

Fear and Trembling in The Amygdala

Fittingly, one of the hottest topics at a recent meeting in New York during a terrorism alert was how fear makes its way through the human brain and guides attention

NEW YORK CITY—You are hiking quietly in the desert when suddenly you find yourself gasping and lurching backward in a panic while a coherent thought slowly wends its way into your consciousness: There's a snake slithering across the trail. Sturdy boots can help protect against such dangers, but the real lifesaver in this and other threatening situations is a part of the brain called the amygdala.

Neurobiologists have known for decades that this almond-shaped structure, which is located deep within the brain, governs other animals' ability to experience fear and learn to avoid pain. Showing that the amygdala plays a similar role in humans has been difficult, however. It's buried under layers of more sophisticated neuronal circuitry, making it tough to detect electrical signals generated by its firing neurons. But accumulating evidence, some of which was described for the first time at the Cognitive Neuroscience Society meeting, held here 30 March to 1 April, indicates that the human amygdala also picks up on scary stimuli and sends out powerful panic signals. These signals can quickly turn peoples' attention to possible threats—a suspiciously snake-shaped stick, for instance.

The amygdala appears to intercede between emotion and attention in two related ways. First, signals from the amygdala enhance the processing of emotion-inducing—or at least fear-inducing—images by higher level cortical regions at the expense of more mundane images. “Emotion helps focus attention at the expense of irrelevant stimuli,” says Jorge Armony of McGill University in Montreal, Canada, who helped organize a session on the topic.

Second, somewhat more controversial studies suggest that the amygdala can also operate without communication from higher visual areas. Instead, the amygdala is able to register danger signals via an ancient, but crude, visual pathway. This direct connection reaches the amygdala faster than the more highly evolved pathway, which shuffles images through the cortex first. The difference is on the order of tens of milliseconds, but to a neuron, that's a huge head start—especially

when responding to danger.

The amygdala as guard dog, constantly sniffing for threats, has evolutionary advantages, points out Joe LeDoux of New York University (NYU), who pioneered amygdala research. And its role in fast but crude visual processing may be particularly advantageous: The pathways leading directly to the amygdala “may be evolutionarily primitive ones. They are likely to have been routes by which sensory information could reach behavioral con-

Image not available for online use.

Screaming for attention. Angst-filled faces draw in the amygdala and other brain regions.

control regions like the amygdala before the cortex developed extensive sensory capacities,” LeDoux says. Thus, they may have provided ancestral vertebrates with a “look out!” signal that protected them from predators.

Attention, attention

Evidence that the human amygdala facilitates the processing of emotion-laden images by the cortex has been building for the past few years. Some of this evidence comes from studies of people who have suffered damage to the brain's parietal lobes. These areas, together with the frontal lobes, are usually in charge of directing attention to visual stimuli.

As a result, patients with parietal lobe damage sometimes suffer from an attentional deficit called extinction, in which they are able to notice one object at a time on either side of a given visual scene, but if two things are flashed simultaneously, they overlook one of them.

Two years ago, however, Patrik Vuilleumier of the University Medical Center in Geneva and colleagues reported that emotion can overcome attentional deficits even in patients with parietal damage. For example, the patients are less likely to miss a flashed face with a fearful expression than a neutral face. At the meeting, Armony reported that such patients are better able to spot normally inoffensive—and normally neglected—shapes such as colored triangles if the figures have been paired in the past with an unpleasant blast of white noise and thus imbued with emotional salience. The work shows that “emotional stimuli have a way of capturing attention and awareness,” says Armony.

Several studies have shown, in neuroimaging Technicolor, that emotion enhances cortical processing in healthy people as well. For instance, a part of the brain called the fusiform face area (FFA) lights up with activity whenever someone views a face (*Science*, 13 April 2001, p. 196). FFA activity can be bolstered by the amygdala; Armony, Vuilleumier, and colleagues found that the FFA's response is heightened if the face is contorted in an expression of fear, which also causes the amygdala to light up. In contrast, the team found that the FFA doesn't register a difference between fearful and calm faces in patients with amygdala damage. This suggests that the amygdala normally drives the cortex to expend extra energy on emotional faces.

