UCD Impact Case Study

New Approaches may Uncover How the Brain Forms Decisions

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"Working a lot with psychologists, I developed a love for the questions, the concepts and constructs of cognitive neuroscience"

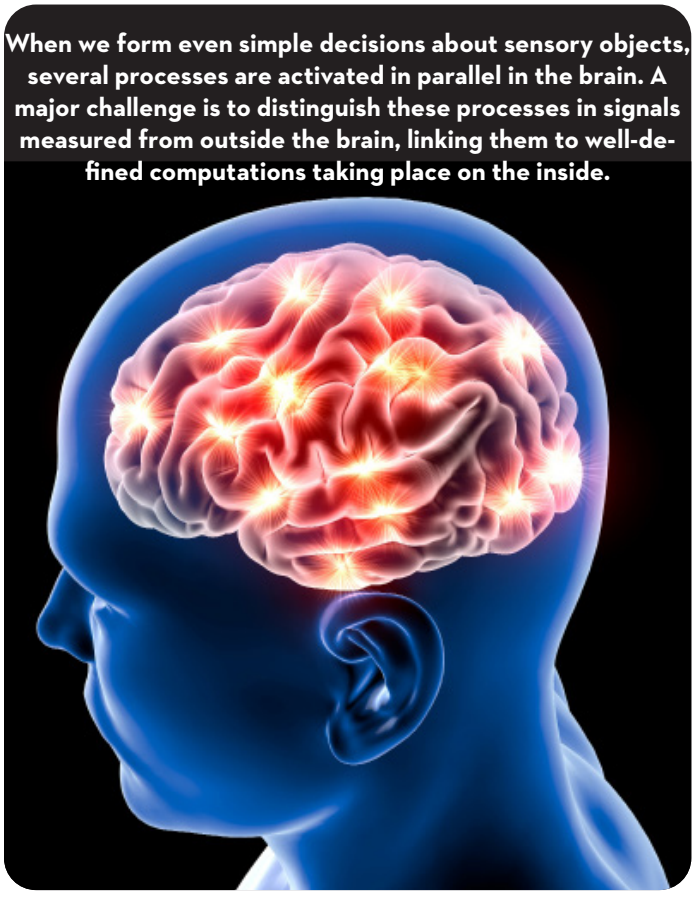
SUMMARY

"Who's that coming towards me? It looks like Maeve, doesn't it? I'll give her a wave. But hold on a second – I could have sworn that was Maeve." That's a common situation that most of us experience from time to time, and an example of a core brain function known as perceptual decision making. But what is actually going on in the brain and how can we get a better understanding of that? For two decades Associate Professor Simon Kelly has been preoccupied with these and related questions. Working closely with psychologists, the electrical and electronic engineer has made important strides in improving how we can disentangle what is happening as the brain progresses from focussing on an initial stimulus, such as seeing a person in the distance, to recognising them as a friend and deciding to wave. He is now engaged in two projects, one funded by the Wellcome Trust and the other under Science Foundation Ireland's US-Ireland R&D Partnership Programme, which build on this important work and could have potential longer-term benefits in diagnostics, and possibly even therapeutics, related to psychiatric and neurological disorders.

A Marriage of Disciplines

Associate Professor Simon Kelly graduated as an Electrical and Electronic Engineer from UCD in 2001 and obtained his doctorate there four years later. His PhD thesis involved a collaboration with Redmond O'Connell, who is now a Professor in the Trinity College Institute of Neuroscience and School of Psychology. The two have worked closely together on a variety of research projects ever since. "From the beginning we came with very complementary skillsets; these days he's almost as much an engineer, and I as much a psychologist, we've worked together for so long," Dr Kelly says.

The partnership arose as part of a drive to foster collaborations between psychologists and engineers in Dublin at that time, spearheaded by Richard Reilly, Ian Robertson and Paul Dockree. "The marriage between what was later to become known as neural engineering and psychology was a very natural one. The psychologists knew a lot about brain states while the engineers knew a lot about signal processing and the inferences come from both sides by melding their mathematical and conceptual perspectives, respectively."



When we form even simple decisions about sensory objects, several processes are activated in parallel in the brain. A major challenge is to distinguish these processes in signals measured from outside the brain, linking them to well-defined computations taking place on the inside.

Decision Making

The brain signals are obtained using human electroencephalography (EEG). This is a long-established non-invasive technique that involves applying electrodes to the scalp in order to measure neural activity in the brain.

"Working a lot with psychologists, I developed a love for the questions, the concepts and constructs of neuropsychology in and of themselves," Dr Kelly says. "I had been recruited initially to be the signal processor but soon found myself musing more and more on the deeper questions. The original goal of the multidisciplinary project was to use EEG signals to classify brain states such as inattentiveness. Back then the term 'machine learning' was not yet in common use, but that's what it was. At the same time, I was taking a cold look at the research I was doing and wondering how I might obtain more information about what these brain signals actually reflect.

"And I believed those lines of research could deliver so much more if we not only measured brain signals and used smart algorithms to transform and classify them, but also actually understood in the first place the function of those electrical signals and how they reflect the ways in which the brain is processing information."

