., Freedman, D. J., Buckley, M. J. (2020). Emergence of abstract rules in the primate brain. Nature Reviews Neuroscience, doi: 10.1038/s41583-020-0364-5

Artwork: Billie, age 6, 2020

A salience misattribution model for addictive-like behaviours

Our survival depends on the brain's ability to adapt to changing circumstances. It does this by creating internal models of our environment, which are constantly updated with new information. These models help us to make predictions based on past experiences and to adapt our behaviour accordingly.

Studies have shown that the anterior cingulate cortex (ACC) and dopamine systems in the brain are involved in updating our internal models. Now, Brain Function CoE researchers present a theory of how dysfunction in the ACC and dopamine systems could be involved in addiction. The work was led by Shivam Kalhan, a PhD student in the lab of Marta Garrido at the University of Melbourne.

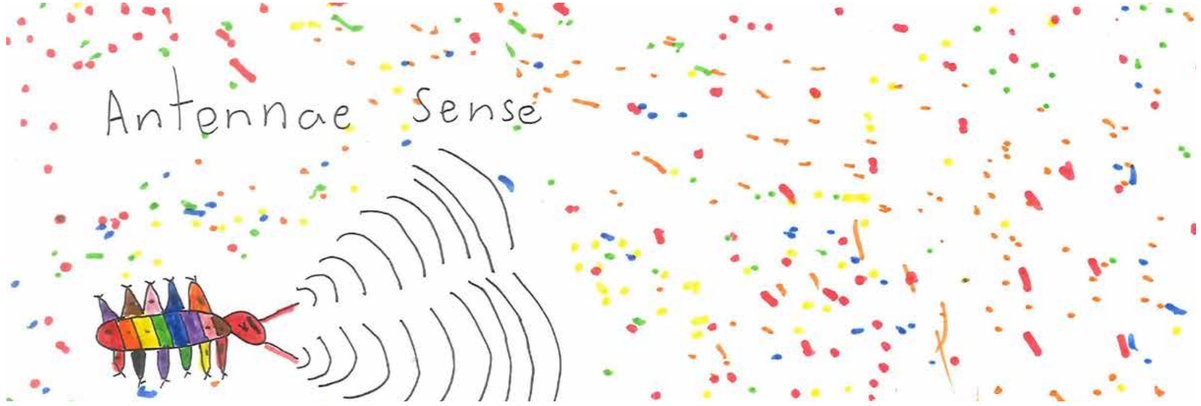
In a review of the literature, the researchers describe how the ACC and dopamine systems are involved in extracting relevant information from the huge volume of sensory input to the brain.

They also discuss the empirical evidence suggesting that in people who have an addiction, the ACC and dopamine systems often function abnormally.

Based on this evidence, the researchers propose that when the ACC and dopamine systems are dysfunctional, some information is considered more important, or salient, than it really is. For example, the brain might mistakenly attribute higher relevance to the sight of cigarettes or a lighter than to other reward-inducing stimuli, such as the sight of exercise equipment. This leads to the production of inaccurate internal models, which drive decisions that reinforce addictive-like behaviours.

The researchers believe that incorrect updating of internal models is one of many possible mechanisms causing abnormal decision-making in people with an addiction.

Article: Based on Kalhan, S., Redish, A. D., Hester, R., & Garrido, M. I. (2021). A Salience misattribution model for addictive-like behaviors. Neuroscience & Biobehavioral Reviews, 125, 466-477. doi: 10.1016/j.neubiorev.2021.02.039



Artwork: Joel, age 8, 2018

What do brain activity and your daily commute have in common?

Think about your daily commute: there are many roads that could get you from A to B, but you likely take the same route each day, probably because it's the most direct or efficient way. The set of elements, or roads, that you use is much smaller than the total set available to you.

Brain activity is much the same. Although there are many different pathways that brain cells could use to communicate with one another, they tend to favour a smaller subset of the total number of available pathways. Relying on this subset of pathways helps the brain to carry out tasks quickly, without having to learn from scratch every time.

But what happens when the brain has to deal with a really complicated or challenging task? Do the patterns of brain activity change in response? And if so, how?

To answer these questions, Brain Function CoE investigators James (Mac) Shine, Luke Hearne, Michael Breakspear and Jason Mattingley collaborated with colleagues in Australia and the USA.

The researchers recruited 60 participants who completed the Latin Squares Task, a Sudoku-like puzzle in which cells in a grid are filled with particular shapes so that no row or column contains more than one of each shape. The researchers varied the difficulty of the task and used magnetic resonance imaging (MRI) to measure the participants' brain activity while they completed it.

They found that as the task became more difficult to complete, the patterns of brain activity changed. And as the patterns changed, participants were more likely to make mistakes on the Latin Squares Task.

It's just as if you altered your commute to avoid unexpected traffic, taking the back roads to reach your destination. In unfamiliar territory, you'd be more likely to take a wrong turn.

The high-resolution MRI used in the experiment also enabled the researchers to pinpoint the region of the brain responsible for bypassing established patterns and creating new ones when necessary. They found that the thalamus is our brain's own satnav system. This small structure in the centre of the brain, which is connected to almost every other region, helps to direct (and redirect) the flow of information in the brain.

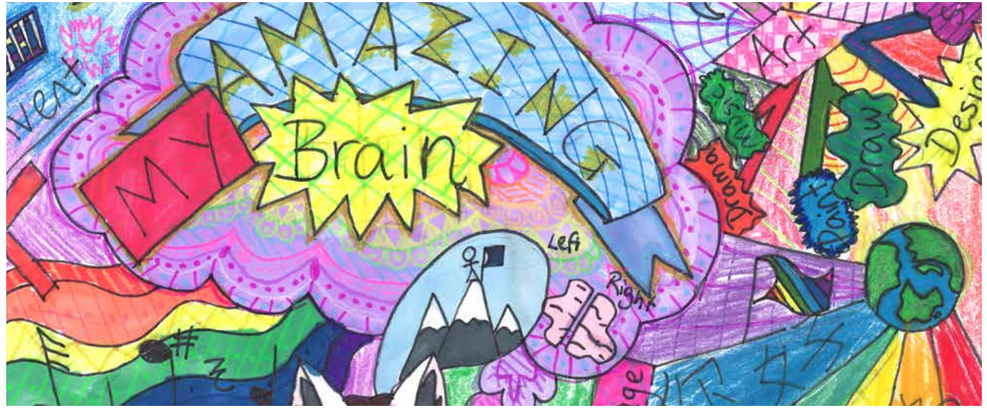
Article: Based on Shine, J.M., Hearne, L.J., Breakspear, M., Hwang, K., Muller, E.J., Sporns, O., Poldrack, R.A., Mattingley, J.B., & Cocchi, L. (2019). The low-dimensional neural architecture of cognitive complexity is related to activity in medial thalamic nuclei. Neuron. doi: 10.1016/j.neuron.2019.09.002

Without eyes, my other senses become alive

Words and artwork,Stefanie, age 7, 2018

Artwork: Cynthia, age 10, 2019

Article: Based on Liu, C., Ye, F. Q., Newman, J. D., Szczupak, D., Tian, X., Yen, C. C., Majka, P., Glen, D., Rosa, M. G. P., Leopold, D. A., & Silva, A. C. (2020). A resource for detailed 3D mapping of white matter pathways in the marmoset brain. Nature Neuroscience. doi: 10.1038/s41593-019-0575-0



Mapping white matter in unprecedented detail

Mapping white matter in unprecedented detail Image credit: Hisagi / Wikimedia Commons. Image licensed under the Creative Commons Attribution-ShareAlike 3.0 Unported license.

Most of the human brain is made up of white matter – the tissue underneath the surface that contains brain cells and their long protruding nerve fibres. Like a public transport network covering a big city, the white matter contains many intersecting pathways that connect cells in different parts of the brain. This connectivity allows us to handle complex learning, memory and cognitive tasks.

Despite the importance of white matter to brain activity in primates, researchers didn't have a clear picture of its overall structure or individual pathways. A better understanding of its connectivity could help to explain symptoms in human diseases such as depression and schizophrenia.

Thanks to research from the Brain Function CoE and the US National Institutes of Health, we now have the first complete high-resolution 3D map of white matter in marmosets. The research team included Brain Function CoE investigators Marcello Rosa from Monash University and Piotr Majka from the Nencki Institute in Poland, and partner investigator David Leopold from the National Institute of Mental Health (NIMH) in the USA.

The NIMH researchers developed a method to scan marmoset brains at much higher resolution than ever before. These small primates were used because their brain is organized in a similar way to that of larger primates like humans. Their brains are also small enough to fit into the most powerful high-resolution scanners.

The researchers combined imaging data with information from the Brain Function CoE's Marmoset Brain Connectivity Atlas, which maps the connections between different areas of the cortex – the part of the brain that covers the white matter.

The resulting map of white matter organization reveals a structure that is even more complex than previously suspected. The unprecedented resolution of the map also uncovered features that hadn't been seen before and allowed the researchers to correctly identify features that had been misidentified in previous maps.

This map opens the way to a precise understanding of the changes in brain connectivity that are related to diseases. When similar data are obtained for other primates, the marmoset white matter map will also be a useful resource for comparing the structures and evolution of primate brains.

To encourage use of this resource, the researchers have made the map and its associated data freely available online through the Marmoset Brain Mapping Project.

Artwork: Lucia, age 10, 2021

Article: Based on Atapour, N., Worthy, K. H., Rosa, M. G. P. (2021). Neurochemical changes in the primate lateral geniculate nucleus following lesions of striate cortex in infancy and adulthood: implications for residual vision and blindsight. Brain Structure and Function, https://doi.org/10.1007/s00429-021-02257-0

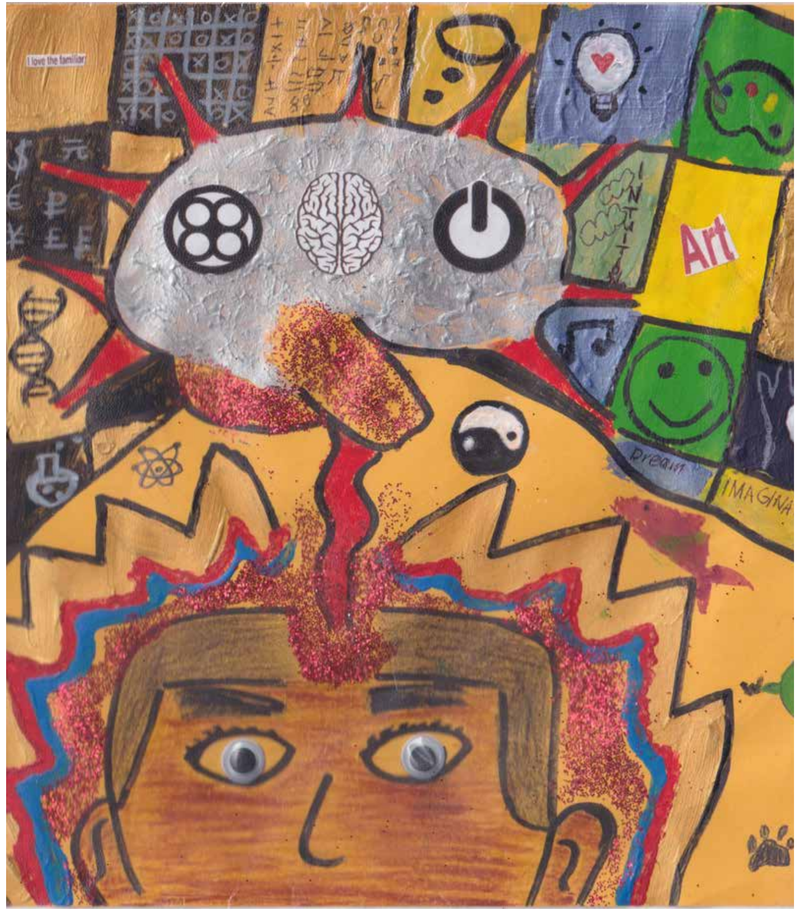
Investigating curious chemical changes to help stroke patients

As many as one-third of people who survive a stroke lose their eyesight – and most will not fully recover their vision. Known as 'cortical blindness', their loss of vision is the result of damage to the primary visual cortex (V1), which blocks the flow of information from the eyes to the brain. This damage also triggers degeneration in brain regions that send visual information to V1, such as the lateral geniculate nucleus (LGN). However, some LGN cells can survive and retain their visual function.

The potential for recovery from cortical blindness was thought to depend on a balance between degeneration and cell survival. But new research from the Brain Function CoE has found a third, previously unknown factor: changes in the chemical activity in LGN cells after V1 damage. The research was carried out by a team led by Marcello Rosa from Monash University.

Normally, LGN cells that send visual information to the cortex use excitatory neurotransmitters – chemicals that help to transmit signals from one cell to the next. Other LGN cells use inhibitory neurotransmitters, which stop signals from going further. This balance of neurotransmitters helps the brain to prioritise which visual information it processes. But after V1 damage, there is a seven-fold increase in the number of LGN cells producing an inhibitory neurotransmitter called GABA. This includes cells that are expected to make the surviving connections to the cortex.

The researchers aren't sure why cells that need to transmit information produce a chemical that stops transmission. Perhaps it has a positive effect, somehow helping the surviving cells to make the most of their remaining resources. Or it might have a negative effect, limiting the potential for recovery. Either way, this discovery provides neuroscience researchers with new information for understanding – and maybe eventually treating – cortical blindness.



Artwork: Aarna, age 7, 2021

Article: Based on Orchard, E. R., Ward, P. G. D., Sforazzini, F., Storey, E., Egan, G. F., & Jamadar, S. D. (2020). Relationship between parenthood and cortical thickness in late adulthood. PLoS One, 15(7), e0236031. doi: 10.1371/journal.pone.0236031

Parenthood permanently changes the brain

The early years of parenthood alter the structure of the brain in both mothers and fathers. The thickness of the cortex – the outer layer of the brain known as the 'grey matter' – changes in different regions of the brain at different stages of child rearing. It can increase, as the brain develops, and decrease, in a process of fine-tuning.

Studies in rodents suggested that these changes might be permanent. But researchers knew very little about the lasting effects of parenthood on the human brain.

A team of Brain Function CoE researchers from Monash University, led by PhD student Edwina (Winnie) Orchard in Sharna Jamadar's group, set out to answer this question. They examined the link between cortical thickness in older adults and the number of children a person has parented.

The researchers used data collected from 547 participants of a clinical trial called ASPREE-NEURO, which involved people aged 70 or above. Participants underwent brain scans and completed a health questionnaire. One of the questions asked how many children they had.

By analysing the brain scans of the participants, the researchers determined the thickness of the cortex in 34 regions of each brain hemisphere. They also calculated the average thickness across each hemisphere.

The researchers then compared these 70 measurements in participants with one or more children. They also compared the measurements between non-parents and parents with one child.

The researchers found that mothers with more children had thicker grey matter in the right parahippocampal gyrus, a brain region associated with memory. By contrast, cortical thickness decreased in regions associated with processing sensory information.

Compared with non-mothers, mothers with one child had thinner grey matter in the left dorsolateral prefrontal cortex. This region of the brain is involved in high-order cognitive functions including problem-solving and emotional regulation.

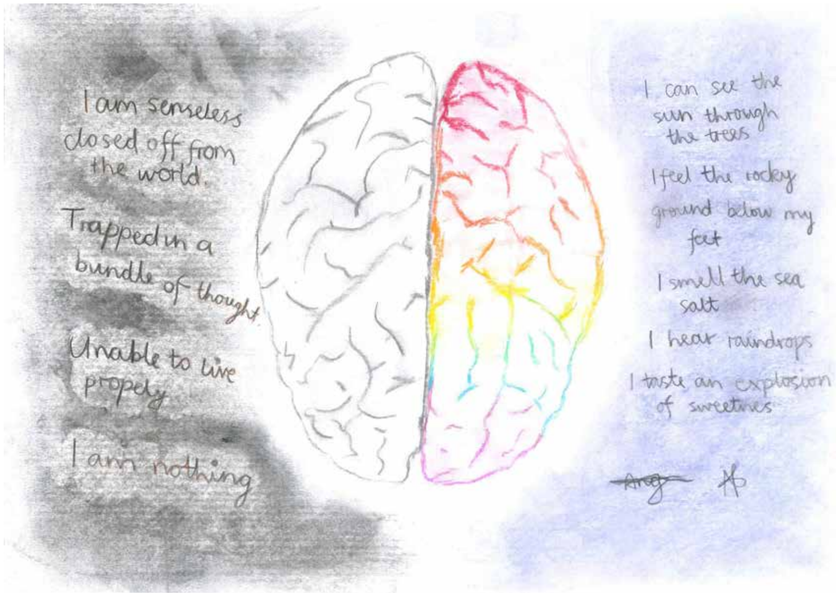
Compared with non-fathers, fathers with one child had thinner grey matter in the left anterior cingulate and thicker grey matter in the right temporal pole. These regions are involved in social cognition, including emotional regulation and empathy.

