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REVIEW ARTICLE

Neuroscience of Emotion, Cognition, and Decision Making: A Review

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ABSTRACT

The traditional idea of emotion and cognition in Western culture is that emotion is separate from, and inferior to, cognition. This article reviews results from experimental neuroscience that refute this notion and support the idea that emotion and cognition are partners that depend on each other for organized decision making. Cooperation between cortical and subcortical parts of the brain is essential for behavior that adapts successfully to the environment in pursuit of goals. Concurrently, there has been a rich development of computational neural network theories that combine emotion as a source of values with reason as a process of discerning the actions that will best implement those values. Incorporating the partnership view of emotion and cognition encourages integration of those two aspects of the psyche, with benefit both for mental illness treatment and for making society more cooperative.

The need to think, feel, and vegetate

The rise of science starting with the Enlightenment of the Seventeenth and Eighteenth Centuries led to a widespread belief in Western culture that cognition and emotion are opposites, with emotion being inferior to cognition.[1,2] Decisions "based on emotion" are characterized as impulsive and unwise, whereas decisions "based on reason" are characterized as well thought through and logical. Yet the findings of modern neuroscience upend this traditional view in favor of the idea of emotion and reason as complementary partners that play interacting roles in the brain's system for behavioral decision making.[1,3]

The clinical neuroscientist Antonio Damasio[1] discussed some of his patients, and the earlier Nineteenth Century patient Phineas Gage, who had extensive damage in the ventromedial prefrontal cortex (VMPFC). The prefrontal cortex is the primary area of cerebral cortex for organizing, planning, and controlling actions, and the VMPFC is particularly important for processing and acting on social and emotional information.[4] Damasio found that people with VMPFC lesions, while their cognitive capacities were intact, were impaired in decision making to the point of difficulty in holding a job or a marriage. These brain-injured patients could be either impulsive, not controlling their behavior to fit the current social context, or over-deliberate, obsessing endlessly over minor decisions – or sometimes both at different times.

Many scientists, and the general public, have attributed emotion to a more primitive part of the brain/mind than cognition. Yet work in this century by the neuroscientist Luiz Pessoa and his colleagues cast doubt on the view of the "emotional brain" as primitive. The amygdala is the brain region most typically associated with emotional responses to specific stimuli.[5] Yet Pessoa, Sabine Kastner, and Leslie Ungerleider[6] did a functional magnetic resonance imaging (fMRI) study of amygdalar responses which demonstrated that the "primitive" amygdala is subject to attentional control. The participants in their study looked at visual displays with faces in the center. The faces were either fearful, happy, or emotionally neutral, and there were also pairs of colored oriented bars above the faces. The participants were sometimes cued to attend to the face by being asked whether the face was male or female, and at other times cued to attend to the bars by being asked whether the bars were of the same or different orientations. Pessoa and his colleagues found that the amygdala responded more to emotional faces than to neutral faces, but for each type of face, amygdalar activation was much larger when subjects were attending to the face than when they were attending to the bar.

The idea that "emotional" is not the same as "automatic" dates back at least to the triune brain theory of Paul MacLean.[7] Through several decades of study of brain structure and behavior in different vertebrate species, MacLean arrived at the theory that the human brain is essentially built of three mutually interacting layers that came from different evolutionary stages. The lowest layer, called reptilian – or, more recently called the R-complex because it exists in many fishes and amphibians as well as reptiles -- is responsible for our basic survival instincts. The middle layer, called old mammalian, is responsible for emotions including those involved in parent-offspring and pair bonding. The top layer, called new mammalian, is responsible for complex thought and planning. The theory as a whole is widely known as the *triune brain theory*.

