STRESS AROUSAL AND EFFECTS ON MEMORY AND PERFORMANCE

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To understand the relationship between art and science or art and the brain, it behooves one to know a little bit about art and a little bit about the brain. The famous artist and scientist, Albert Einstein said, "Most of the fundamental ideas of science are essentially simple and may as a rule be expressed in a language that is comprehensible to everyone." One simple idea that we have about the brain relates to how memories are stored. The fundamental ideas of this relate to the topic of emotion and memory -- or how emotional arousal influences how the brain makes memories.

One example relating to how memories are stored is taken from a story in the *Los Angeles Times* of a man who recently experienced an emotional event. He was driving across a bridge and the bridge collapsed. One hour later he was quite upset. He is probably going to have an exceptionally good memory of this event, and we are starting to understand why. The answer involves the relationship between emotional arousal, memory, and the body's stress hormone or adrenaline response. In high school biology classes, many people learn about the fight-or-flight syndrome. It is possible that this same fight-or-flight syndrome that helped the Neanderthal Man escape from the saber-toothed tiger also helped him remember the incident better. Therefore, he could use it better the next time.

The key player when it comes to the brain in this story is a little structure called the amygdala, which is Latin for almond. It is a structure about the size of an almond, which is located a couple inches in from the ears on either side. Most people have two amygdalas. This little structure called the amygdala seems to be the key brain player for *creating strong memories for emotional events.* One famous example of this would be a person's ability to remember where she was, and what she was doing when she heard that President Kennedy had been shot. The amygdala got activated around that time, and that is why a person would remember this event better.

People are routinely experiencing many things. The brain has wonderful mechanisms for storing memories of these experiences. Different parts of the brain store different kinds of memory. We think there is a different part of the brain that is involved in storing memories of how to play a piano than there is in storing memories of what piano pieces a person has played, and when a person has played them. This is also different than the part of the brain a person uses to remember where she parked her car this afternoon. In relatively non-emotional situations, we think the amygdala is not particularly activated. The stress hormones are not fluxing, and the amygdala does not care. If a room starts shaking the chandeliers and a person is diving under the table, the adrenaline is flowing, and ten years from now the person might remember everything about that event. The stress hormone serves the fight-or-flight response and feeds back to the brain through the amygdala, which in turn tells the rest of the brain to remember that event better because it is important.

To better understand how the brain works, it is important to realize that the brain is not a sponge. The brain is a very active mechanism. It actively builds things that might not visually exist. The brain's visual cortex has different parts to it. And they are busy breaking up the homogenous field called vision. They are breaking it into sub-components that can be manipulated. In some situations these sub-components will muscle and fight with each other. Different parts of the visual system will elbow each other to decide what a person is going to see. This will not happen if the brain is a sponge, if it passively takes things on. The brain actively builds what a person sees. The brain wants to build things, and it comes to situations with expectations of what the memory believes will be seen.

In the brain, there is a system fundamentally designed to remember emotional events better. Without it, a person would remember every time she tied her shoe as vividly as she would remember almost getting hit by a bus or hearing that a loved one died. This is a built-in waiting system. The act of remembering is an active building process, just as the acts of looking and listening are active processes. The evidence for this view that the amygdala is expecting or waiting for memory is built on animal research. Much of the research has been done at U.C. Irvine in Dr. Jim McGaw's laboratory over the last 40 years. In one test, a rat is put in a maze, and he learns a very simple thing. When he goes from the white side over to the dark side, he gets a half-second foot shock, which he does not like. The next day the rat is put back in the light side, and we measure how long it takes him to go in the dark side. We make the inference that the longer the rat takes to go in there, the more he remembers. In Dr. McGaw's laboratory about 25 years ago, it was discovered that injections of adrenaline into the rat, right after he learned this, enhanced his memory of it. We measured the time it took for rats to go in that were injected with saline with the time it took for rats that were injected with adrenaline to go in. The adrenaline made the rats stay out longer. The adrenaline enhanced the memory storage after the rats learned. It actually made the rats remember better because of stress hormones.