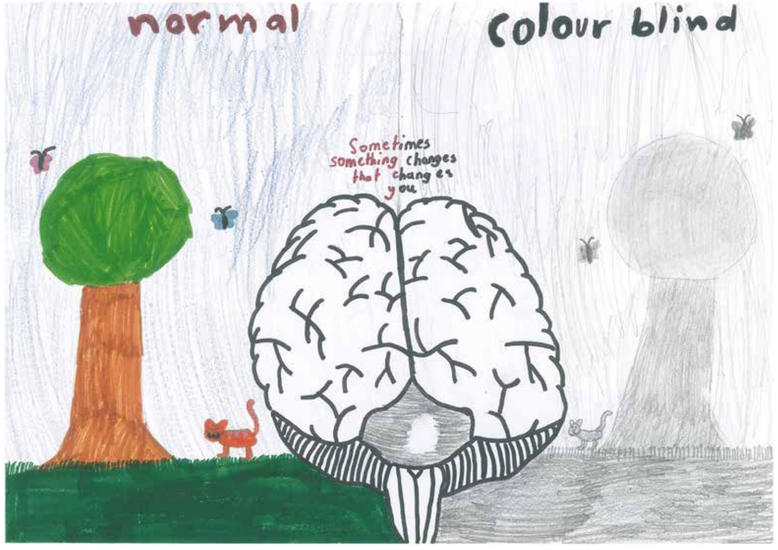
These findings suggest that parenthood causes life-long changes to the brain's structure in both mothers and fathers. The researchers believe that these changes are related to the complexity of raising children – an ongoing experience that provides parents with rich sensory stimulation while requiring them to learn new skills and behaviours.

I am senseless
closed off from the world
Trapped in a bundle of thought
Unable to live properly
I am nothing

I can see the
sun through the trees
I feel the rocky
ground below my feet
I smell the sea salt
I hear raindrops
I taste an explosion of sweetness

Poem and artwork by Angela, age 12, 2018





Artwork: Caela, age 10, 2018

A newly discovered pathway in the brain helps us recognise fearful expressions

To evade danger, we need to detect and respond to threats quickly. These actions involve several different areas of the brain, including the amygdala – a small, highly connected structure that is responsible for coordinating fear and emotional responses.

When rodents hear sounds of danger, auditory signals are transmitted along a brain pathway to the amygdala – even if the brain region normally responsible for processing sound has been damaged. Whether a similar pathway exists for humans, and for visual information, is a topic of longstanding debate.

The location of the amygdala, deep within the brain, makes it difficult to study. But such a pathway could explain the phenomenon of 'blindsight' – the ability of some blind people to react to sudden movements or facial expressions without being able to see them. Although people with blindsight have vision loss as a result of damage to the primary visual cortex (V1), certain visual information seems to reach their brain through an independent pathway.

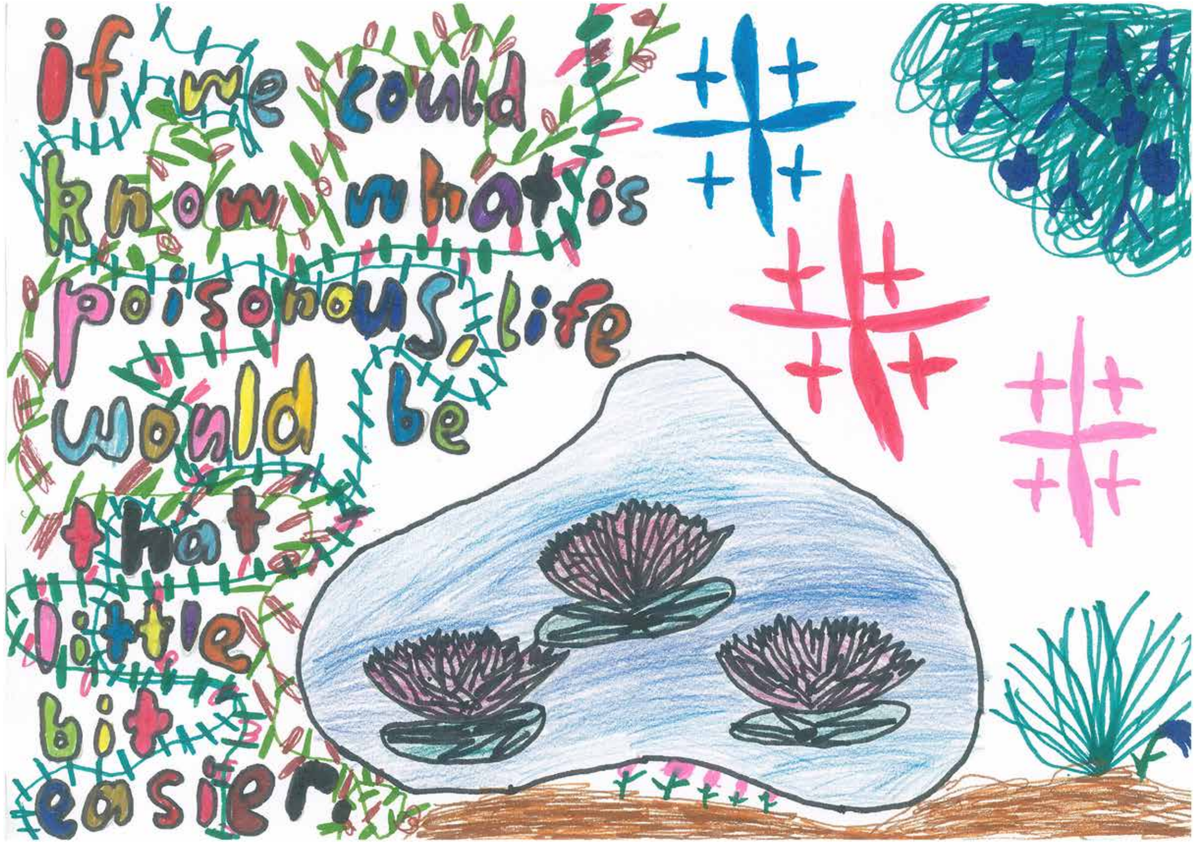
Queensland Brain Institute researcher Jessica McFadyen and her colleagues, Brain Function CoE chief investigators Jason Mattingley and Marta Garrido, looked for evidence of this pathway in humans. Using 3D modelling based on detailed brain scans from more than 600 people with undamaged V1 regions, they mapped connections between cells across the brain. In every single case, the researchers were able to reconstruct a pathway from the brainstem (which controls the flow of information between the body and the brain) to the amygdala.

Having found the pathway in humans, the researchers wanted to determine if it was involved in behaviour. They examined behavioural data from experiments in which participants were shown images of human faces and tested on their ability to recognise different expressions – fear, anger, happiness, sadness or neutral. The participants' brain activity was measured as they completed the task, and the researchers used these measurements to make computer models of the blood flow in their brains.

The researchers found that when the participants looked at images of fearful or angry faces, the blood flow along the pathway increased. The stronger the connections were along the pathway, the better the participants were at recognising fear – but not other negative emotions, such as sadness or anger.

The discovery of the alternate pathway in humans settles a longstanding debate. In addition to explaining blindsight, it could also have implications for conditions such as autism and anxiety, which often affect how people recognise fear.

Article: Based on McFadyen, J., Mattingley, J. B., & Garrido, M. I. (2019). An afferent white matter pathway from the pulvinar to the amygdala facilitates fear recognition. eLife, 8, e40766. doi: 10.7554/eLife.40766



If we could, know what is poisonous, life would be that little bit easier.

Words and artwork, Freya, age 10, 2018

Artwork: Chantal, age 6, 2021

Understanding SK1, a channel protein that doesn't act like a channel protein

Cells in the brain communicate with each other by sending and receiving electrical signals. This activity transmits information from one brain region to another, which enables the brain to carry out its various functions.

Brain cells make different types of proteins that affect their electrical behaviour. One group of proteins, called small-conductance calcium-activated potassium channels (SK channels), helps to control the movement of electrically charged molecules across the cell membrane. When the concentration of calcium inside a brain cell reaches a certain level, SK channels are activated, allowing potassium to cross from the inside of the cell to the outside. This reduces the cell's electrical activity, decreasing the number of signals that it transmits.

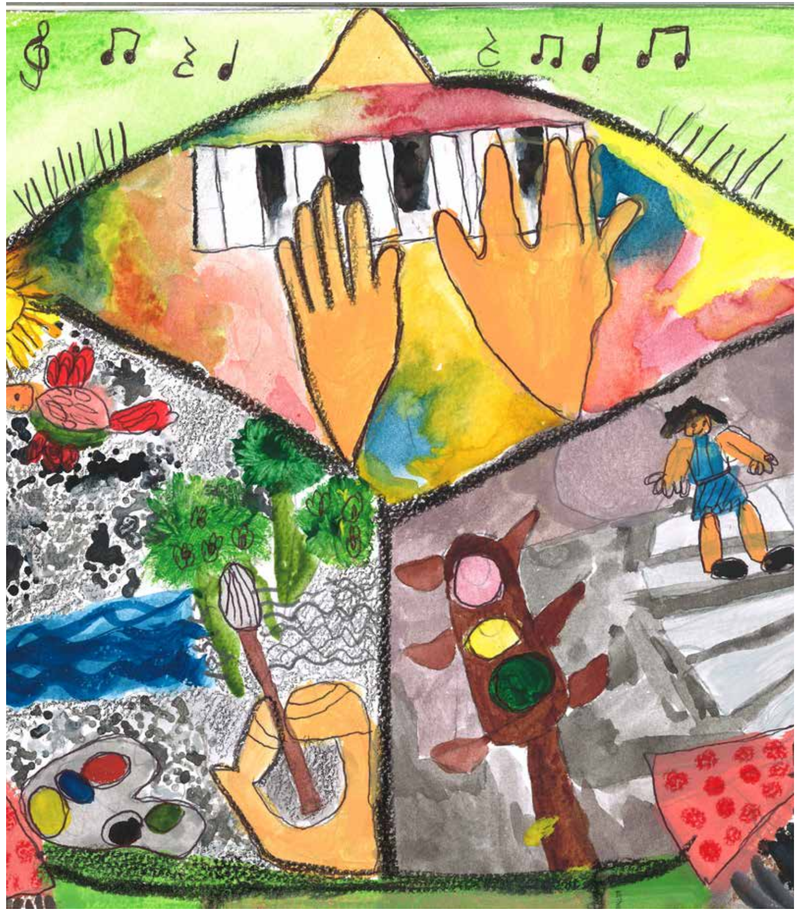
In mammals, three types of SK channel – SK1, SK2 and SK3 – are found throughout the brain. Studies in rats have shown that SK2 and SK3 are embedded in the cell membrane and act as channel proteins. However, SK1 does not end up in the cell membrane and does not seem to affect the electrical behaviour of brain cells.

To understand the role of SK1, Brain Function CoE researchers at the University of Queensland, led by chief investigator Pankaj Sah, looked more closely at brain cells in rats. In particular, they investigated how SK1 affected the activity of other SK channels.

The team found that after SK1 is made, it stays in a compartment inside the cell, rather than moving to the cell membrane. When SK2 is in the same compartment, the two proteins bind together, which prevents SK2 from moving to the cell membrane as well.

Rather than acting as a channel itself, SK1 seems to control the amount of SK2 in the cell membrane. In this way, SK1 can indirectly change the electrical activity of rat brain cells and, possibly, the transmission of information across the brain.

Article: Based on Autuori, E., Sedlak, P., Xu, L., Ridder, M. C., Tedoldi, A., & Sah, P. (2019). RSK1 in rat neurons: A controller of membrane rSK2? Frontiers in Neural Circuits, 13, 21. doi: 10.3389/fncir.2019.00021



Artwork: Modamsuvee, age 6, 2021

Light-sensitive cells in the retina play a role in subconscious and conscious vision

Everybody knows that we need our eyes to see. But did you know that our eyes also help us to get out of bed in the morning?

Visual information travels from the retina to the brain via nerve cells called ganglion cells. A tiny subset of these cells – about 5000 – contain a light-sensitive protein called melanopsin. When daylight penetrates our eyelids in the early morning, melanopsin-containing ganglion cells send messages to our brain to reset our body clock.

Although research has revealed useful information about these light-sensitive cells in rodents and non-human primates, little was known about them in humans.

Graduate student Subha Nasir Ahmad from the University of Sydney, together with Brain Function CoE chief investigators Ulrike Grünert and Paul Martin and research fellow Sammy Lee studied the density and distribution of melanopsin-containing ganglion cells in human retina.

They found that these cells are present throughout the retina, but are concentrated near the fovea – the part of the eye responsible for sharp vision. They also found that the cells receive information from photoreceptors and thus – like other ganglion cells – might play a role in visual processing.

Article: Based on Nasir-Ahmad S, Lee, S.C.S., Martin, P.R, & Grünert, U. (2017). Melanopsin-expressing ganglion cells in human retina: Morphology, distribution, and synaptic connections. The Journal of Comparative Neurology, doi: 10.1002/cne.24176

Artwork: Lara, age 11, 2018

A new survey reveals how different cell types in the retina contribute to vision

Our eyes send different types of messages to our brain to signal the colour, movement and shapes of the objects that we see. This helps us to spot things in our central and peripheral vision – so we can avoid other pedestrians when crossing the road, for example, while also keeping an eye on any fast-approaching cars nearby.

The messages are transmitted by nerve cells in the retina called ganglion cells. Although researchers knew that there are different types of ganglion cells, they were missing information about the number and location of these cells in the retina, and how each type contributes to vision.

Recent research from Brain Function CoE PhD scholar Rania Masri and chief investigators Ulrike Grünert and Paul Martin from the University of Sydney along with colleagues from the National Institute of Natural Sciences in Japan, has revealed important details about the shape, location and function of many of these cells.

The team used a new method to label ganglion cells in primate retinas, and found more than 20 different types distributed throughout the retina. Their shape provided the team with clues about the specific functions of some of the cells.

Based on calculations of cell density in the retina, the team also speculate that even more ganglion cell types might await discovery.

The study is expected to help researchers better understand the visual inputs to the parts of the brain that control attention, prediction and decision – all of which are necessary to notice an oncoming car, judge its speed in relation to our own, and jump out of the way if necessary.

Article: Based on Masri, R.A., Percival, K.A., Koizumi, A., Martin, P.R., & Grünert, U. (2017). Survey of retinal ganglion cell morphology in marmoset. The Journal of Comparative Neurology, doi: 10.1002/cne.24157

Artwork: Mia, age 11, 2020

Exciting news about an inhibitory neurotransmitter

Our brains are constantly processing information – such as what we see, hear, or smell – and finding the appropriate response. Brains do this by converting information into an electrical signal, which is transmitted from cell to cell. Everything we do – from sensing our environment, to thinking and then acting – relies on these signals travelling to the right locations in the brain at the right time.

The transmission of signals around the brain is controlled by neurotransmitters. Each brain cell usually has only one type of neurotransmitter – either excitatory or inhibitory. Excitatory neurotransmitters help to spread the electrical signal to other brain cells, whereas inhibitory neurotransmitters stop it from going further.

One of the main inhibitory neurotransmitters in the adult mammal brain is gamma-aminobutyric acid (GABA). Because of the way the brain changes from birth to adulthood, GABA was believed to have excitatory activity in the developing brain before becoming completely inhibitory in the mature brain.

But research from the Brain Function CoE is challenging that view. PhD student Dr Alex Bryson and his supervisor, Professor Steven Petrou from the Florey Institute of Neuroscience and Mental Health, have shown that even in adulthood, GABA can act as both an inhibitory and an excitatory neurotransmitter.

Together with colleagues at the University of Melbourne, they collaborated with researchers from the Blue Brain Project – a Swiss research initiative that aims to build digital reconstructions and simulations of the rodent brain using supercomputers.

Using computer models from the Blue Brain Project, they predicted that GABA might have both inhibitory and excitatory properties. By carrying out lab experiments in adult mice, the researchers confirmed that GABA can, in fact, excite certain types of brain cell.

This unexpected discovery reveals that GABA is more complicated than previously thought. It also gives researchers clues as to how the brain finds the right balance between excitation and inhibition – and how imbalances could potentially be treated.

Article: Based on Bryson, A., Hatch, R. J., Zandt, B.-J., Rossert, C., Berkovic, S. F., Reid, C. A., Grayden, D. B., Hill, S. L., & Petrou, S. (2020). GABA-mediated tonic inhibition differentially modulates gain in functional subtypes of cortical interneurons. Proceedings of the National Academy of Sciences USA, 117(6), 3192-3202. doi: 10.1073/pnas.1906369117

Artwork: Beth, age 5, 2018

Paying attention promotes surprise-based brain activity

The human brain processes a massive amount of sensory information each day, enabling us to interpret everything we see, smell, hear, taste and touch – and respond appropriately. To manage this workload in the most efficient way, the brain builds a predictive model of the outside world and updates it when surprising events occur. At the same time, attention helps the brain to process the most important sensory events first.

