The Science of Memory

Scientists are beginning to crack the mystery of memory – and their studies offer some hope for the treatment of PTSD, dementia and Alzheimer's disease.

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Imagine being convicted of a crime you didn't commit, thanks to a failure of memory. This happened to Ronald Cotton, who was imprisoned for 10 years in the US for rape, before DNA evidence proved his innocence. The conviction stemmed from two critical memory failures – that of his alleged victim, who insisted Cotton was her assailant; and of Cotton himself, who claimed he was with friends when the assault occurred. When they couldn't corroborate this, Cotton realised he had remembered the wrong weekend – but changing his story only led to suspicions about his honesty.

While becoming embroiled in such a situation is unlikely, memory is still crucial to our lives – it enables us to do everything from driving a car to performing complex work tasks. Memories also help to inform our identity and sense of belonging. It's only when it begins to fail that we appreciate memory's importance for our sense of self and coherence, says Associate Professor of Psychology, Muireann Irish, from The University of Sydney's Brain & Mind Centre.

Scientists are discovering how our brains create, store and retrieve memories and use them to make plans. Their findings offer hope for people with dementia – the second-leading cause of death in Australia, and the leading cause of death for Australian women, according to the Australian Bureau of Statistics. In 2018, an estimated 425,416 Australians are living with dementia. A report by the National Centre for Social and Economic Modelling revealed that without a medical breakthrough, this number will rise to about 1.1 million by 2056 – at a cost to the economy of more than $36.8 billion.

Professor Irish explains that memory has several categories, and each one relies on different brain pathways. Semantic memory refers to "our repository of world knowledge or facts, such as 'Paris is the capital of France'," she says.

Spatial memory, on the other hand, enables us to navigate and remember things such as our route to work. Procedural memory covers non-conscious activities such as typing or riding a bike. Episodic memory is our recollection of experiences and events – often with rich detail and emotion.

The director of the Queensland Brain Institute, Professor Pankaj Sah, explains that the study of one man – known as HM – became a "goldmine" for memory research.

After structures from HM'S temporal brain lobes were removed to treat epilepsy, he couldn't create any new, conscious memories. "He couldn't remember the nurses that visited him each day or what he ate for dinner the previous night, and if you told him the US had a new president, he'd forget it within a few minutes," Professor Sah states. Despite this, HM's fine motor skills improved with practice, proving that motor learning used different structures to autobiographical and factual memories.

Much of our knowledge about memory comes from laboratory experiments, but a team at the University of Melbourne are taking their research into the real world. The team, led by Professor Simon Dennis of the Melbourne School of Psychological Sciences, are using contemporary technology to study normal episodic memory.

In one experiment, participants wore a smartphone around their neck which captured images, audio, GPS and movement information. About two weeks later, participants were shown images and asked to recall when they occurred. Professor Dennis's team was surprised to discover that the visual information wasn't as important as the GPS, accelerometry and audio information for accurate memory.

He explains that the unique audio signature of an environment, combined with specific movements such as walking or sitting, seem to get bound together in episodic memory without our conscious awareness.

PROFESSOR DENNIS'S TIPS FOR ENHANCING MEMORY

1. Become an expert in an area you want to remember. "Experts are able to code new memories in ways that protect them from interference from other memories and thus improve performance," says Professor Simon Dennis, of the Melbourne School of Psychological Sciences.
2. Focus on encoding. For example, when you meet someone new, try to use their name in conversation before you part.
3. Create routines so you don't have to remember things. For example, always put your keys in the same place so you needn't remember where you left them each time.
4. Forgot why you entered a room? "This is typically a failure of short-term memory and occurs because you start thinking about something else," he says. Try retracing your steps to put yourself back into the context where you decided to enter the room – this acts as a retrieval cue.
5. Put yourself back into the state you were in when you were encoding the memory. Professor Dennis says this is even true for alcohol. "If you are inebriated when you learn something, it is actually better to become inebriated again if you want to recall it. However, the best recall occurs when you are sober at both study and test."

"People tend to have a notion of 'What I'm remembering is what I saw'," Professor Dennis says, "but it seems to be these are the things that actually [cause] the errors."

These findings could have huge and widespread implications for cases such as Cotton's, where a failure of memory proved critical.

Forming a memory involves strengthening connections between certain brain cells. "What used to be a faint whisper becomes a more robust conversation," Professor Sah explains. "This strengthening makes it easier to reactivate, or recall, the particular neural pathway that represents an event in the world."

Scientists have discovered the molecules and processes needed for this strengthening, but nobody has yet figured out how to turn this knowledge into better human memory.