Complementary evidence comes from studies of a phenomenon known as “attentional blink.” A series of words is flashed in quick succession on a screen, with some words appearing in an unusual color. People asked to remember the colored words do so easily, but they can't remember a second colored word if it appears shortly after the first one—that is, if it appears during the refractory period dubbed the attentional blink.

Elizabeth Phelps and Adam Anderson of NYU reported in 2001 that people remember emotion-laden curse words even if they come hard upon the heels of other target words. “Emotion can break through” to attention, she says. Patients with amygdala damage, however, overlooked both emotional and neutral words, suggesting that the amygdala is necessary for the high-speed, heightened attention to emotional words seen in healthy volunteers.

Emotionally salient images can lend their attention-grabbing powers even to mundane stimuli under the right circumstances,

Phelps found in new work reported at the meeting. She and Marisa Carrasco of NYU flashed a picture of a face on a screen followed by a patch of subtle, slightly tilted stripes. People were better able to distinguish the orientation of the stripes if the patch appeared where a frightened rather than neutral face had just been.

Vuilleumier speculates that “most of these findings wouldn’t necessarily generalize” to other emotions. But fear, at least, drives attention, whether provoked by an image that inherently signals danger, such as a terrified face, or by an inoffensive image repeatedly paired with an unpleasant experience. As Armony claims, “some stimuli are special; you can’t afford to ignore them.”

Eternal vigilance

The amygdala shares a rich network of connections with other sensory areas that allows it to receive information about the external world. The standard visual pathway feeds information to the amygdala via the cortex in a raging river of refined, highly detailed visual information. But there’s also a back road to the amygdala, a stream of visual information that flows from the eyes through other subcortical structures directly to the amygdala. It’s just a trickle of information—a rudimentary, rough-hewn picture of the world—transmitted by cells that lack fine-tuning. Researchers have long debated whether the amygdala makes use of these crude subcortical inputs. Two studies reported at the meeting suggest that, at least for processing the powerful danger signal of a frightened face, the back road to the amygdala may be all the brain needs.

Earlier neuroimaging studies showed that emotional stimuli can grab the amygdala’s attention even if other parts of the brain are

focusing on something unrelated—and even when people don’t report noticing the scary object. For instance, if an emotional face is flashed briefly on a screen and then immediately replaced by an unruffled face, people report seeing nothing but the blank expressions. But the amygdala knows the difference; its activation increases in response to emotional but unnoticed faces.

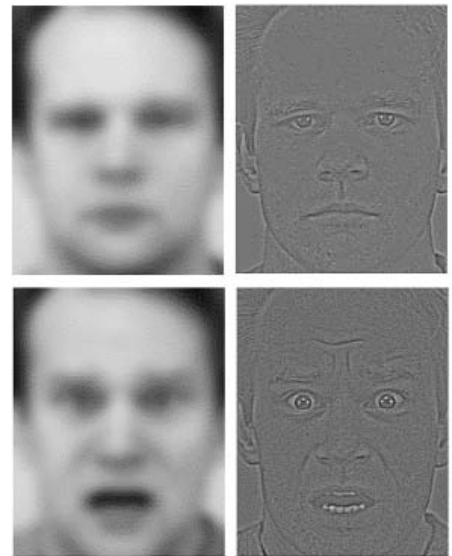
Such experimental designs don’t rule out cortical contributions, however. Some areas of the cortex also show an enhanced response to the masked faces. But new work by Brian Pasley of NYU and Robert Schultz of Yale University provides more direct evidence that the amygdala detects information transmitted through the subcortical route.