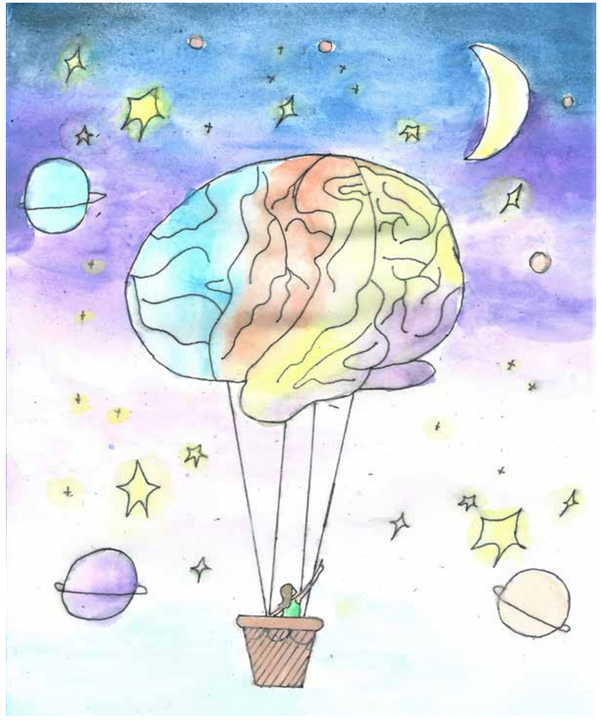
Although we use attention and prediction all the time, researchers didn't know exactly how they work together in the brain. To find out, Brain Function CoE investigators Cooper Smout, Matthew Tang, Marta Garrido and Jason Mattingley investigated what type of information is processed in the human brain when we pay attention to expected or surprising visual events in the environment.

The researchers asked participants to view a monitor showing patterns in orientations that were either predictable, surprising or unpredictable. In some cases, the participants were asked to look out for particular changes in the appearance of the patterns, and to press a button as soon as they detected a change. In other cases, they were asked to focus instead on a dot on the monitor, thus ignoring the patterns in the background. While participants completed the tasks, their brain activity was recorded using electroencephalography.

The researchers found that paying attention to patterns increased the activity of populations of brain cells that manage surprise. The brain pathway for managing surprise assesses the difference between observed and predicted events, helping the brain to refine its predictions so it can respond more efficiently when it next encounters the same event.

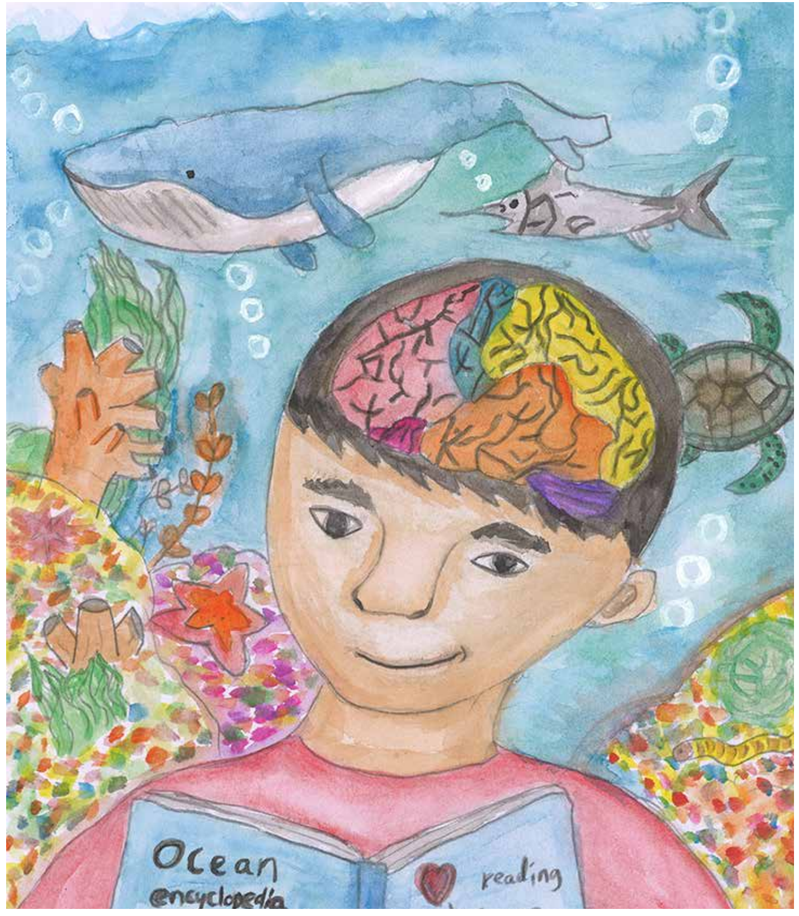
The fact that these populations of brain cells are most active in response to surprising, 'attended' events suggests that attention and prediction both operate within the same fundamental pathway in the brain.

Article: Based on Smout, C.A., Tang, M.F., Garrido, M.I., & Mattingley, J.B. (2019). Attention promotes the neural encoding of prediction errors. PLoS Biology 17(2): e2006812

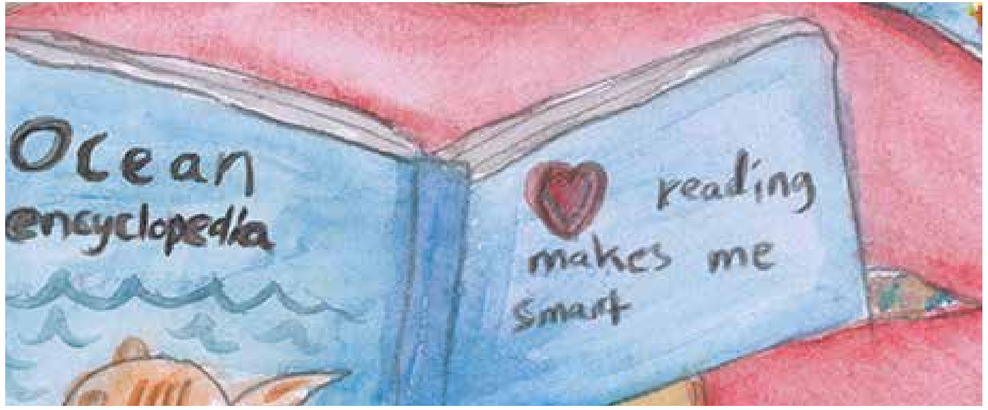


My brain helps me to dream

Words and artwork by Ahavniyah, age 10, 2021



Artwork: Ethan, age 7, 2020



New recommendations on best practices in neuroimaging research

Neuroimaging has become an integral part of neuroscience research. Non-invasive techniques such as electroencephalography (EEG) and magnetoencephalography (MEG) map human brain activity by recording electrical activity or magnetic fields in the brain, respectively.

To ensure that neuroimaging studies can be reproduced – a fundamental tenet of scientific research – the Organization for Human Brain Mapping has called for standards in how data is acquired, analysed, reported and shared.

The organization's Committee on Best Practices in Data Analysis and Sharing has now released recommendations on best practices in EEG and MEG research.

The recommendations were put together by an international committee of expert researchers, including Brain Function CoE investigator Marta Garrido, who collaborated with the EEG and MEG research communities.

The recommendations include best practices in research methodology and reporting. They outline the basic features of neuroimaging experiments that researchers should describe when reporting on their research. They also promote sharing of data and code.

Pernet, C., Garrido, M. I., Gramfort, A., Maurits, N., Michel, C. M., Pang, E., Salmelin, R., Schoffelen, J. M., Valdes-Sosa, P. A., & Puce, A. (2020). Issues and recommendations from the OHBM COBIDAS MEEG committee for reproducible EEG and MEG research. Nature Neuroscience, doi: 10.1038/s41593-020-00709-0

Artwork: Alana, age 9, 2020

Random noise can boost visual perception

We generally think of random noise as an unwanted interference, obscuring a signal that we want to receive. And in some cases, that's true: adding superfluous information can make it more difficult to detect the information of interest.

But in other cases, adding noise can actually help to boost a signal that would otherwise be too weak to detect. This is due to a phenomenon called 'stochastic resonance' (SR).

Noise contains many different frequencies all mixed together. Think of the static displayed on old analogue televisions when no signal was received, or the sound of a non-existent radio station. In SR, the frequency in the noise that matches the weak signal helps to strengthen it, boosting the signal-to-noise ratio and enabling the signal to be detected.

In humans, various brain activities can be affected by SR. For example, random noise is believed to affect binocular rivalry. When two different images are presented to our eyes at the same time – one to the left and one to the right – we don't see both images superimposed. Instead, our brain switches our visual awareness spontaneously between the two images. We see either one image at a time (exclusive perception) or, during the transitions between images, an unstable composite of the two (mixed perception).

To study this further, Onno van der Groen and Nicole Wenderoth from ETH Zurich and Jason Mattingley, a Brain Function CoE investigator from the Queensland Brain Institute, ran two experiments in which participants performed tests involving binocular rivalry. In each case, the participants viewed low-contrast or high-contrast visual stimuli on a computer screen.

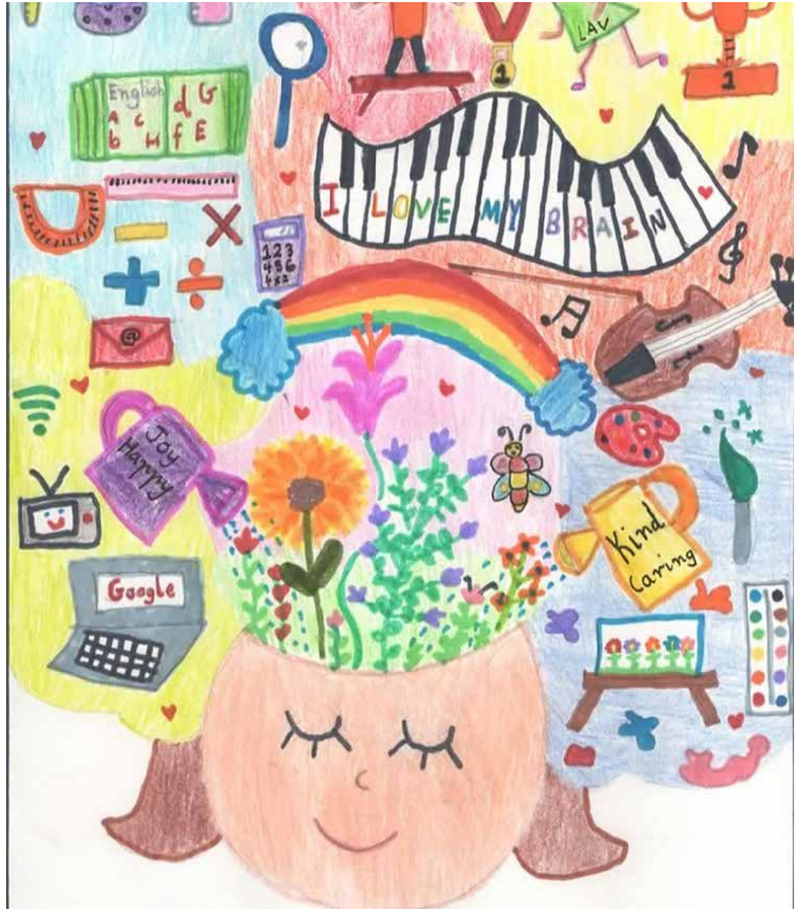
In the first experiment, the researchers added noise to the visual stimuli. In the second experiment, they used transcranial random noise stimulation (tRNS) to add noise directly to the participants' visual cortex – the part of the brain involved in processing visual information.

The researchers found that adding noise during binocular rivalry significantly affected participants' perception in both experiments – but only for low-contrast images. The added noise reduced the duration of mixed perception by up to 16%, allowing the brain to switch more quickly between periods of exclusive perception. No similar effect was found with the high-contrast images.

The researchers now have more information about how noise affects brain activity, which could help them to understand conditions in which the brain responds differently to binocular rivalry. Studies have shown that in people with autism, for example, periods of mixed perception during binocular rivalry last longer than in people without autism.

This study also confirms that the visual cortex is involved in binocular rivalry, which was previously a matter of debate.

Article: Based on van der Groen, O., Mattingley, J. B., & Wenderoth, N. (2019). Altering brain dynamics with transcranial random noise stimulation. Scientific Reports, 9(1), 4029. doi: 10.1038/s41598-019-40335-w



Artwork: Selini, age 7, 2020

When vision is affected by eye damage, the brain can create its own imagery

Our brains can adapt in response to nerve damage, but sometimes those adaptations have unexpected effects. For example, changes in how the brain interprets nerve signals can lead to unpleasant sensations, such as tinnitus in the ears or pain in missing limbs.

Another example is found in people with non-inherited eye diseases – like age-related degeneration of the retina – who have lost their central vision but still have some peripheral vision.

About 40% of these people develop long-term hallucinations involving flashes of light, shapes, geometric patterns or more detailed visions. Rather than indicating brain disease or mental illness, these hallucinations seem to be a natural consequence of the brain adapting to changing sensory input.

Although this condition, known as Charles Bonnet syndrome (CBS), was discovered more than 250 years ago, researchers didn't know what causes these hallucinations or why only some people suffer from them. One hypothesis is that when the retina is damaged, objects in our peripheral vision cause cells in the early visual cortex – where visual information is first processed in the brain – to become more active than normal. Under certain environmental conditions, which vary for each person with CBS, this hyperexcitability can cause the brain to create images that aren't really there.

David Painter, a postdoctoral researcher working with Brain Function CoE chief investigator Jason Mattingley, wanted to test this hypothesis. He and his colleagues at the University of Queensland studied the brain activity of people with and without CBS.

The participants performed a task requiring their full visual attention, while coloured checkerboard patterns flickered on a computer screen in their peripheral vision. The researchers used electroencephalography (EEG) to record how brain cells in the participants' visual cortex reacted to the checkerboard patterns, each of which flickered at a unique rate.

The researchers found that the brain cells in participants with CBS were much more active in response to certain images than the cells of people without any retinal damage or hallucinations. This hyperexcitability happened only when the participants' peripheral visual field was stimulated, not during rest.

Their discovery directly supports the hypothesis that hyperexcitability in the early visual cortex is responsible for the hallucinations in CBS. By pinpointing how future treatments might alleviate these hallucinations – for example, by decreasing hyperexcitability in certain brain cells using methods such as transcranial magnetic stimulation – the researchers' work also offers hope to the people with CBS who find their hallucinations distressing.

Article: Based on Painter, D. R., Dwyer, M. F., Kamke, M. R., & Mattingley, J. B. (2018). Stimulus-driven cortical hyperexcitability in individuals with Charles Bonnet hallucinations. Current Biology, 28(21), 3475-3480.E3. doi: 10.1016/j.cub.2018.08.058

Artwork: Advika, age 6, 2018

Twisted topographic maps in the brain

When the brain processes visual information, it breaks each image down into pieces. Each piece is analysed by a different group of brain cells in the visual cortex. The cells that analyse adjacent pieces of the image are next to each other in the brain. This means that what we see is essentially 'mapped' onto our visual cortex.

Traditionally, these so-called topographic maps have been classified according to whether they represent visual information as a mirror image or a non-mirror image of what you see. This classification is widely used to determine the transition between areas in the visual cortex.

Now, researchers have identified a third type of map that combines both types of representation within a single area.

Led by Brain Function CoE investigators Marcello Rosa and Elizabeth Zavitz from Monash University, in collaboration with IBM Research, the researchers modelled how topographic maps are formed during brain development. For the first time, they investigated what happens when two maps develop in adjacent areas, which is common in the brain.

The researchers found that some configurations of areas led to a previously unknown, 'twisted' type of map, which combines regions that represent images as both mirror images and non-mirror images. Using advanced electrophysiological techniques, they showed that this type of map actually exists in the primate brain.

The primate cortex is separated into dozens of visual areas that form a mosaic of individual visual maps. This study demonstrates that the formation of two adjacent areas can create new types of organization that would not be predicted by modelling the formation of each area independently.

This means that to capture the full complexity of the human brain, it will be necessary for models to incorporate multiple areas of the brain and take into account the fact that they develop at different times.

Article: Based on Yu, H.-H., Rowley, D. P., Price, N. S. C., Rosa, M. G. P., & Zavitz, E. (2020). A twisted visual field map in the primate dorsomedial cortex predicted by topographic continuity. Science Advances, 6, eaaz8673. doi: 10.1126/sciadv.aaz8673

Artwork: Emilio, age 6, 2020

Could K-cells save your life?

