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New Insight into "Aha" Memories

When we suddenly get the answer to a riddle or understand the solution to a problem, we can practically feel the light bulb click on in our head. But what happens after the "Aha!" moment? Why do the things we learn through sudden insight tend to stick in our memory?

"Much of memory research involves repetitive, rote learning," says Kelly Ludmer, a research student in the group of Prof. Yadin Dudai of the Institute's Neurobiology Department, "but in fact, we regularly absorb large blocks of information in the blink of an eye and remember things quite well from single events. Insight is an example of a one-time event that is often well-preserved in memory."

To investigate how lessons we gain from insight get embedded in our long-term memory, Ludmer, Dudai and Prof. Nava Rubin of New York University designed a test with "camouflage images" – photographs that had been systematically degraded until they resembled inkblots. When volunteers first viewed the images, they were hard pressed to identify them. But after the camouflage was switched with the original, undoctored picture for a second, the subjects experienced an 'Aha!' moment – the image now popped out clearly even in the degraded image. Their perceptions, says Ludmer, underwent a sudden change – just as a flash of insight instantly shifts our world view. To tax their memory of the insightful moment, participants were asked to repeat the exercise with dozens of different images and, in a later repeat session, they were given only the camouflaged images (together with some they hadn't seen before) to identify.

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The team found that some of the memories disappeared over time, but the ones that made it past a week were likely to remain. All in all, about half of all the learned "insights" seemed to be consolidated in the subjects' memories.

To reveal what occurs in the brain at the moment of insight, the initial viewing session was conducted in a functional MRI (fMRI) scanner. When the scientists looked at the fMRI results, they were surprised to find that among the areas that lit up in the scans – those known to be involved in object recognition, for instance – was the amygdala. The amygdala is more famously known as the seat of emotion in the brain. Though it has recently been found to play a role in the consolidation of certain memories, studies have implied that it does so by attaching special weight to emotion-laden events. But the images used in the experiment – hot-air balloons, dogs, people looking through binoculars, etc. – were hardly the sort to elicit an emotional response. Yet, not only was the amygdala lighting up in the fMRI, the team found that its activity was actually predictive of the subject's ability to identify the degraded image long after that moment of induced insight in which it was first recognized.

"Our results demonstrate, for the first time, that the amygdala is important for creating long-term memories – not only when the information learned is explicitly emotional, but also when there is a sudden reorganization of information in our brain, for example, involving a sudden shift in perception," says Ludmer. "It might somehow evaluate the event, 'deciding' whether it is significant and therefore worthy of preservation." ❙

Getting a Grasp on Memory

Long-term memory is a slippery thing. Just how slippery it can be was demonstrated a few years ago by Weizmann Institute scientists, who erased entire memories in rats just by blocking a certain protein in the brain. In other words, memory – even the part

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we imagine to contain neatly packed files – is in reality a dynamic piece of equipment that must be actively maintained to work. Now, in research published in *Science*, these scientists have shown that manipulating the same protein can enhance memory.

The protein – PKMzeta – is produced in the brain in response to learning, and it acts on the synapses – the active contact points between neurons. It continues to operate there long after the memory has been formed, suggesting that its function is tied not to learning (that is, absorbing information), but to keeping what is learned available in the long-term memory. In 2007, Prof. Yadin Dudai and research student Reut Shema of the Neurobiology Department, together with Prof. Todd Sacktor of SUNY Downstate Medical Center, New York, trained rats to avoid a specific taste and then blocked the activity of PKMzeta in their brains. While the control rats still had a strong aversion to the taste, even months after the training, those in which the activity of the protein was briefly blocked had no such qualms, appearing to have forgotten what they had learned.

But, could extra doses of PKMzeta actually improve memory? Investigating this claim turned out to be a more difficult prospect than blocking protein activity. Simply injecting the protein into the rats' grey matter was not an option, as the brain is built to keep such extraneous material from reaching the neurons. So Dudai, Shema and Sacktor teamed up with Dr. Alon Chen and Sharon Haramati, also of the Neurobiology Department, to create harmless viruses that carry extra copies of the PKMzeta gene into the brain cells' nucleus, tricking the neurons themselves into producing greater quantities of the protein.

Once again, they trained the rats to avoid the taste. Weeks after the training, the rats whose brains were churning out more of the proteins were much more likely to avoid the taste. In other words, an excess of PKMzeta effectively enhanced their memories. This is the very first demonstration that memories formed long ago can be augmented by manipulating a component of the memory machinery in the brain.

While the technique they developed is only suitable for the lab, the researchers hope that by shedding light on the function of this key component of the memory machinery, their findings might eventually point to ways of preventing or treating memory loss. Shema: "Our research is evidence that our brains are very plastic – even our long-term memories can be augmented." ❙

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Biological Molecules Select Their Spin

New findings could help build better biomedical devices

Do the principles of quantum mechanics apply to biological systems? Until now, says Prof. Ron Naaman of the Institute's Chemical Physics Department (Faculty of Chemistry), both biologists and physicists have considered quantum systems and biological molecules to be like apples and oranges. But research he conducted together with scientists in Germany, which appeared recently in *Science*, definitively shows that a biological molecule – DNA – can discern between quantum states known as spin.

Quantum phenomena, it is generally agreed, take place in extremely tiny systems – single atoms, for instance, or very small molecules. To investigate them, scientists must usually cool their material down to temperatures approaching absolute zero. Once such a system exceeds a certain size or temperature, its quantum properties collapse, and "every day" classical physics takes over. Naaman: "Biological molecules are quite large, and they work at temperatures that are much warmer than the temperatures at which most quantum physics experiments are conducted. One would expect that the quantum phenomenon of spin, which exists in two opposing states, would be scrambled in these molecules – and thus irrelevant to their function."

But biological molecules have another property: they are chiral. In other words, they exist in either "left-" or "right-handed" forms that can't be superimposed on one another. Double-stranded DNA molecules are doubly chiral – both in the arrangement of the individual strands and in the direction of the helices' twist. Naaman knew from previous studies that some chiral molecules can interact in different ways with the two different spins. Together with Prof. Zeev Vager of the Particle Physics and Astrophysics Department, research student Tal Markus, and Prof. Helmut Zacharias and his research team at the University of Münster, Germany, he set out to discover whether DNA might show some spin-selective properties.

The researchers fabricated self-assembling, single layers of DNA attached to a gold substrate. They then exposed the DNA to mixed groups of electrons with both directions of spin. Indeed, the team's results surpassed expectations: The biological molecules reacted strongly with the electrons carrying one of those spins, and hardly at all with the others. The longer the molecule, the more efficient it was at choosing electrons with the desired spin, while single strands and damaged bits of DNA did not exhibit this property. These findings imply that the ability to pick and choose electrons with a particular spin stems from the chiral nature of the DNA molecule, which somehow "sets the preference" for the spin of electrons moving through it.

In fact, says Naaman, DNA turns out to be a superb "spin filter," and the team's findings could have relevance for both biomedical research and the field of spintronics. If further studies, for instance, bear out the finding that DNA only sustains damage from spins pointing in one direction, then exposure might be reduced and medical devices designed accordingly. On the other hand, DNA and other biological molecules could become a central feature of new types of spintronic devices, which will work on particle spin rather than electric charge, as they do today. ❙

Prof. Ron Naaman is head of the Nancy and Stephen Grand Research Center for Sensors and Security, and his research is supported by Rachel Schwartz, Canada. Prof. Naaman is the incumbent of the Aryeh and Mintzi Katzman Professorial Chair.