In recent experiments, we found the same thing in humans. After people had been shown a series of 21 slides, we injected them with adrenaline. When they came back a week later and I gave them a surprise memory test, they actually remembered some of the slides better. The animal research directly tested on humans is holding up well.

If adrenaline enhances memory, we speculated that memory might be impaired if adrenaline is blocked. This is not necessarily the case for everything, but it is exceptional for emotionally charged events. In this experiment, we looked at the results of a memory test in which people saw three phases of a story. Two phases were boring, and one was emotionally arousing. The emotional story involved a boy who was walking with his mother. He got hit by a car. His feet were cut off and sewn back on. We showed pictures of this to people. One week later, people came back and had a memory test, and they remembered that story better. The exciting thing was that if we gave them a beta-blocker, a drug that blocked the adrenaline system, they did not remember the emotional story any better than the neutral story.

We have given adrenaline that enhanced memory in rats and in humans. We have given blockers of adrenaline that impaired memory. One other key player in this is the amygdala. We have evidence from animal studies that shows adrenaline is acting through the amygdala to affect memory. There is a study of a rare patient in Germany, who had a disease that selectively lesioned his amygdala. His whole brain was intact, but his amygdala was gone. We tested this man on the same story about the boy, where most people best remember the emotional part about the car accident. The man who did not have his amygdala remembered the initial boring part fine. He was not an amnesiac patient. What he did not do was show the boost in memory about emotional parts. By lesioning the amygdala, he has been selectively robbed of the ability to remember the important emotional events better.

If we just studied the amygdala in humans by chasing these rare patients, we would ultimately not go very far. In the last twenty years, there has been a revolution that allows scientists to study healthy, functioning human brains without harming them. This is done through brain imaging techniques. Using these techniques, we have also implicated the amygdala. In an experiment that shows emotionally arousing films to a person, the activity of the amygdala correlates very highly with how well the person remembers those films. Activity of the amygdala in the brain did not correlate so well with the memory of neutral films. Some of the neutral films will be remembered, but it appears that the amygdala does not care about them.

People's emotions can be engaged every day by music, the arts, an earthquake, crashes, or even by operations. In association with the adrenaline response system and memory, there is a societal problem that people experience called "Post-traumatic Stress Disorder (PTSD)." With this disorder, the adrenaline system is busy making strong memories for things, but the system gets out of hand. A person might activate the whole stress hormone system every time she recalled an emotional event. This, in turn, might beat the memory into the head more and more strongly. This is a reasonable possibility. But we are getting a handle on this system that helps a person remember important things better, and this means that we should be able to block the adrenaline system and reduce or prevent the formation of Post-traumatic Stress Disorder. Two studies are underway right now, one at Harvard and one at Yale, growing out of our research to test this very idea.

We have progressed from testing rats running around mazes to testing people who were just sexually assaulted or in car crashes to testing the prevention of PTSD. By studying emotional arousal, memory, and the stress hormone response, we are beginning to unravel important functions of the brain. These studies are also interested in the relationship between art and the brain. In the spring 1998 issue of *Daedalus, The Journal of the American Academy of Arts and Sciences*, there is an article entitled, "Art and the Brain," by Semir Zeki. Zeki is, perhaps, the leading neuroscientist in the world, who studies the incredible complexity of vision. There are at least thirty different parts of the visual cortex that are all doing different things. Some are related to motion, some are related to color, some are related to angled lines, and some are related to lack of motion. He writes that the great artists, like Picasso, were basically great neuroscientists. They were figuring out things about how the brain's visual system works long before the neuroscientists.

The relationship between art and the brain is an area in which scientists are increasingly interested. Science is an art. And the art of science involves the art of collaboration. It often takes collaboration to make discoveries in any area. The great artistic scientist, Albert Einstein said, "The most beautiful thing we can experience is the mysterious. It is the source of all true art and science." Those people who want to believe that art and science are completely different things -- or that art is not as important as science -- should know that Albert Einstein thinks they are wrong.