Your brain makes sense of what you see by processing signals that are sent from the retina. The first stop on that journey is a relay centre called the lateral geniculate nucleus (LGN): a pea-sized collection of one million nerve cells, tucked deep inside the brain.

The LGN is made up of layers of different cell types: magnocellular cells (M-cells), parvocellular cells (P-cells) and koniocellular cells (K-cells). M-cells help us perceive movement and depth, while P-cells are involved in sharp vision. Less is known about K-cells. Although they have been implicated in colour vision and blindsight – the ability of blind individuals to respond to visual stimuli without realising they can see – their functions in the LGN weren't clear.

Brain Function CoE researcher Calvin Eiber, a postdoctoral fellow in chief investigator Paul Martin's lab, wanted to investigate K-cells in more detail. He and his colleagues showed marmoset monkeys different visual stimuli – moving or stationary, coloured or black and white – and then studied how single K-cells in the LGN responded.

The researchers found that one subset of K-cells responds very rapidly to any flashing or moving stimulus. The simple visual system of animals such as rats and mice is packed with this kind of K-cell to help them escape quickly from predators like cats. The team's discovery of the same kind of K-cell in the marmoset LGN suggests that these cells are involved in guiding similar rapid responses in humans and other primates.

Based on these observations, the researchers believe that K-cells may help you process visual information quickly and thus respond more rapidly to nearby threats – perhaps even saving your life.

Article: Based on Eiber, C. D., Rahman, A. S., Pietersen, A. N. J., Zeater, N., Dreher, B., Solomon, S. G., & Martin, P. R. (2018). Receptive field properties of koniocellular on/off neurons in the lateral geniculate nucleus of marmoset monkeys. Journal of Neuroscience. doi: 10.1523/JNEUROSCI.1679-18.2018

**If I could gain a sense
from nature I would have
echolocation so I could
communicate to people
from kilometres away.**

**So in video games I
could do chat and play
because you can only do one at a time but
with echolocation could do both.**

Words and artwork by Albie, age 10, 2018

Artwork: Jonah, age 5, 2020

Reliving suppressed fear

Anxiety disorders, such as post-traumatic stress disorder, are often treated using exposure therapy, where the patient is repeatedly presented with the source or context of the anxiety, but in a safe environment where no harm ensues.

Unfortunately, even if patients learn to extinguish their fear during treatment, the fear response can re-emerge if they encounter the trigger outside the context of the clinic. Sometimes that fear is warranted – such as in dangerous situations – but other times, it is unnecessary and detrimental to their treatment. Understanding what causes fear relapse is therefore critical for developing effective therapy for trauma-related disorders.

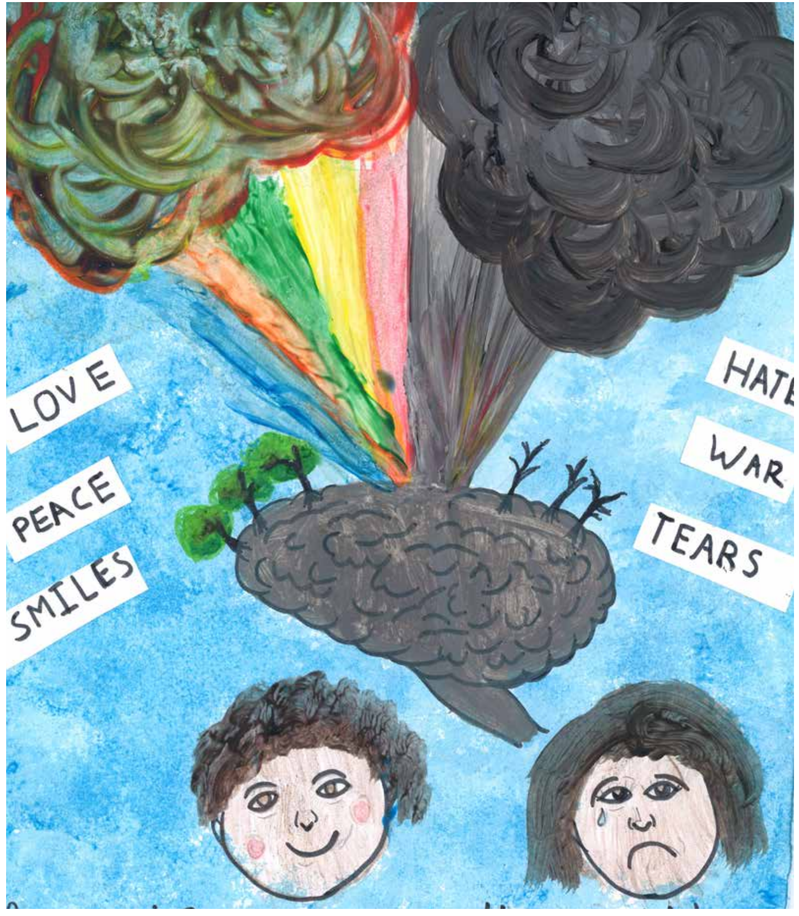
Together with international collaborators, Brain Function CoE postdoctoral research fellow Roger Marek, chief investigator Pankaj Sah, and colleagues from the Queensland Brain Institute studied the brains of rats to see how fear relapse is controlled.

The researchers placed rats in a box with white lighting, and trained them to expect a mild electric shock after hearing a tone. When the rats were presented with the same tone after the initial training period, they displayed a fear response, even in the absence of the electric shock. After repeated exposure to the tone in the same box without receiving the subsequent shocks, their fear response was extinguished. However, when rats were placed in a different box – with fluorescent red lights – and presented with the same tone, the fear relapsed.

The team identified a previously unknown brain circuit in these rats that reignited the fear response: brain cells in the hippocampus – a brain region that is involved in memory storage – form connections with structures in the prefrontal cortex. This circuit enables the rats to express fear in the second box, where fear had not been previously extinguished. However, by artificially activating the circuit while rats were in the box where the fear had already been extinguished, the researchers reignited the rats' fear.

The team's discovery of this novel circuit presents a potential target for new treatments to reduce the possibility of fear relapse after therapy.

Article: Based on Marek, R., Jin, J., Goode, T. D., Giustino, T. F., Wang, Q., Acca, G. M., et al. (2018). Hippocampus-driven feed-forward inhibition of the prefrontal cortex mediates relapse of extinguished fear. Nature Neuroscience, doi: 10.1038/s41593-018-0073-9



Artwork: Kamran, age 9, 2019

Redrawing the map of brain connections involved in extinguishing learned fear

When we feel fear in response to a threat, networks of brain cells work together to evaluate the threat, helping us to learn from experience and to react appropriately to dangerous situations. Dysfunction of these circuits – which involve several different parts of the brain – can lead to anxiety-related disorders such as post-traumatic stress disorder.

In certain circumstances, the brain can be trained to reduce the fear response – a process known as fear extinction. Behavioural studies suggested that fear learning and extinction both begin in the amygdala but are then regulated by distinct parts of the medial prefrontal cortex: the prelimbic (PL) for learning and the infralimbic (IL) for extinction. However, anatomical and electrophysiological studies have shown that the PL and IL are significantly connected.

To see if the PL is involved in fear extinction as well as fear learning, Brain Function CoE postdoctoral research fellow Roger Marek, chief investigator Pankaj Sah and colleagues from the Queensland Brain Institute mapped these connections in rats. They found not only that brain cells in the PL can send signals to cells in the IL, but also that activating this connection enhances fear extinction.

This discovery redefines the role of the PL and means that the current brain circuitry model of fear learning and extinction needs to be revised. The finding will also help us to better understand the brain circuits involved in anxiety disorders.

Article: Based on Marek, R., Xu, L., Sullivan, R. K. P., & Sah, P. (2018). Excitatory connections between the prelimbic and infralimbic medial prefrontal cortex show a role for the prelimbic cortex in fear extinction. Nature Neuroscience, 21(5), 654-658. doi:10.1038/s41593-018-0137-x

Artwork: Gaby, age 7, 2017

Using physics to understand the ‘music’ of the brain

Our understanding of how the brain works has been based mostly on observation, with little ability to predict behaviour or analyse its underlying mechanisms. Techniques such as electroencephalography (EEG) are used to measure electrical activity in the brain and link it to brain function – or dysfunction.

When the cerebral cortex is stimulated in one location by randomly flickering light, EEG recordings show that the resulting brain activity oscillates in other locations in a way that is closely related to changes in the light. These oscillations, known as perceptual echo, were first discovered in 2012 but have remained a mystery ever since.

Perceptual echo might have implications for the processes involved in visual perception, so learning more about it could increase our understanding of human vision. However, there have been no studies to predict perceptual echo or analyse its underlying mechanisms.

Brain Function CoE Chief Investigator Peter Robinson and his colleagues from the University of Sydney aimed to fill this gap using neural field theory – a comprehensive model of the connections between brain stimuli, activity and measurements that is based on physics rather than statistics.

The researchers used neural field theory to predict the frequency and spatial patterns of perceptual echo by splitting the brain’s oscillations into ‘natural modes’ (like the notes produced by a musical instrument) and their patterns on the cortex – as shown in the illustration, where strong oscillations in the visual cortex are shown in red. They found that two modes dominated, which closely matched experimental observations. This finding is comparable to striking a musical instrument, such as a drum: even if you hit it randomly, the resulting sound will be dominated by its favoured notes.

The team’s work – which combined theory, experiment, and physical and biological sciences – demonstrates the power of interdisciplinary methods to explain brain activity.

Article: Based on Robinson, P. A., Pagès, J. C., Gabay, N. C., Babaie, T., & Mukta, K. N. (2018). Neural field theory of perceptual echo and implications for estimating brain connectivity. Physical Review E, 97, 042418. doi: 10.1103/PhysRevE.97.042418

If I had
X-ray power
I would do
X-ray for
Free and
Help (the) poor

Worlds and artwork by Anvay, age 5, 2018

Artwork: Ella, age 7, 2018

Creating and sharing detailed maps of brain connections

The defining characteristic of the nervous system is the network of connections that let cells communicate with other cells in precise locations. Understanding these connections and their complexity in the cerebral cortex is crucial for deciphering brain function. However, mapping this system is an enormous challenge, particularly in complex brains like those of primates.

Brain Function CoE researchers have now developed the Marmoset Brain Connectivity Atlas, the first large-scale map of brain connectivity in a non-human primate.

The research team, led by Brain Function CoE chief investigator Marcello Rosa from Monash University, involved Brain Function CoE researchers from Australia, Poland and Italy, plus collaborators from China and the USA.

To create the Atlas, the researchers combined the results of retrograde tracer injections in marmoset monkeys. These results, which describe the locations of individual cells in the cerebral cortex, were obtained from over two decades of research. The locations were all fitted to a standard template so that the results from different experiments can be compared. For the same reason, consistent terminology is used to describe the results.

The Atlas includes several integrated, online tools to help users visualise and analyse cellular connections – within a single monkey or across the same brain region in all monkeys. Users can also compare the locations of certain brain cells with the results of their own imaging studies.

The Atlas is part of a series of open-access resources released by Brain Function CoE researchers. To encourage further research on brain connectivity, the Atlas is freely available to the scientific community. The raw data is also provided in full and in a machine-readable format. The researchers hope that the full availability of data, which can be analysed independently in different contexts, will reduce the number of animals needed to study the organization of the primate nervous system.

Article: Based on Majka, P., Bai, S., Bakola, S., Bednarek, S., Chan, J. M., Jermakow, N., . . . Rosa, M. G. P. (2020). Open access resource for cellular-resolution analyses of corticocortical connectivity in the marmoset monkey. Nature Communications, 11, 1133. doi: 10.1038/s41467-020-14858-0

All of these famous moments in history were made with their brains. You have one so use IT!

Words and artwork by Betthany, age 11, 2017

Artwork: Ava, age 10, 2016

Examining the brain under threat

Novel or uncertain situations can make us a little anxious and more alert to potential danger. This state of hypervigilance is helpful in the case of real threats, but when it becomes persistent – such as in post-traumatic stress disorder (PTSD) – it can be incapacitating.

Encountering unexpected stimuli, like a change in a repetitive sequence of sounds, elicits a response in the brain called 'prediction error'. This prediction error is increased in people with PTSD, and even in psychiatrically healthy people when they are made to feel anxious.

In most cases, when there is a mismatch between what we predict will happen and what actually happens, the brain has a process for adjusting and improving its prediction through connections between the front and the sides of the brain. This process and connections are disrupted during anxious hypervigilance, as discovered in a recent study by Brain Function CoE Chief Investigator Marta Garrido and colleagues.

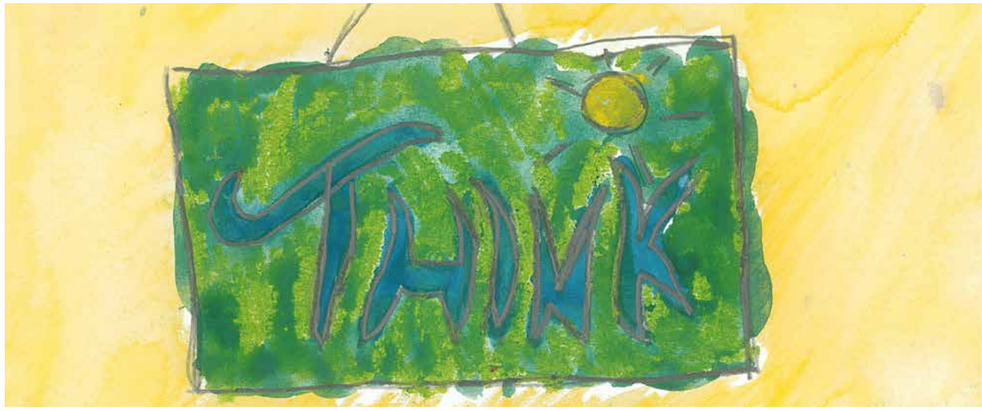
The team presented a group of participants with a series of sounds designed to elicit surprise. Occasionally the participants heard a voice recording that alerted them to an impending electrical shock to the wrist (the threatening condition) or notified them that no shock would occur (the safe condition).

Compared to the safe condition, the threatening condition generated larger prediction errors in the brain, and led to an imbalance in the process of adjusting and improving predictions. Both processes were restored when the participants were given alprazolam, an anti-anxiety medication.

As well as revealing more detail about how the brain behaves during anxious hypervigilance, these findings offer a possible target for developing more selective drugs to treat conditions like PTSD.

Article: Based on Cornwell, B. R., Garrido, M. I., Overstreet, C., Pine, D. S., & Grillon, C. (2017). The unpredictive brain under threat: A neurocomputational account of anxious hypervigilance. Biological Psychiatry, 82, 447–454.

Artwork: Billie, age 9, 2016



Transmission wires alert the brain to what the eyes see

When we see something, our eyes send messages to our brain through the optic nerves. Each nerve contains around a million long 'wires', called axons, which carry information from ganglion cells in the retina to relevant parts of the brain. Although at least 20 ganglion cell types have been discovered in primate retinas, how each type contributes to visual processing is not clear.

Brain Function CoE investigators Ashleigh Chandra, Sammy Lee and Ulrike Grünert have taken a big step towards identifying which wires are responsible for sending alerting messages to the brain areas that regulate attention. The team used a biological marker to tag all the brain cells in the retina that contain a protein called calretinin. Closer inspection revealed that most of the tagged cells were thorny cells – named after their special thorn-like connections to other cells in the retina.

"We knew that thorny cells project to areas of the brain that help you adjust to new or threatening stimuli in the environment, for example the image of an approaching car when you start to cross the street," says Chandra. "What surprised us when we counted the thorny cells is that there are a lot more of them than we previously thought."

This discovery suggests that the eye and brain devote a lot of processing power to threat detection, which may reflect the importance of survival for our ancestors. "Of course, now we have traffic lights to help us avoid threats from cars, but our thorny cells are still there if we need them," Chandra says.

In addition to revealing an important role for this ganglion cell type, the researchers have confirmed that tagging calretinin is a useful method for studying these cells in the retina.

Article: Based on Chandra, A. J., Lee, S. C. S., & Grünert, U. (2017). Thorny ganglion cells in marmoset retina: Morphological and neurochemical characterization with antibodies against calretinin. Journal of Comparative Neurology, doi: 10.1002/cne.24319.

Artwork: Nilla, age 9, 2016

Brain research moving in the right direction

Brain activity ebbs and flows like ocean waves during a tropical storm. The turbulent waves of activity form micro patterns even when we're sleeping or under anaesthesia, but how these patterns relate to what we're currently seeing and experiencing is not completely understood.

Brain Function CoE researchers Rory Townsend, Pulin Gong and Paul Martin, together with colleagues at the University of Sydney and University College London, wanted to see what these wave patterns look like in the visual areas of the brain while we're watching moving objects. The team showed marmosets a series of moving patterns on a computer screen. They rotated the patterns – either circular white dots or sets of parallel lines – by 90 degrees until the marmosets had seen them 100 times in all four cardinal directions.