“Binocular rivalry” is the principle that allows you to look through a microscope with one eye and have your visual attention captured by budding yeast rather than the desktop clutter visible to your other eye. Mimicking that situation, the researchers fitted subjects with goggles that showed a bouncing, bright picture of a house in one eye—an arresting image they saw clearly—while slowly morphing a picture of a face or a chair into the other eye’s view.

Using functional magnetic resonance imaging (fMRI), Pasley and Schultz found that the cortex, even the face-sensitive FFA, didn’t distinguish between faces and chairs. As in earlier findings, rivalry from the dominant eye’s image seemed to prevent the pictures from making their way through the cortical visual system. In contrast, the amygdala’s activity jumped in response to unnoticed fearful faces compared with neutral faces or chairs. The amygdala, it seems, can distinguish between fearful and sedate faces even without cortical inputs.

Not everyone is convinced that the amygdala can make such distinctions without cortical help, however. Phelps points out that fMRI might not be sensitive enough to detect enhanced cortical responses to scared faces that may be driving the amygdala’s distinction between the expressions.

In other situations, the subcortical route may not be able to act independently of the cortex: The amygdala can be prevented from picking out emotional expressions if the cortex is sufficiently distracted. Last year, Luiz Pessoa of the National Institute of Mental Health in Bethesda, Maryland, and colleagues pitted attention to faces against attention to another task, comparing the orientations of two bars. If people were asked to decide whether a face was male or female, their amygdalas, as seen in fMRI, buzzed pref-



Back road. The subcortical visual pathway may transmit low-frequency images (left) that arouse the amygdala better than high-frequency ones (right).

erentially to emotional faces. This happened even when subjects compared the orientations of the bars—as long as the bars were very different. When the bars were difficult to tell apart, people devoted more attention to the problem, and the amygdala’s response to nearby emotional faces was shut down.

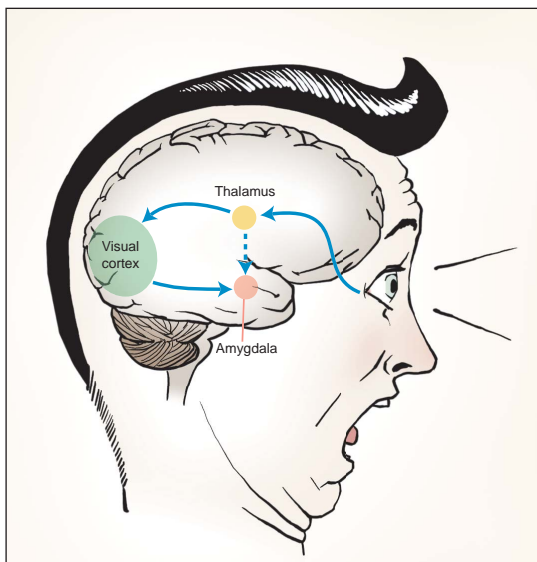
Indeed, Pessoa doubts that the subcortical route transmits enough information for the amygdala to pick up much emotionally salient content. The cells along the subcortical route “give a very blurry image of the world,” he says. But humans and other primates “are very sophisticated at reading nuances of expressions, and for that they have very rich cortical areas.”

But Vuilleumier presented evidence at the meeting that the blurry images carried by the subcortical pathway might carry exactly the information the brain needs to tell a scared face from a calm one. His team filtered faces to extract either low spatial frequency (that is, coarse) or high spatial frequency information.

As detected by fMRI, the finely detailed images elicited a greater response from the FFA and other cortical areas. The amygdala was relatively blind to these pictures even when they showed emotional expressions. However, blurry images of frightened faces elicited a vigorous response in the amygdala, suggesting that the crude information carried by the subcortical pathway is plenty, in certain cases, to put the amygdala on red alert.

Researchers are just beginning to work out when and how the subcortical shortcut to the amygdala helps direct attention. But in certain perilous situations, it seems, even if the rest of the brain is preoccupied, the amygdala is guarding against disaster.

—LAURA HELMUTH



Two routes. Most visual input heads for the cortex (solid arrow), but some is shuttled subcortically (dotted arrow).