HM's case has helped to show researchers how and where memories are stored and retrieved. HM couldn't remember much from right before his surgery, but he could still retrieve events from years earlier. "This hinted that long-term memory storage doesn't require the temporal lobe structures he lost during his surgery," explains Professor Sah.

We now know that factual and autobiographical memories are formed and temporarily stored in the hippocampus – an area within the temporal lobe that gets its name from the Latin word for seahorse, thanks to its shape. Over time, they move to the cortex – "the wrinkly sheet of tissue that forms the visible outer surface of most of the brain", Professor Sah says.

Called consolidation, this transfer literally happens overnight, as the hippocampus and cortex "undergo a choreographed interplay while you sleep, replaying events from the previous few days of your life," Professor Sah says. He adds that researchers have observed this in animal studies, showing that "the same sequence of cells active during a certain moment of the day can be repeated multiple times, in a time-compressed manner, during sleep".

To retrieve a conscious memory, it seems that we use the hippocampus like an index, which sends messages to the storage regions in the cortex. When these areas are reactivated in a similar manner to the original event, we recall that event. For example, reading the word "Rome" could trigger the "Rome" index card. "The hippocampus then rounds up other circuits throughout the brain that make up the full memory – a vision of the Colosseum, the taste of pizza and gelato, the sound of an Italian guy shouting something incomprehensible at you," Professor Sah says.

AN AREA OF PROMISE FOR PTSD

Researchers have studied animals to see how associations are made between an innocuous event, like the ringing of a bell, and an adverse event, like a mild electric shock. The director of the Queensland Brain Institute, Professor Pankaj Sah, says research has shown that if the bell is repeatedly rung without being followed by an electric shock, the animal eventually learns to dissociate the bell from the trauma – the fear associated with the bell gets "extinguished". Professor Sah explains that translating these findings to human therapies has proven challenging, but understanding what is changing in the brain – and how it can be manipulated – offers the best chance of treating conditions such as PTSD.

Professor Dennis adds that people who lose their hippocampus develop a phenomenon called Ribot's gradient, where their memory is better for things further back in time. "If you take out the hippocampus, those things that are more recent didn't have a chance to get out into the cortex," he says.

Professor Dennis has studied how the hippocampus codes memories of time and space. He says his previous lab research – which occurred in small spaces over about an hour – showed the back of the hippocampus to be most active in episodic memory. His team scanned participants' brains in a functional MRI while they were shown images from their lives and asked to recall when and where they happened. They discovered that when events over larger periods of time and space were recalled, the front of the hippocampus was more active.

Another area that's involved in memory is the amygdala. Also in the temporal lobe, Professor Sah says it attaches emotional significance to sensory inputs, which explains why emotionally-charged events – like meeting your partner – are firmly stored. Animal studies have shown fear memories are made and possibly stored in the amygdala, and that it is required for retrieving fear memories. The amygdala, hippocampus and cortex all work together to process, store and retrieve memories.

Professor Irish notes that memory is "constructive" rather than "reproductive" – when we recollect events, we don't simply play back the memory like a DVD. Rather, we reassemble information about the space, time, sensory and emotional details of the event – which creates a new memory trace. "This may offer important insights into the error-prone nature of memory, and its vulnerability to distortion," she says.

She adds that while memory has usually been viewed as a past-oriented system, its constructive nature is actually well suited for envisaging the future. The same brain regions that remember the past have been demonstrated to activate when we think ahead.

"Recent studies have shown that when we simulate the future, we draw upon our episodic and semantic memory systems, extracting the relevant details and recombining them to simulate new events and experiences," she says. "Damage to the episodic memory system has also been observed to compromise the capacity to envisage the future in such syndromes as Alzheimer's Disease."

Professor Irish says given that memory dysfunction is a key feature of dementia syndromes, understanding where things go wrong is critical for enabling earlier diagnosis and appropriate interventions. "How such difficulties in future thinking affect the everyday functioning of the individual is an important question to address, given that so many of our behaviours depend upon the ability to anticipate and to plan ahead."

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As for the future, while researchers have learned a lot about memory, there is still so much to be understood. Professor Dennis says technology is a game changer because it enables massive amounts of data to be collected and analysed. He says analysing this data will help answer real-world questions like, how likely is it that a person would make an error in their alibi? "That's going to make a huge difference in the relevance of memory research."

Professor Irish says that gaining a better understanding of memory will provide new ways to evaluate and treat mental and neurological disorders, offering hope to the many people suffering these conditions.

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