Using methods for analysing turbulence patterns in gases and liquids, the team found that the direction in which the patterns moved across the screen altered the direction of the corresponding brain waves in areas of the brain that respond to visual information.

This discovery marks the first time that the movement direction of brain waves has been directly linked to movement in the environment. "These waves were not previously detected," explains Gong, "because we normally average brain activity across many repetitions of the experiment. This averaging process makes the responses easier to interpret, but we found that it also removes all of the interesting wave activity."

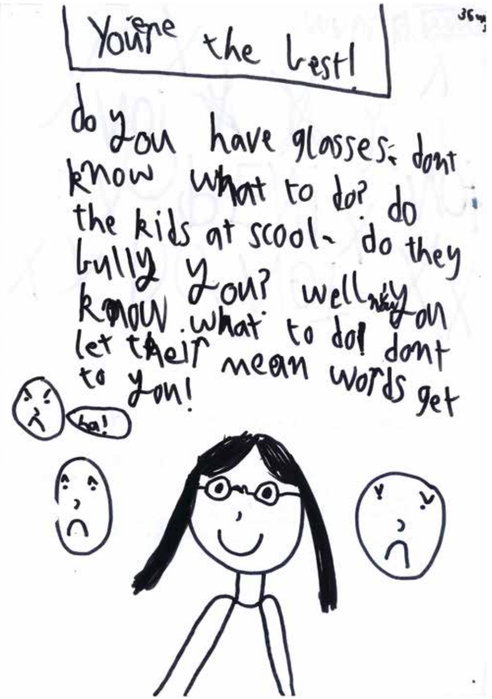
The team speculates that these moving waves have a specific role in information processing in the brain.

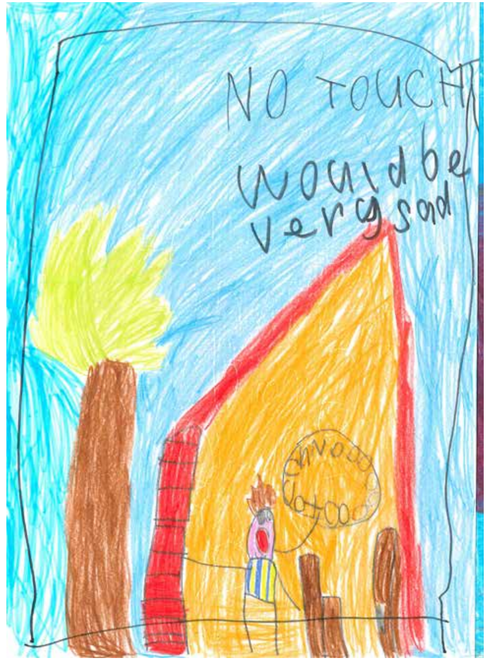
Article: Based on Townsend, R., Solomon, S. S., Martin, P. R., Solomon, S. G., & Gong, P. (2017). Visual motion discrimination by propagating patterns in primate cerebral cortex. Journal of Neuroscience, doi: 10.1523/JNEUROSCI.1538-17.2017

You’re the best

Do you have glasses, don’t
know what to do?
Do the kids at school -
do they bully you? Well, now you
know what to do! Don’t
let their mean words get to you!

Worlds and artwork by Emily, age 7, 2018





Artwork: Anwyn, age 6, 2018

A new open dataset for studying the brain

The Monash rsPET-MR dataset was generated by Brain Function CoE investigators Sharna Jamadar and Phillip Ward, in collaboration with colleagues from Monash University and Siemens Healthineers.

It includes data on brain activity that was captured from 27 healthy young adults using two methods applied simultaneously. These methods measure the two main sources of energy in the brain. The 'rs' in the dataset name refers to 'resting state', as the volunteers were measured as they lay awake with their eyes open.

BOLD-fMRI (blood oxygen level-dependent functional magnetic resonance imaging) measures oxygen use in the brain. FDG-PET ([18 F]-fluorodeoxyglucose positron emission tomography) measures glucose use in the brain. The team used a new technique, 'constant infusion', which allows a PET measure to be taken every 16 seconds. The standard approach can take 10–30 minutes to provide a single PET measure.

Using these two techniques simultaneously, the physiological processes underlying brain activity can be examined from multiple sources at the same time. This approach can also be used to measure changes in brain activity in response to certain tasks or at different stages of rest.

Since simultaneous fPET-fMRI is a new technology, few biomedical imaging facilities worldwide have produced datasets like this one. As a result, the researchers have publicly released the Monash rsPET-MR dataset for the use of the neuroimaging community. It is freely available from the OpenNeuro repository.

Researchers in the brain imaging community can use this unique dataset to understand the relationship between oxygen and glucose use during dynamic brain function. They can also use it to develop new methods and scientific discoveries.

Article: Based on Jamadar, S. D., Ward, P. G. D., Close, T. G., Fornito, A., Premaratne, M., O'Brien, K., Stäb, D., Chen, Z., Shah, N. J., Egan, G. F. (2020). Simultaneous BOLD-fMRI and constant infusion FDG-PET data of the resting human brain. Scientific Data, 7, 363. doi: 10.1038/s41597-020-00699-5

I use my brain to do everything

Words and artwork by Seb, age 6, 2016

Artwork: Amelia, age 10, 2016

A part of the brain specialised in humans helps manage competing goals

One of the defining characteristics of primate brains, including humans, is the existence of 'cortical area 10' in a part of the brain called 'frontopolar cortex'. This area is unique to primates and is proportionally larger in humans compared to other primates.

Previous studies have suggested that the frontopolar cortex is involved in advanced brain functions such as recalling memories, making decisions, multitasking, planning, and exercising moral judgement. However, the precise role of this part of the brain in cognition remains poorly understood.

The study of primates with damage in the frontopolar cortex has revealed a complex mix of impaired, spared, and even enhanced cognitive abilities. Lesions in this area do not affect overall intelligence, language, or sensory-motor skills; but lead to more subtle impairments in goal-directed behaviour.

This research by Brain Function CoE associate investigator Farshad Mansouri, chief investigator Marcello Rosa, and colleagues proposes a new theory for describing the functions of this key brain region.

According to this study, the frontopolar cortex is where we keep track of the importance of current and alternative goals to enable a switch in behaviour when the latter outweighs the first. For example, leaving the comfort and stability of your current job to explore a new career interest. People (and monkeys) with damage to the frontopolar cortex tend to have problems disengaging from what they are doing, even when something more valuable or important tries to get their attention.

The study further proposes that the evolution of the frontopolar cortex might have led to the advanced intelligence and creativity of the human mind.

Article: Based on Mansouri, F. A., Koechlin, E., Rosa, M. G. P., & Buckley, M. J. (2017). Managing competing goals – a key role for the frontopolar cortex. Nature Reviews Neuroscience, doi:10.1038/nrn.2017.111

Artwork: Isabella, age 11, 2017

Training + stimulation = better brain performance

In the past decade, interest in increasing our brain power has cultivated a multibillion dollar industry offering various products to improve cognitive ability. Online 'brain training' tools can improve performance on specific mental tasks through repetition. Battery-operated devices can be used to stimulate the brain via electrodes on the wearer's scalp. However, how well these products boost general brain performance – on their own or in combination – remains unclear.

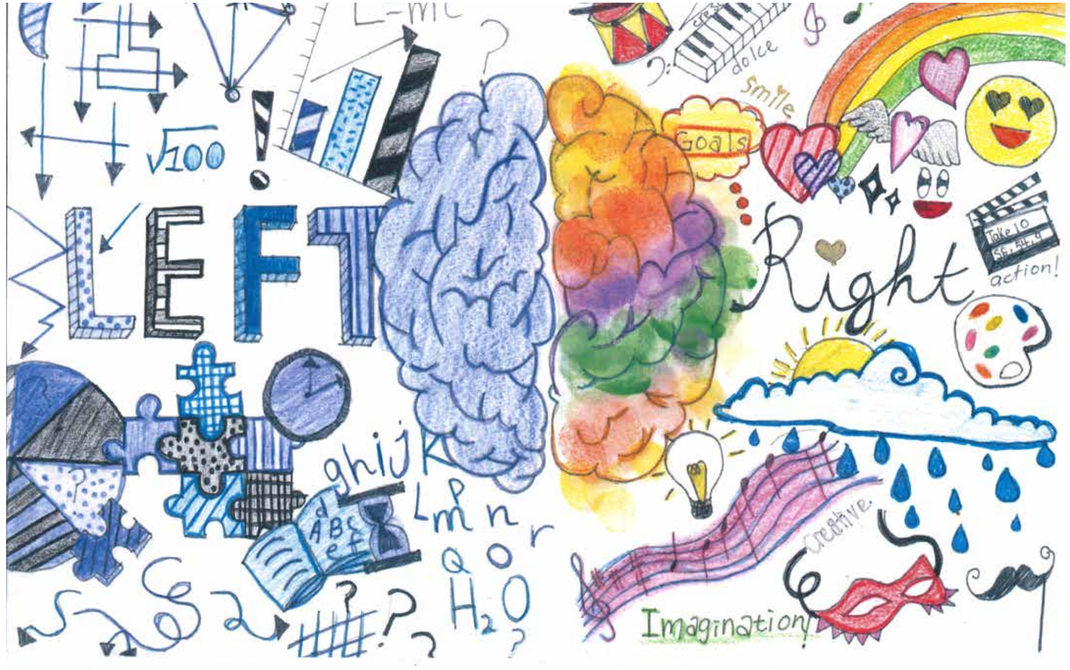
Post-doctoral fellow Hannah Filmer and her colleagues – including Brain Function CoE Associate Investigator Paul Dux and Chief Investigator Jason Mattingley at the University of Queensland – tested whether applying non-invasive brain stimulation during brain training could enhance general cognitive performance.

Participants trained on a specific task over four consecutive days while receiving transcranial direct current stimulation (tDCS). At the end of training, they were re-tested on the same task and on an unrelated task.

Using mathematical modelling, the researchers found that the participants' performance had significantly improved – not just on the task they'd practiced, but also on the unrelated task. This general benefit was still evident 2 weeks after the end of training.

The researchers' results suggest that the combination of brain training and tDCS works by enhancing the brain's ability to acquire and process information efficiently. This has important implications not only for understanding how the brain changes with experience, but also for treating people at risk of cognitive decline – such as the elderly, or individuals with neurological problems.

Article: Based on Filmer, H. L., Varghese, E., Hawkins, G. E., Mattingley, J. B., & Dux, P. E. (2017). Improvements in attention and decision-making following combined behavioral training and brain stimulation. Cerebral Cortex, 27, 3675–3682.



Artwork: Tasha, age 11, 2019

Honeybees could teach drones a thing or two about safe landing

When honeybees fly around from flower to flower, they control their flight speed so that the images of the world on their retinas move at a fixed speed. But why would they care what speed objects appear to be moving? It turns out that this is a great strategy for safe landing. When a bee moves towards a flower to land on it, the size of the flower expands on the retina as it gets closer. Keeping the speed of expansion constant on the retina results in the bee gradually and gently slowing down until it reaches a complete stop right as it lands.

Brain Function CoE researchers Michael Ibbotson and Hamish Meffin, and their colleagues in the USA, Germany, and Queensland, studied the brain circuits that allow for such a clever strategy for safe landing.

The team found brain cells in the bee that carry information about the speed of images to flight control centres in the body. These cells have all the necessary qualities to control bee landing strategies: they signal the direction in which objects around the bee move, they are fine-tuned to detect changes in speed, and their electrical activity is adequate to monitor the bee's flight speed.

Bees can communicate to their hive mates the direction and distance of food sources through their waggle dance. Current theories propose that bees keep track of the distance travelled to a flower using this same ability to monitor the speed of images on the retina.

Article: Based on Ibbotson M. R., Hung Y. S., Meffin H., Böddeker N., & Srinivasan M. V. (2017). Neural basis of forward flight control and landing in honeybees. Scientific Reports, doi: 10.1038/s41598-017-14954-0

My bossy brain

Hands! Move to the beat

Legs! Tap away.

Hips! Sway to the music

Mind! Imagine all things beautiful

Memory! Save this picture

Worlds and artwork by Catherine, age 7, 2019

Artwork: Juanita, age 7, 2016

Not so different from our monkey cousins for decision-making on the fly

You sit in the cinema and your phone buzzes in your pocket. Overriding that instinctive urge to check your phone is the job of the brain's executive control system. It ensures you don't make bad decisions based on impulse alone.

According to the influential 'conflict-monitoring' model, proposed by Matthew Botvinick (who was recently snapped up by Google's DeepMind) and colleagues 15 years ago, a region of our frontal lobe called the anterior cingulate cortex, or ACC, is responsible for identifying these moments of conflict and adjusting our behaviour so that we take a prudent course of action (don't touch that phone!).

But the model, based largely on brain imaging studies of people making such conflict-laden decisions, hasn't always fit the evidence.

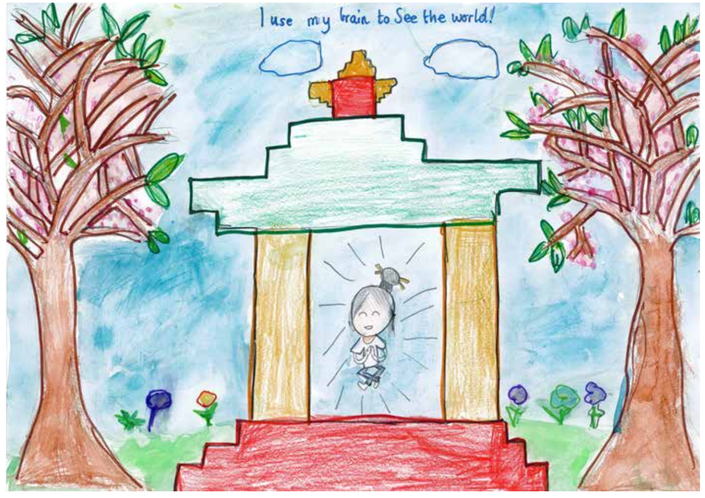
In 2007, work by ARC Centre of Excellence for Integrative Brain Function associate investigator Farshad Mansouri, then at the RIKEN Brain Sciences Institute in Japan, showed that monkeys with damage to their ACC navigate decision-making conflicts without difficulty.

Since then, neuroscientists have debated whether anatomical differences in human and monkey brains are the reason.

In this paper, Mansouri and colleagues suggest this isn't the case. The review of dozens of published research findings suggests that humans and monkeys are remarkably similar in the way their brains deal with conflict, and that the ACC isn't the sole region involved in conflict detection either.

Instead, they suggest that a distributed network of brain regions – including, but not limited to the ACC – are involved in decision-making on the fly. They also propose that conflict between options comprises just one of a constellation of factors – including risk, novelty and uncertainty – that helps to dial up executive control when needed.

Article: Based on Mansouri, F.A., Egner, T., & Buckley, M.J. (2016) Monitoring Demands for Executive Control: Shared Functions between Human and Nonhuman Primates. Trends in Neurosciences.



I use my brain to see the world

Christine, age 9, 2017

Artwork: Mackinlee, age 10, 2017

Mapping brain-spinal cord connections with CLARITY

Just a few short years ago, working out how the brain connected to the spinal cord depended on dissection, and the microscopic analysis of tissue slices. But cutting distorts tissue, introducing inaccuracies. What's more, the maps these techniques produce are usually two-dimensional – less than ideal for navigating the three-dimensional nervous system.

Fast forward to 2015, and this team has used a combination of conventional analysis and new 3D imaging techniques such as CLARITY to trace individual nerve cell projections or axons — some extending 4 cm — between the brain and the spinal cord of the mouse.

CLARITY is a technique that removes fat molecules from the tissues of the brain and spinal column, while preserving 3D structure. Proteins and nucleic acid molecules remain intact, and they can be coloured using antibodies and other markers tagged with fluorescent labels. The result: a semi-transparent brain with the business parts — for example, the wiring between nerve cells, the chemicals they release, and the genes that are active — captured in a 3-D colour snapshot.

Led by chief investigator George Paxinos at Neuroscience Research Australia and The University of New South Wales in Sydney, the team used CLARITY and other techniques to focus on axons extending between regions of the spinal cord and the hind brain that process information affecting movement and balance.

