

LeDoux outlines his theory of emotions and memory

A neural model of fear may lead to a better understanding of other emotions.

By Beth Azar
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During a car crash a man smashes his head on the steering wheel, setting off the car's horn and crushing his nose. He's hurt, scared and the horn is deafening.

A few months later, a car horn blares outside his house and triggers the memory of the accident: He remembers the facts, including the road he was on, the color of an oncoming car and the impact of the crash, but he also "feels" the memory—his heart starts to race, he begins to sweat and his muscles tense.

The factual and "feeling" components of this memory may seem inseparable, but in reality, they come from two distinct areas of the brain, said Joseph LeDoux, PhD, professor of psychology and neuroscience at New York University. The "facts" are stored in the brain's cortex along with other concrete memories. The memories of the feelings—the heart beating, the sweating—is stored in the amygdala, deep in the brain's center. This is the part of the memory that makes it emotional; it's the true emotional memory, said LeDoux.

"Memories about emotions are just facts," he said. "Emotional memories give the emotional quality to those explicit memories, and the brain fuses the two so it makes it seem like they're coming from the same place."

It's taken LeDoux and his colleagues a decade to piece together this basic understanding of the neurobiology of fear. Their work is one of the first rigorous attempts to understand emotions, and it may also lead to an explanation of such disorders as phobias, panic attacks and post-traumatic stress disorder.

LeDoux described the research on the neurobiology of fear at the Neal Miller Distinguished Lecture at APA's Annual Convention.

Fear conditioning

Researchers are far from explaining what controls emotions in a rigorous physiological sense, said LeDoux. Emotions consist of a conscious experience as well as physiological and neurological reactions and voluntary and involuntary behaviors, he said. And any model of emotions must tie together all these aspects. To begin forming a detailed physiological model of emotions, researchers turned to relatively simple—some say primal—emotions that are easy to define and measure. For LeDoux, that emotion has been fear. In particular, he's studied the connection between memory and fear created through experiences that elicit fear, like a car crash.

Most research on the links between memory and emotion has been conducted on rats using a classical fear conditioning paradigm, which pairs a tone or flashing light with a mild electrical foot shock. After conditioning, the animals react to the sound or light as if to a threatening situation—they freeze, their blood pressure rises and their heart rate increases. This response dies out only after many presentations of the sound or light without the shock.

Fear conditioning is an ideal starting point for studying emotional memory in part because nearly every animal group studied—from fruit flies and snails to monkeys and humans—becomes physiologically aroused when facing a threatening stimuli and gets conditioned in this way, said LeDoux. And it's likely that the underlying neurological pathways are basically the same for all mammalian species, and possibly some non-mammalian vertebrates.

Studies on rats

LeDoux has worked mostly with rats, pairing foot shock with a tone. He started with the assumption that the brain somehow pairs the tone and the shock in memory, thereby making the tone a harbinger of threat. The tone alone then triggers a fear response: It activates the autonomic nervous system, which controls heart rate and blood pressure, and the sensory motor system, which controls muscle movement.

LeDoux and his colleagues sought to find out where the brain stores the emotional memory, which pairs the tone and shock. They began by making small lesions in different parts of the rats' brains to see if they could derail the conditioning response. The first lesion they made was in the auditory cortex, the highest level at which the brain processes sound. But when they made the lesion, the rats still learned to fear the tone.

Just below the auditory cortex is the auditory thalamus, which provides most auditory inputs to the cortex. When the researchers damaged that, they eliminated the rats' susceptibility to fear conditioning. They then found that, although most of the cells in the thalamus transmit to the cortex, some transmit to the amygdala, a region of the brain already implicated in various emotional behaviors.

A lesion to the amygdala wiped out fear conditioning in the rats. In more specific studies, researchers found that they could eliminate various aspects of the fear response if they made lesions in specific areas downstream from the amygdala. A lesion on one site stopped the animals' blood pressure from rising, while another in a different site limited their ability to freeze.

Characterizing the signals

Once LeDoux and his colleagues found the seat of emotional memories, they sought to characterize the fear response at the level of individual neurons. They knew that the amygdala receives auditory information from two different brain areas: the auditory thalamus and the auditory cortex. The amygdala then processes the signals and generates

a fear response by stimulating other areas of the brain that control muscle function, heart rate and blood pressure.

To examine the signals coming into the amygdala from the thalamus and the cortex, LeDoux and his colleagues recorded electrical activity from single neurons. In general terms, they found that signals coming from the thalamus are fast and crude, reaching the amygdala before signals from the cortex, but providing only general information about the incoming stimulus. In contrast, the signals from the cortex are slow and refined, providing detailed information about the stimulus.

“The signals coming from the thalamus allow an animal to respond quickly without thinking too much first,” said LeDoux. Then, as more information reaches the amygdala from the cortex, the animal can re-analyze the situation to determine if a threat really exists.

This process is quite adaptive, said LeDoux. It’s safer to respond quickly to a benign stimulus than to respond slowly to a true threat.

“When you see a snake, you don’t need to know that a snake is a reptile or that its skin can be used to make belts before you start running,” said LeDoux. And if what you see turns out to be a stick and not a snake, you’re no worse off for running.

A brain malfunction

For some people, the urge to run is triggered too often. Many human maladies, including phobias, panic attack and post-traumatic stress disorder, involve malfunctions in the brain’s ability to control fear, said LeDoux.

In animals, researchers can extinguish a fear response by repeatedly giving the stimulus without pairing it with the feared experience—a technique similar to exposure therapy for people with phobias. But extinguishing the emotional response doesn’t destroy the factual memory of the fear, said LeDoux. Rats no longer show signs of being under threat when they hear the tone, but the memory in the cortex still responds. Similarly, people successfully treated for acrophobia still remember that they used to be afraid of heights but they no longer have the emotional response to being in tall buildings.

Researchers also find that if they damage a rat’s prefrontal cortex, extinction of fear becomes difficult. This implies that people with phobias may have a dysfunction in their prefrontal cortex that doesn’t allow them to automatically unlearn a fear once new information is provided.

Learning to detect and respond to danger is an evolutionary system, said LeDoux. Emotional feeling is what humans have evolved by adding consciousness to this basically adaptive, physiological response. The work of LeDoux and his colleagues may, in time, lead to a better understanding of the conscious, subjective, emotions that have evolved from their more primitive cousins, LeDoux said.

Suggested reading

“Emotion, memory and the brain,” by Joseph LeDoux (Scientific American, June 1994, p. 50–57).

“The Emotional Brain” by Joseph LeDoux (Simon and Schuster, 1996).

“The role of the amygdala in fear and anxiety.” by M. Davis (Annual Review of Neuroscience, 1992, Vol. 15, p. 353–375).

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