Dr Kelly has focused his research on these questions, with a growing interest in the specific area of perceptual decision making. But it can be incredibly difficult to devise experiments that allow him to disentangle what is actually happening.

"There's always a temptation when you're working with human subjects to give them 'interesting' things to do. My contribution has really been to whittle things back to the kinds of paradigms that we would use with an experimental animal. I give humans things to do that mice and monkeys would be asked to do in other laboratories," Dr Kelly freely admits.

But it is by stripping away the unnecessary and irrelevant that he has obtained a clearer view of the key neural signals enabling decision making. "For example, we might ask subjects to look at a flickering image on a screen and press a button when they think it's faded. In this instance the stimulus and the signals we are measuring are simply about coming to a decision on whether there has been a change in intensity of the stimulus. This is a mind-numbing task but doing it this way means we can measure the sensory activity related to the brain's representation of how intense that stimulus is, which is the very thing they are deciding about, and eliminate signals that might be triggered by other more complex stimuli but have nothing to do with the decision process.

A Breakthrough Discovery

"We came up with this approach around 2012, which is when we published our first research in this area, and it has enabled us to discover signals in human EEG that seem to reflect the accumulation of evidence required to make a decision. As well as sensory signals representing the evidence being decided about, the brain also needs processes to translate those sensory representations into a plan of action.

"We discovered a signal that seems to slowly rise over time as subjects were looking for this fading of the stimulus. The stronger you make the evidence, the more steeply the signal climbs, but it also stops climbing around the time they respond with a decision. While people are very variable in their response times, the building and peaking of the signal aligns closely with when the subject commits to making a decision and acting on it by pressing the button."

Dr Kelly and his colleagues have since generated many more questions about this signal, as well as more general questions about the factors involved in how the brain arrives at decisions. He is now pursuing two strands of research. One is a four-year individual investigator project funded by the Wellcome Trust in which he is seeking to identify what factors influence the level of evidence that people need to accumulate in order to make decisions in different circumstances.

Over the past 10 years many models have been developed to try to represent mathematically how the brain arrives at a commitment about a decision. Unfortunately, alternative models sometimes fit behavioural data equally well but lead to fundamentally different conclusions. "This particular project will hopefully give us a better fix on which of the alternative models apply in any given situation. I'm not expecting to fully solve this question across all situations that can arise, but I do hope to achieve some insights into fundamental principles governing how we form decisions differently to suit the situation we're in," he says.

The second project is a grant funded under Science Foundation Ireland's US-Ireland R&D Partnership Programme. This involves Dr Kelly and Prof O'Connell working in partnership with Professor KongFatt Wong-Lin of Ulster University, Prof Michael Shadlen of Columbia University New York, and Dr Stephan Bickel of the Northwell-Hofstra School of Medicine. Their aim is to identify the underlying neural mechanisms of decision-making in order to understand a core element of both normal and abnormal cognition.

"One of the great advances that has really revolutionised the study of decision making is the observation that as we are deciding about something, we're also planning the action that we need to take based on that decision," Dr Kelly explains.

"For example, I know that if I recognise the person coming I will wave to them and if it's a stranger I won't, so the decision about whether or not I recognise someone is represented in the same neural circuits that plan the action of waving. There are even situations where the decision is partially executed – I might lift my hand to start waving, for example, then drop it.

"And because of that trick, being able to get a window into somebody's decision based on their motor planning, most of what we know about decision making is specific to the situation. But not all our decisions are like that. Some are more abstract and not tied to any particular course of action until perhaps a later time. We've come together to try to identify the nature of the core representation used to make those decisions in the brain."

Significant Potential Impacts

Kelly is a strong believer in the importance of basic research and its potential role as a foundation for subsequent initiatives that deliver practical impacts for society. "Some of the most significant advances that underpin progress in modern society can be traced back to basic research. There is a need to fund research which may not have an obvious and direct route to civic or commercial application in the immediate short-term," he insists.

But at the same time his research has consistently contributed advances in knowledge in areas with tremendous potential health benefits, particularly in areas of cognition associated with neurological disorders, including Parkinson's disease.

His early doctoral research sought to devise a way of detecting when someone is losing focus, with the ultimate aim of developing applications to detect this in situations where the consequences could be catastrophic, such as driving, he recalls.

His subsequent research led him to develop an interest in an area known as "brain computer interfacing". This captures, analyses and translates brain signals into commands that can then be relayed to devices to assist people with a variety of neuromuscular disorders, such as cerebral palsy, stroke or spinal cord injury for example, to communicate or undertake a range of tasks. He and his colleagues have published a number of well-regarded papers on this topic.

Because decision-making is a basic building block of cognition essential to almost all mental activities, its disruption is central to the cognitive impairments associated with a wide variety of brain disorders. His latest collaborative research with partners in the Republic, Northern Ireland and the US seeks to identify the underlying neural mechanisms of decision-making in order to understand both normal and abnormal cognition in primate and human subjects. This could have potential in diagnostics and maybe even therapeutics for mental health, whether they be psychiatric or neurological disorders – areas on which there has been little headway made up to now.

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Social Media References

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