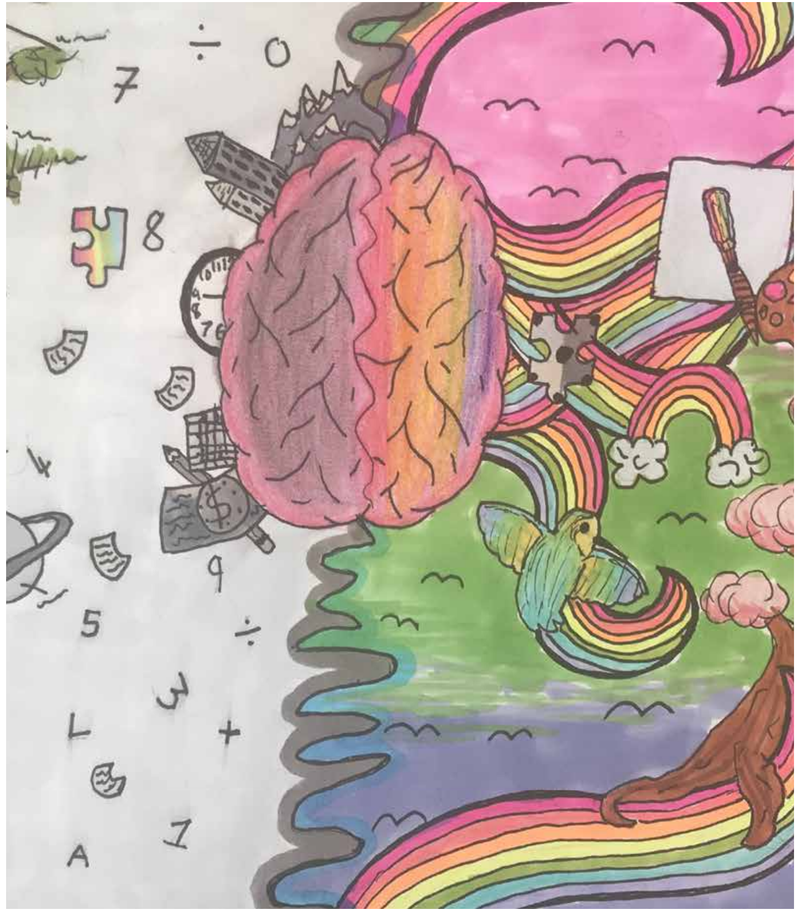
"Seeing the projections in three dimensions instead of two [means] we can follow the nerve fibres down and see exactly where they are within the spinal cord and where each one ends," says Andy (Huazheng) Liang, post-doc and lead author on three of the studies. That continuity isn't possible in two dimensions because the fibres move in and out of the view plane.

Article: Based on Sengul, G., Fu, Y., Yu, Y., & Paxinos, G. (2015). Spinal cord projections to the cerebellum in the mouse. Brain Structure and Function, 220(5), 2997-3009.

Liang, H., Bácskai, T., & Paxinos, G. (2015). Termination of vestibulospinal fibers arising from the spinal vestibular nucleus in the mouse spinal cord. Neuroscience, 294, 206-214.

Liang, H., Watson, C., & Paxinos, G. (2016). Terminations of reticulospinal fibers originating from the gigantocellular reticular formation in the mouse spinal cord. Brain Structure and Function, 221(3), 1623-1633.

Liang, H., Wang, S., Francis, R., Whan, R., Watson, C., & Paxinos, G. (2015). Distribution of raphespinal fibers in the mouse spinal cord. Molecular pain, 11(1), 1.



Artwork: Jordyn, age 11, 2020

Stripes and pinwheels, the fashion for vision

What we see during our early life has a strong effect on the way that our brain's visual areas are organised.

The "primary visual cortex" is a key area of the brain that receives information from the eyes. Brain cells here respond differently depending on the orientation of stripes, or edges, that we're looking at — some respond to vertical edges, as on a light post, some to slanted edges, as on a roof, and so on. These different orientations get organised in the visual cortex forming a map that follows a pinwheel formation.

In normal conditions approximately equal numbers of brain cells are devoted to each orientation, as in the figure above. But if brought up in a stripy world with only one orientation of stripes, say vertical, a greater number of brain cells would be devoted to that orientation (in the image above, it would result in a lot more yellow on the map, compared to other colours).

In this research by authors including Brain Function CoE chief investigator Michael Ibbotson, associate investigator Geoff Goodhill, and affiliate research fellow Shaun Cloherty, a new method was used to study changes in the pinwheel structure of primary visual cortex. This method was able to pinpoint changes in other aspects of the pinwheel map (besides the proportion of cells devoted to each orientation) resulting from seeing only one orientation in early life.

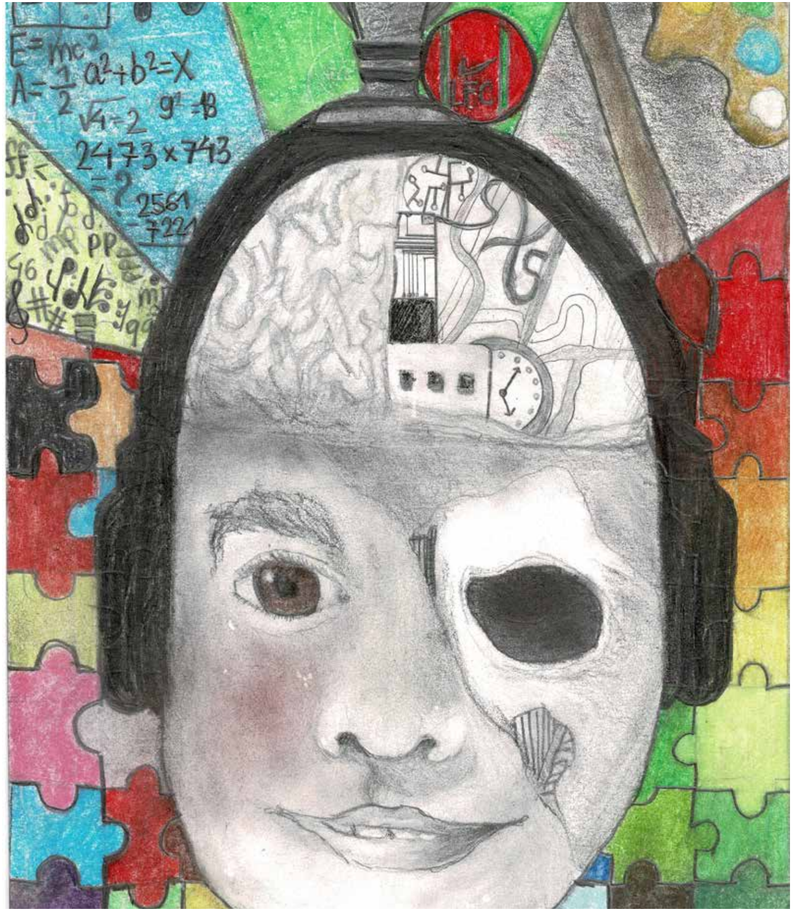
In addition to responding differently to the orientation of stripes, brain cells in primary visual cortex can be categorised depending on whether they respond mostly to input from the right or the left eye, or a combination of both. The primary visual cortex therefore also contains an "eye preference" map.

In a follow up study, the team used similar techniques to assess the effect of visual experience on both the pinwheel map (shown above) and the eye preference map. They found that changes in both maps were predictably related.

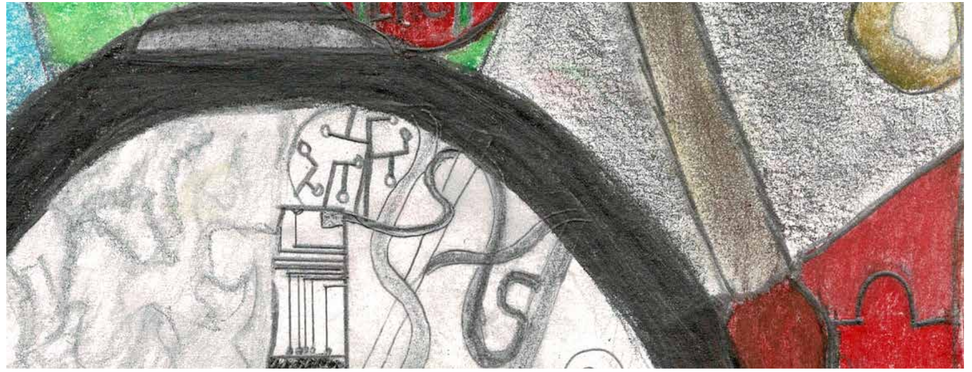
These studies reveal the extent to which brain organisation is determined by experience in early life and advance our understanding of disorders where the visual input is disrupted early in life, as occurs during misalignment of the two eyes (strabismus).

Article: Based on Hughes, N. J., Hunt, J. J., Cloherty, S. L., Ibbotson, M. R., Sengpiel, F., & Goodhill, G. J. (2014). Stripe-rearing changes multiple aspects of the structure of primary visual cortex. NeuroImage, 95, 305-319.

Cloherty, SL, Hughes, NJ, Hietanen, MA, Bhagavatula, P, Goodhill, GJ, Ibbotson, MR (2016). Sensory experience modifies feature map relationships in visual cortex. eLife Jun 16;5: e13911.



Artwork: Maxim, age 9, 2021



A new way to study how the brain prioritises attention to sensory information

A way to investigate how rat brains subconsciously prioritise sensory information — a skill critical to survival in any animal, including humans — has been developed by chief investigator Ehsan Arabzadeh and his team at the Eccles Institute of Neuroscience at the Australian National University.

The Arabzadeh team trained rats to respond in a set way to two different stimuli—a vibration through the whiskers or a flash of light. The trained rats were then exposed to one stimulus much more than the other in testing sessions — think of them as whisker sessions or light-flash sessions.

Rats responded faster and more accurately to the most common stimulus. For example, in a "whisker session", they were quicker to respond to vibrations, and better able to detect weak vibrations than light flashes. And neuronal activity was correspondingly enhanced in the sensory cortex region that processes whisker vibrations.

From a survival perspective this makes sense, says Conrad Lee, a PhD student in Arabzadeh's team, and the lead author of the paper. In a dark space, a rat gets more information about the environment from its exquisitely sensitive facial whiskers than from its eyes. In daylight, in an open field, what a rat sees will likely be more useful than what it feels through its whiskers.

Article: Based on Lee, C. C., Diamond, M. E., and Arabzadeh, E. (2016). Sensory Prioritization in Rats: Behavioral Performance and Neuronal Correlates. The Journal of Neuroscience, 36(11), 3243-3253.

If you couldn’t smell

If you had a lack of smell in this place
you would feel left out because
you would be in a cupcake store
and they always have good smells in them
because there’s cakes and things everywhere.

You would feel unhappy
and sad because you can’t smell anything.

Worlds and artwork by Claire, age 11, 2018

Artwork: Aya, age 9, 2016

Flop when you drop

Ever noticed how floppy a person goes when they sleep? This almost complete lack of muscle tone, called muscle atonia, happens in REM sleep, which is characterized by rapid eye movement and dreaming, and occurs 4 or 5 times during a night's sleep.

A small cluster of nerve cells between the midbrain and hindbrain called the oral pontine reticular nucleus, or PnO, is key to cycling between REM and non-REM sleep. Changes in the activity of chemical messengers in the PnO, or damage to it, increase or decrease the amount of time spent in REM sleep

Nerve cell projections from the PnO to sites along the entire length of the spinal cord have been found in rats and some other species, showing the pathway by which this tiny brain region could also affect muscle tone in the whole body.

The study described here, by a team led by Brain Function CoE chief investigator George Paxinos, confirm those findings, showing that the same is also true for mice.

"It suggests an anatomical basis for the loss of muscle tone while we sleep," says Andy (Huazheng) Liang, a post-doc in Paxinos' lab and lead author on the study.

Article: Based on Liang, H., Watson, C., & Paxinos, G. (2015). Projections from the oral pontine reticular nucleus to the spinal cord of the mouse. Neuroscience letters, 584, 113-118.

I use my brain to remember everything.

Words and artwork by Abdo, age 9, 2017

Artwork: Eliza, age 7, 2017

Lost in the landscape of the brain? Get out the atlas

You're lost in the desert and, after wandering for days, in the distance you spot a giant red rock jutting out of the barren landscape. Had you never encountered this landmark before (and your smart phone hadn't run out of battery), Google Maps could help you identify it as Australia's most famous natural wonder. Share your location with friends, and the coordinates will tell them where you can be found … exactly.

And so the new MRI/DTI Atlas of the Rat Brain offers guidance to brain researchers.

"MRI gives you the structure…high resolution and good contrast to see where things are. DTI (diffusion tensor imaging) shows the direction in which the water travels. It gives you the direction of the fibres," says Brain Function CoE chief investigator George Paxinos of Neuroscience Research Australia and the University of New South Wales in Sydney.

Paxinos created the atlas with Centre associate investigator Charles Watson, also of Neuroscience Research Australia, and researchers at the Centre for In Vivo Microscopy at Duke University Medical Centre in Durham, North Carolina, with support from the National Health and Medical Research Council and Brain Function CoE.

The MRI/DTI Atlas of the Rat Brain is a collection of high-contrast maps to navigate the brain, 250 microns at a time – equivalent to the diameter of a grain of fine sand. Its resolution is nearly 400 times what any other lab has achieved with MRI and DTI.

By checking what might be expected at given coordinates, researchers can identify the anatomical structures. Or, when studying rat models for human diseases like Parkinson's, epilepsy, autism or Alzheimer's, they can compare the diseased brain with the healthy brain depicted in the atlas. They can use the coordinate system as a frame of reference for relaying information to others.

The biggest advantage of MRI/DTI imaging over the histologic procedures used for Paxinos' previous atlases is that there is no cutting with a knife. This eliminates tissue distortion and makes for a more accurate coordinate system.

MRI/DTI Atlas of the Rat Brain is available in hardcover or e-book.

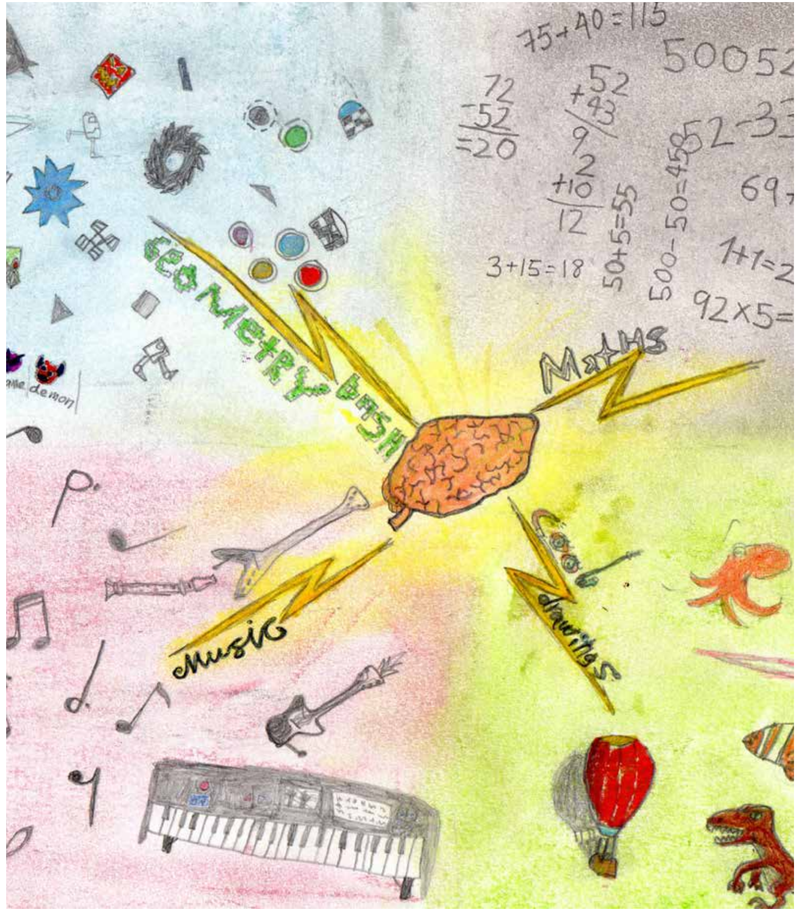
An online 3D version of the atlas is in the pipeline, which will allow researchers to overlay data onto the maps, creating a central repository of findings.

Is the human brain similar to that of the rat? "Embarrassingly so," says Paxinos. "For many years, people used our [original histologic] rat brain atlas to interpret their human images."

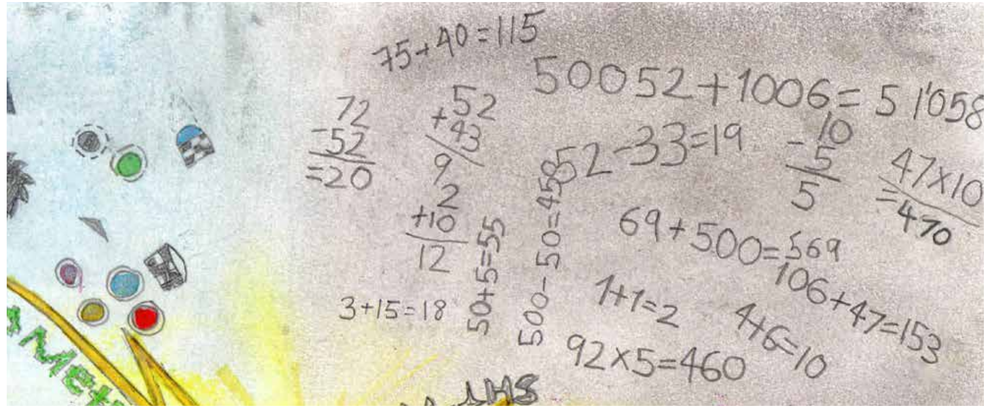
Despite that, Paxinos did eventually map the human brain. And the monkey, the mouse and even the bird brain.

But now, after decades of exploration, he has returned to his first love (yes, the rat) to produce this new-generation brain atlas.

Article: Based on Paxinos, G., Watson, C., Calabrese, E., Badea, A., & Johnson, G. A. (2015). MRI/DTI Atlas of the Rat Brain. Academic Press



Artwork: Jaime, age 8, 2017



Blink and you'll miss it

When people are asked to monitor a rapid stream of images for two target objects, they will almost always spot the first target. However, if the second target is presented soon afterwards – as little as 200–500 milliseconds later – they will often have no conscious awareness of it. It's as if their attention has blinked and missed it.

Neuroscientists thought that this phenomenon – known as 'attentional blink' – might be a result of the brain reaching the limit of its attention capacity. But it was difficult to study in detail, because brain imaging methods weren't sensitive enough to measure activity at such short time scales.

A research team led by Brain Function CoE researcher Matthew Tang, then in Jason Mattingley's group at the University of Queensland and now at Australian National University, developed a new experiment and imaging method to look at what happens in the brain during attentional blink.

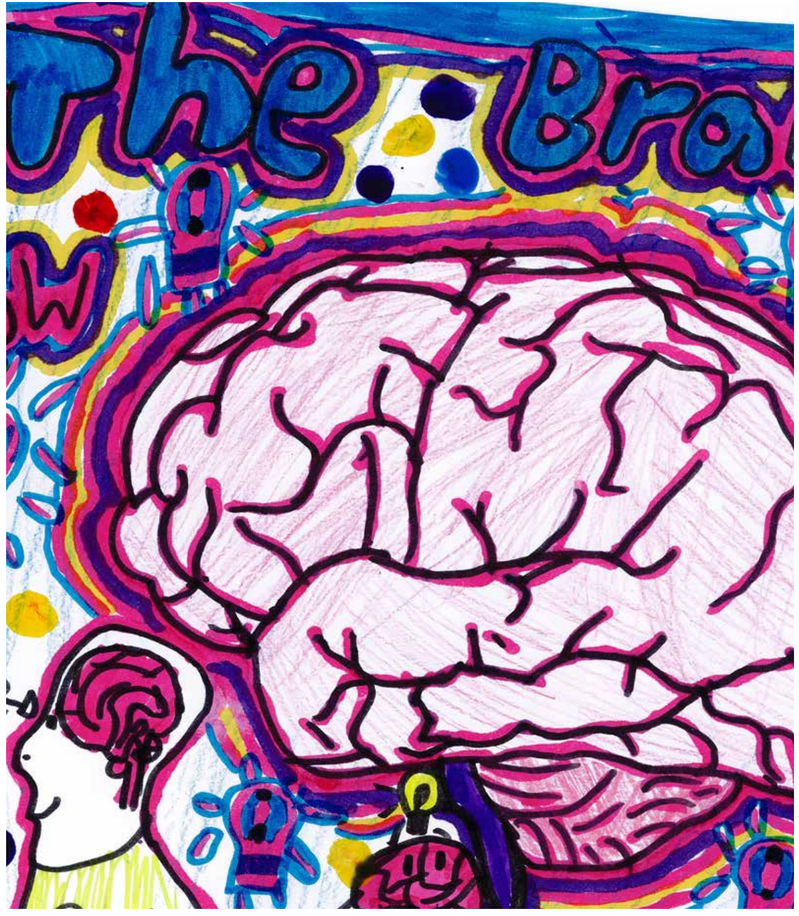
The researchers showed participants a rapid stream of images on a screen. All the images featured parallel stripes pointing in different directions. In the two target images, the stripes were narrower and closer together. While the participants watched the screen, their brain activity was monitored using electroencephalography (EEG) – a non-invasive brain monitoring technique. After they had viewed all the images, they were asked to report the direction of the stripes in the two target images – either by remembering or by guessing.

The researchers found that participants' recollection of each target was affected not just by the target itself, but also by images they saw immediately afterwards. This suggests that as soon as we pay attention to something, the brain starts to integrate the visual information that follows, even if it is not relevant.

Thanks to their new experimental approach, the researchers were able for the first time to determine which images the brain was processing. They did this by combining statistical analyses with the EEG recordings to decode the direction of the stripes in each image. When participants recalled the second target correctly, the researchers could accurately decode the direction from the EEG recording. However, when participants missed the second target, the quality of the decoding was significantly worse, even poorer than for non-target images.

Based on their results, the researchers believe that attentional blink is caused by the brain balancing demands on its limited resources. As soon as the brain processes the first target, it can focus attention on the second target, allowing us to become aware of it and remember it. But if the second target appears while the first target is still being processed, then the brain actively suppresses information about the second target to avoid it interfering with the first target.

Article: Based on Tang, M. F., Ford, L., Arabzadeh, E., Enns, J. T., Visser, T. A. W., & Mattingley, J. B. (2020). Neural dynamics of the attentional blink revealed by encoding orientation selectivity during rapid visual presentation. Nature Communications, 11(1), 1–14. doi: 10.1038/s41467-019-14107-z



Artwork: Lucia, age 7, 2017

It takes confidence

Survival, for most animals, hinges on making good decisions on the fly in changing, uncertain surroundings.

In this study, the researchers were able to get a handle on the confidence rats had in those decisions.

"Mostly choice itself has been studied. But we were interested in what happens before a choice and after," says Brain Function CoE chief investigator Ehsan Arabzadeh of the Australian National University, who led the team.

In sessions of about 25 minutes, the rats were allowed to drink from either of two spouts that delivered a set amount of sugary water with different probabilities — 80 percent of the time versus 20 percent of the time. Within a couple of sessions, the rats had learned to rush to the spout that was most likely to work.

Next, an element of uncertainty was introduced that more closely mimicked real life: the sugary water was delivered with the same probabilities but after unpredictable amounts of time. In the face of that uncertainty, the rats had to decide whether to persist with their choice or to abandon it. The higher the likelihood of reward, the more they persisted, pursuing the more profitable choice for between 50 and 300 extra milliseconds.

"Confidence is introspective, so it's hard to rate even in humans," says Arabzadeh.

"But we found confidence can be quantitatively measured in rats by the time spent pursuing a particular choice."

In a second set of trials, two spouts provided sugary water, again with different probabilities, but this time the sugary water would stay in a spout until the rat drank it.

Once again, when the element of uncertainty was introduced by changing delivery times, the rats were more confident about choosing the spout that offered the most sugary water. At the same time, they were able to keep a running tally, feeding repeatedly from the high-likelihood spout, and then periodically going to the low-likelihood one — which with time became increasingly likely to contain sugary water — for a bonus.

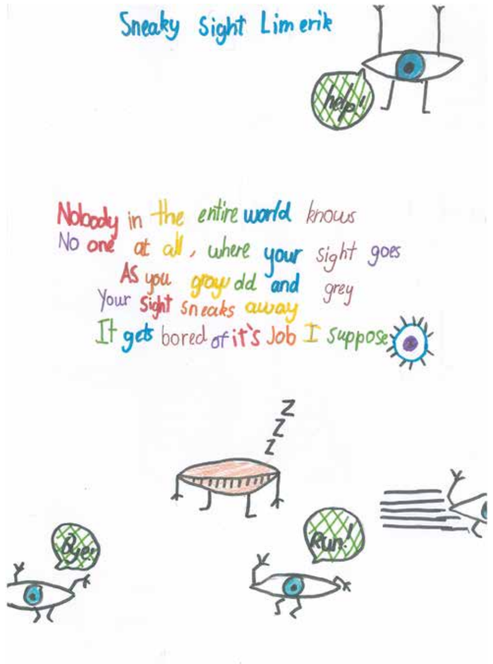
"It's striking. Even with such a complicated task, they choose the optimal strategy," says lead author Justine Fam of the University of New South Wales. "One explanation is that the rats are able to keep the information in their working memory to act on later."

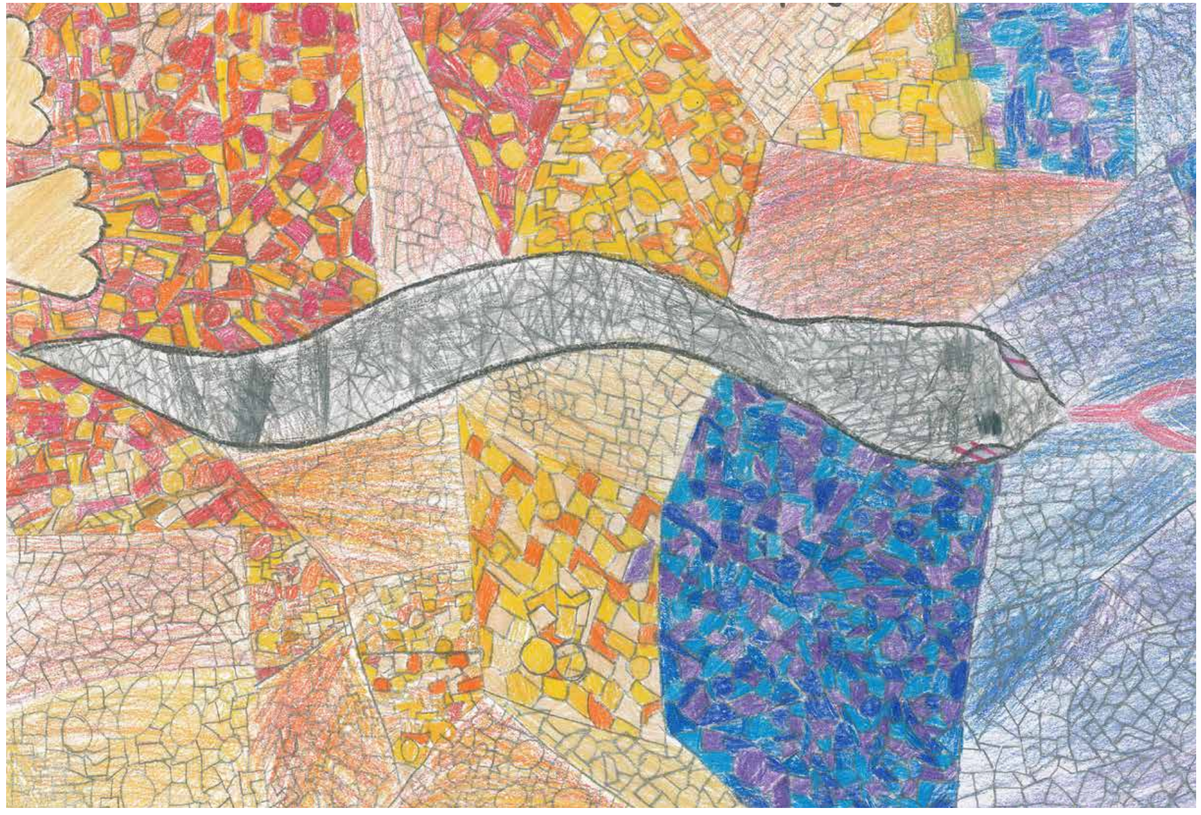
Article: Based on Fam, J., Westbrook, F., & Arabzadeh, E. (2015). Dynamics of pre-and post-choice behaviour: rats approximate optimal strategy in a discrete-trial decision task. Proceedings of the Royal Society of London B: Biological Sciences, 282(1803), 20142963.

Sneaky Sight Limerick

Nobody in the entire world knows
No one at all where your sight goes
As you grow old and grey
Your sight sneaks away
it gets bored of its job I suppose.

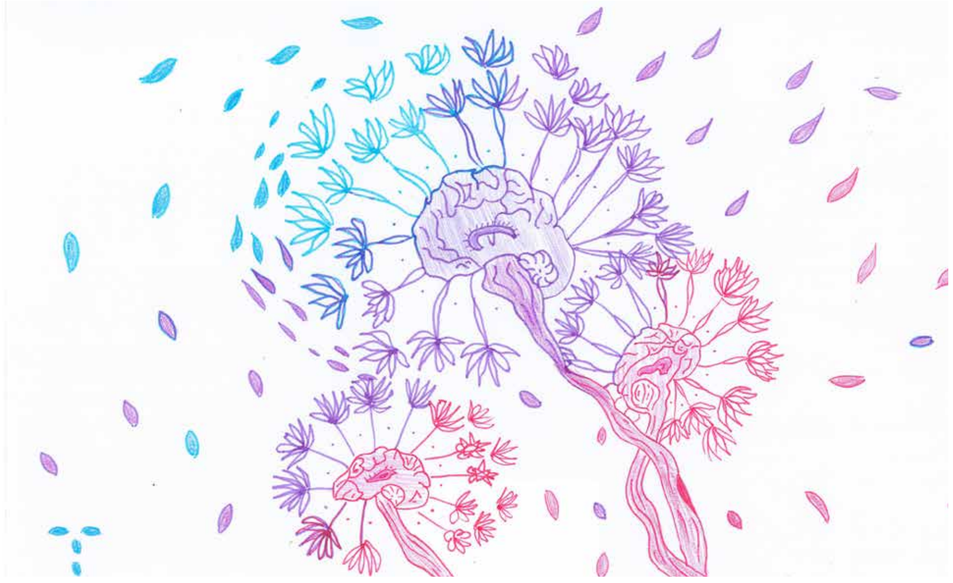
Worlds and artwork by Asha, age 10, 2018





A blind snake using its hear sense to sense what it thinks is its prey.

Words and artwork by Annabel and Ellie, both age 10, 2018



Artwork: Joanna, age 10, 2017

A single finger nerve cell distinguishes between touch stimuli better than the whole person

"We are dealing with a very surprising scenario—we didn't expect that a single cell would perform better than the brain," says Brain Function CoE chief investigator Ehsan Arabzadeh at the John Curtin School of Medicine in Canberra.

Arabzadeh is referring to a study by his team which shows that a single nerve cell in the fingertip can discriminate between two consecutive stimuli of differing strength better than the brain, which gets information from multiple nerve cells experiencing the same stimuli.

In their study, the researchers inserted very fine electrodes through the skin of volunteers into the median nerve at the wrist. The electrodes were fine enough to contact just one of the many nerve cells that send tactile information from fingers to the brain. A quick test established the "receptive field"—the exact area of skin which, when touched, triggered an electrical impulse in that cell. It is about the size of a pencil tip.

Next, the researchers used a device to stimulate the receptive field with pulsed vibrations.

The volunteers were asked to say which of a sequential pair of vibrations was stronger—this tested psychophysical performance, based on the brain interpreting the signals from tens to hundreds of nerve cells. It was compared to the neuronal response — the electrical activity generated by one nerve cell in response to each stimulus. The magnitude of this electrical activity depends on the strength of the stimulus.

Unexpectedly, single nerve cells were better able to discriminate between two subtly different stimuli than the brain.

There are two possible explanations. One is that the signal gets corrupted as it is relayed from the fingertip to the brain via a series of nerve cells. The second possibility is that as the brain pools signals from all nerves from the fingertip, signals from individual cells, which may vary in their response to stimulus, are lost.

In the end, it is probably a combination of both, says Arabzadeh.

Article: Based on Arabzadeh, E., Clifford, C. W., Harris, J. A., Mahns, D. A., Macefield, V. G., and Birznieks, I. (2014). Single tactile afferents outperform human subjects in a vibrotactile intensity discrimination task. Journal of neurophysiology, 112(10), 2382-2387.

Artwork: Shagun, age 6, 2017

Lopsided brains

People who have had a stroke can end up with a condition called "spatial neglect": their brain ignores objects and sounds on one side of the body. This can make everyday tasks like dressing or eating next to impossible.

Curiously, spatial neglect is far more common and severe following damage to the right side of the brain.

Why the brain behaves in this lopsided way has puzzled neuroscientists for decades.

According to one theory, the left side of the brain gets sight and sound inputs from the right side of the body, while the right side gets inputs from both sides. Because the right side is carrying more of the brain's processing load, when it's damaged, the outcome is worse.

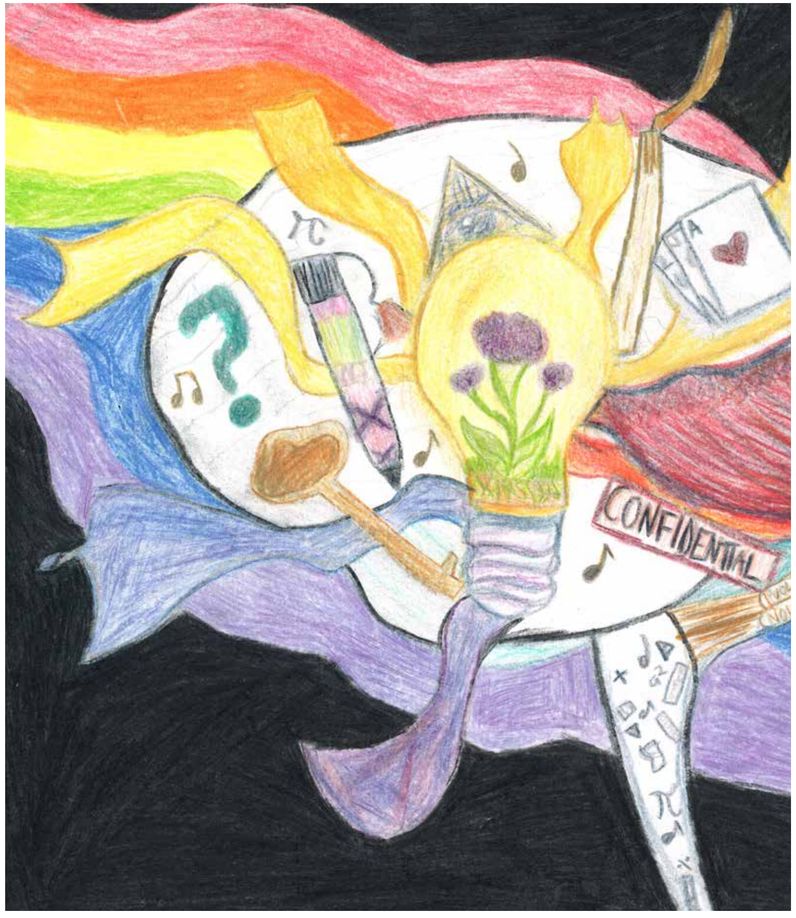
To test whether this theory was correct, Marta Garrido and her colleagues recorded brain activity in 12 healthy people as they responded to sounds from their left and right sides. They used electroencephalography (EEG) – a way of monitoring rapid changes in electrical activity across the scalp.

Their observations strongly suggested that the theory was correct. "The right hemisphere seems to be interested in sounds coming from the left and the right, whereas the left hemisphere seems to be just interested in things coming from the right side of space," says Garrido.

But EEG recordings only give a rough idea of where brain activity is occurring. So Garrido and her colleagues also used mathematical modelling to map the EEG activity onto discrete parts of the brain, confirming the finding.

"With modelling, we can tap into the networks and the mechanisms. We can really look at how information travels through different areas of the brain," explains Garrido.

Article: Based on Dietz, M. J., Friston, K. J., Mattingley, J. B., Roepstorff, A., & Garrido, M. I. (2014). Effective connectivity reveals right-hemisphere dominance in audiospatial perception: implications for models of spatial neglect. The Journal of Neuroscience, 34(14), 5003-5011.



Artwork: Harper, age 11, 2021

Injuries disrupt the brain's distributed connectivity

If a person has damage to the right side of their brain, they often lose awareness on the left side of their body. This effect, known as 'neglect', is common after a stroke.

The symptoms of neglect are often similar, regardless of what part of the right hemisphere has been injured. This suggests that neglect is the result of changes across the whole brain, not just in the damaged part.

An international team of researchers sought to test this hypothesis. The team was led by Martin Dietz at Aarhus University, Denmark, and Brain Function CoE investigator Marta Garrido from the University of Melbourne.

The researchers recruited 21 participants: ten people who had left-sided neglect after damage to the right side of the brain, and 11 people who were healthy. They used electroencephalography (EEG) to measure the participants' brain activity during an auditory oddball task. This task tests how the brain responds to unexpected sounds played on either the left or the right side of the head. In particular, the researchers used the EEG recordings to calculate the connectivity between two regions of the brain: the parietal and frontal cortex. These regions, which span both hemispheres, are involved in processing unexpected stimuli.

In healthy participants, regardless of which side of the body an unexpected sound was played on, the connectivity between the parietal and frontal cortex was higher on the opposite side of the brain. This confirmed results that the group had found previously.

But in participants with left-sided neglect, the brain connectivity increased only in the left hemisphere in response to an unexpected sound to their right. When a sound appeared to their left, there was no increase in brain connectivity in their right hemisphere. However, there was an increase in connectivity between two other brain regions in the left hemisphere. This suggests that the brain might have strengthened intact pathways to compensate for damaged ones.

These results support the idea that neglect is caused by a disruption to the network of connections across the brain, rather than to just one region.

Article: Based on Dietz, M. J., Nielsen, J. F., Roepstorff, A., & Garrido, M. (2020). Reduced effective connectivity between right parietal and inferior frontal cortex during audiospatial perception in neglect patients with a right-hemisphere lesion. Hearing Research, doi: 10.1016/j.heares.2020.108052

Artwork: Stefanie, age 10, 2021

On-line gaming gives brain research a leg-up

Industries from marketing to financial services are amassing vast quantities of digital data. With ever more powerful brain imaging, neuroscience is no exception.

Take Computed Tomography. A single CT scan captures over 2000 images in under a minute – equivalent to tens of thousands of smart phone photos — requiring tens of gigabytes storage. Multiply that by the hundreds of scans that go into the typical brain study, and it easy to see why processing the data is beyond the capacity of most computers. This is where facilities like MASSIVE come in.

MASSIVE, for the Multi-modal Australian ScienceS Imaging and Visualization Environment, is one of a growing number of neuro-computing facilities around the globe. Indeed, the success of The European Union's Human Brain Project and the US-based BRAIN Initiative will depend in large part on the development of supercomputing technologies and novel neuroinformatics.

MASSIVE gets brain image data directly from MRI machines, electron microscopes, CT scanners, and other imagers from around Melbourne, and increasingly across Australia, including from the Australian Synchrotron. Two powerful computers at its heart provide a combined 170 teraflops of processing power – almost 2000 times the speed of a desktop computer. A desktop interface and cloud computing means that neuroscientists can use MASSIVE from their offices.

Facilities like MASSIVE owe much of their prowess to online gamers, whose demands for ever more immersive virtual environments have driven innovation in visualisation technology. For example, MASSIVE has 148 Graphics Processing Units (GPUs) – standard computers have just one.

Those speeds are a game-changer for brain research. Neuroscientists can collect and examine information about the living brain in near real time, and even watch changes in the brain of a person lying in an MRI scanner as they complete different tasks, tasks that can be modified according to what appears on the scan.

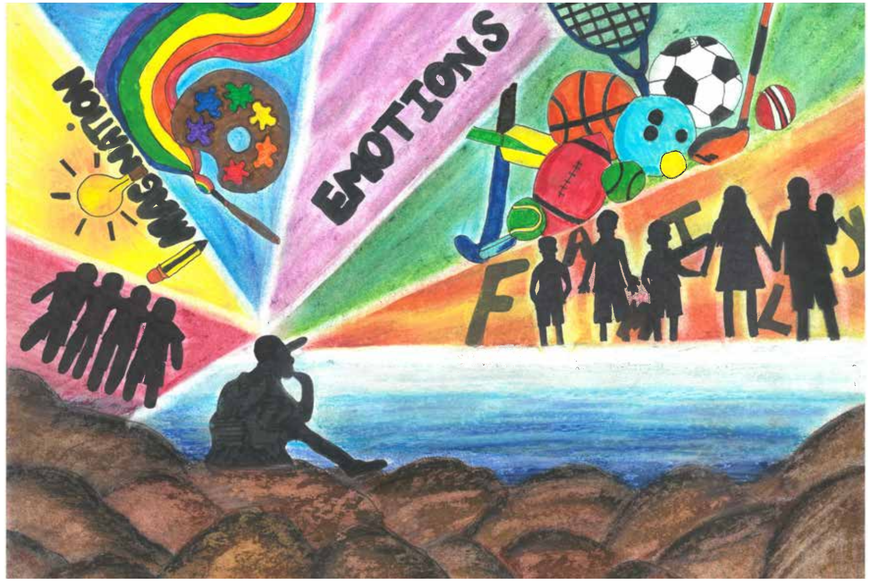
Article: Based on Goscinski, W. J., McIntosh, P., Felzmann, U., Maksimenko, A., Hall, C. J., Gureyev, T., Thompson, D., Janke, A., Galloway, G., Killeen, N. E. B., Raniga, P., Kaluza, O., Ng, A., Poudel, G., Barnes, D. G., Nguyen, T., Bonnington, P., and Egan, G. F. (2014). The multi-modal Australian ScienceS Imaging and Visualization Environment (MASSIVE) high performance computing infrastructure: applications in neuroscience and neuroinformatics research. Frontiers in Neuroinformatics 8.

A doll, that's how I would feel, like floating in space, nowhere to go, nothing to do, see smell touch, taste or hear.

It would feel like I was cut off from the world.

I would be floating in thin air, no one would understand how I feel, except me.

Worlds and artwork by Sara, age 10, 2018



Artwork: Cooper, age 11, 2020

CLARITY, the performance, with CUBIC variation

Science can sometimes seem a mysterious art, especially with tricky techniques. One way to share tacit knowledge that is needed to replicate a complex method, but so difficult to capture in words, is to show the method rather than describe it. That's the premise behind the Journal of Visualized Experiments (JoVE).

Andy (Huazheng) Liang, a post-doc in the lab of Brain Function CoE chief investigator George Paxinos of Neuroscience Research Australia and the University of New South Wales in Sydney, "performs" the CLARITY technique in a JoVE video paper.

CLARITY — it stands for Clear Lipid-exchanged Acrylamide-hybridized Rigid Imaging / Immunostaining / in situ-hybridization-compatible Tissue hYdrogel— renders the mouse spinal cord into a transparent, stainable structure ready for 3-dimensional analysis in exquisite detail.

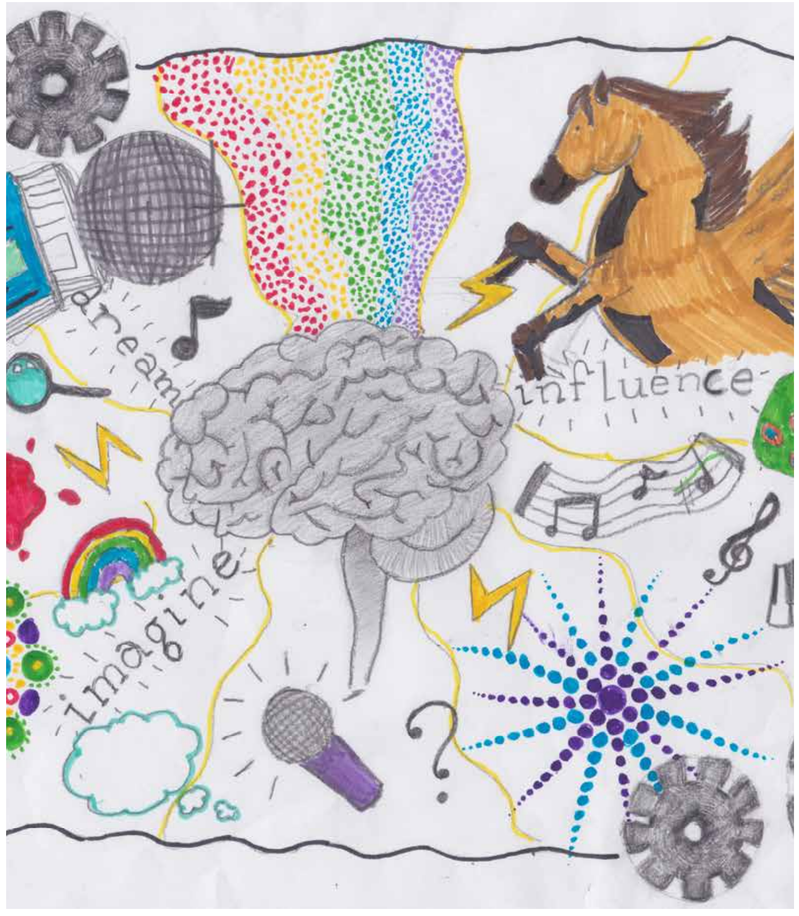
First, the spinal cord is infused with a hydrogel solution, which acts as transparent scaffold, anchoring the proteins and nucleic acids in place. Then a series of detergent washes remove fats from the tissue, making it transparent enough to read 8pt font through. Next, fluorescent antibodies are used to tag molecules of interest, such as serotonin. Finally, a "light sheet" fluorescent microscope, which can quickly scan three-dimensional pieces of tissue, is used to visualize the molecules within and around neurons and nerve fibres.

The whole process can take from a week to a couple of months, depending on the protocol used. To speed up the fat-clearing process, Liang has incorporated a variation into the technique called CUBIC.

JoVE's papers are peer-reviewed, and show techniques within the context of an experiment — in this case, Liang is studying connections between the mouse hindbrain and spinal cord.

Video, says JoVE editorial director Avital Braiman, improves the reproducibility of results—long a roadblock to scientific progress. "Science can't advance without reproducible results," she says.

Article: Based on Liang, H., Schofield, E., & Paxinos, G. (2016). Imaging Serotonergic Fibers in the Mouse Spinal Cord Using the CLARITY/CUBIC Technique. JoVE (Journal of Visualized Experiments), (108), e53673-e53673.



Artwork: Georgia, age 10, 2020

Slow blue road

Our brain is responsible for assigning colour to the images that our eyes see. It does this by bringing signals from three different colour receptors in the eyes together with streams of information about shape and movement.

Just to make the brain's job that bit harder, blue nerve signals move more slowly from the eye to the brain than red and green signals, according to this research led by Brain Function CoE fellow Alexander Pietersen of the University of Sydney.

"We don't notice that the brain processes blue colours slower," says Pietersen. "The brain compensates for [the lag]."

Although colour assignment occurs mainly in the visual cortex, the outer region of the brain that runs its most complicated processing tasks, this team had showed previously that a deep-brain region, the thalamus, also plays a significant role.

In this study, direct recordings from the thalamus, showed that the processing of blue colour signals from the eyes started later than for other colours.

The time lag suggests that the blue signal may be transmitted by more primitive, slower nerve pathways, says team member Centre chief investigator Paul Martin, also of the University of Sydney.

The finding fits with detailed lab tests that show that human reaction times are longer for blue colours. However, the team also found that red-green colour-blind marmosets process black, white and blue patterns at the same speed as marmosets with normal colour vision. That suggests that in the messy real world, where the brain processes floods of visual information, timing differences in colour processing are unlikely to affect performance.

"If we want to understand colour phenomena like that crazy blue dress, we need this basic knowledge" says Martin, referring to the optical illusion of a blue and black dress …or was it a white and gold dress… that went viral in 2015.

Article: Based on Pietersen, A. N., Cheong, S. K., Solomon, S. G., Tailby, C., & Martin, P. R. (2014). Temporal response properties of koniocellular (blue-on and blue-off) cells in marmoset lateral geniculate nucleus. Journal of neurophysiology, 112(6), 1421-1438.

Artwork: Sara, age 6, 2016

Mapping cell density in the human eye

Visual processing starts in the retina where photoreceptor cells – the rods and cones – capture light and convert it into electrical signals. Depending on the type of visual information contained in these signals, they are transmitted to the brain along different pathways.

The midget-parvocellular (P) pathway is involved in red-green colour vision. The parasol-magnocellular (M) pathway is involved primarily in detecting motion. But how the two pathways contribute to spatial vision – which we use to recognise objects and see fine details in the world around us – was not well understood.

To better understand spatial vision, Brain Function CoE researchers Rania Masri, Ulrike Grünert and Paul Martin from the University of Sydney tracked different cell types involved in the P and M pathways. They tagged the cell networks in these pathways using newly developed molecular markers, then used high-resolution microscopy to take images of the whole retina.

Their goal was to analyse cell density, which underpins the ability of each pathway to detect fine details. A high-density cell network is like a fine-grain sieve that can catch small details. By contrast, a low-density cell network lets fine details slip through undetected.

By analysing the retinal images, the researchers found that the density of the cell network in the M pathway is too low to support detailed spatial vision. However, the density in the P pathway precisely matches the level that people typically need to observe fine detail.

Article: Based on Masri, R. A., Grünert, U., & Martin, P. R. (2020). Analysis of parvocellular and magnocellular visual pathways in human retina. Journal of Neuroscience, 40(42), 8132-8148. doi: 10.1523/JNeurosci.1671-20.2020

Hearing the beauty of nature's sounds
Emotions heightened when music is played
A brain is a super important organ
Love the smell of fresh flowers
Touching means close love
Happiness when you taste your favourite food
Yummy baklava

Brain function is tremendously imperative
Rest is paramount for the brain so mediate
All the senses create therapy
I see beauty in faces of loved ones and my pet
Never take the brain for granted

Arielle, age 8, 2018

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