MacLean based his assignment of functions to brain regions on the neuroscience known when he wrote, and more recent neuroscientists have criticized the triune brain theory as out of date and simplistic in its assignment of functions to brain areas.[8] Yet MacLean was aware of the nuances of the data he used to support his theory: mental processes such as emotions and instincts depend on networks of brain regions rather than single regions, and the functions he assigned to particular classes of animals are present earlier in the evolutionary scale. The triune brain theory remains a useful summary of the evolution of instincts, emotions, and cognitions in the animal kingdom.[9] While the basic instinctive behaviors underlying self-preservation and reproduction, including territorial and courtship rituals, are found in most reptiles, parental care as we know it is typically absent in reptiles but emerges in mammals. Much of the emergence in mammals of both positive and negative emotions, and emotional-cognitive interactions, can be attributed to developments in the brain. These developments include growth of the anterior cingulate cortex and loops between the thalamus and cerebral cortex.

Perhaps MacLean's most important intellectual contribution was the distinction he made between emotionally driven and automatic behavior. The dichotomizing of emotionally and cognitively driven responses is ingrained in Western culture and dies hard in the sciences. This contributes to the popularity of the two-systems theory of human decision making,[10] whereby we normally follow the promptings of an intuitive, often emotionally driven, fast System 1 but when that system runs into difficulties it transfers control to a deliberate, slow System 2. The two-systems theory is a useful simplification but needs to be nuanced: deliberation is not always slow if the problems are simple enough,[11] and intuition is not always fast but sometimes awaits the right circumstances.[2] The triune brain theory is also a simplification but points to the fact that we have interacting brain systems for thinking, feeling, and automaticity, all of them needed for adaptive behavior and none of them "superior to" the others in any meaningful way.[12]

A systems approach to emotion and cognition

The area of the brain most associated by neuroscientists with emotional evaluation of stimuli or actions is the amygdala. For a long time the amygdala was more associated with negative emotions, especially fear, than with positive emotions. Yet in this century data have increasingly emerged that point to the importance of that region in positive as well as negative conditioning. Hence, an alternative to the view of the amygdala as a fear module is the view of the amygdala as a *relevance detector*, that is, choosing out of salient stimuli which ones are most relevant for a pre-selected plan or for response to a current need.[13,14]

The amygdala's connections with ventromedial prefrontal cortex are one vehicle for its role in relevance detection and setting positive and negative emotional values for particular stimuli and actions.[15] Another relevance-related connection is the more recently discovered input in primate brains from the amygdala to the reticular nucleus of the thalamus, an area that has long been implicated in selective attention via its selective inhibitory effect on thalamocortical pathways.[16]

The relationships between emotion and cognition have increasingly been illuminated by computational neural network models.[17-21] Neural networks are commonly thought of as artificial intelligence devices that can mimic certain aspects of cognitive functioning, and the best known are built on the notion of deep learning[22] which has little in common with brain structure. Yet in fact considerable progress has been made on computational neural network models that incorporate known connections between specific brain regions and equations for single neuron dynamics, including spiking.

A model by Yohan John and his colleagues[18] builds on the connections from amygdala to the attentional area in the reticular nucleus of the thalamus, a mechanism for selecting emotionally important stimuli from sensory cortical areas out of those stimuli that are salient.[16] This model also allows for influence on the amygdala from the ventromedial prefrontal cortex, thereby biasing that stimulus selection if favor of stimuli relevant for current behavioral plans. This network can account for many of the effects of emotion on cognition and behavior. Yet these effects may either increase or decrease accuracy of cognition. If emotion is overwhelming, as in the grip of either a fear for one's life or a great enthusiasm about something likely to satisfy an important goal, the attentional focus in the network can be narrowed to the point that stimuli other than the strong emotion-producing ones are ignored even though they may be relevant for other goals.

A more recent model by the same research group[19] explores a different set of amygdalar influences via the connections from the amygdala to memory consolidation areas in the hippocampus (areas CA3 and CA1). This model captures emotional influences on episodic memory. As is the case with attention, moderate amygdalar inputs can lead to enrichment of detail for context and memory processing. Sufficiently intense amygdalar inputs can lead to the opposite, a loss of contextual detail which can lead to overgeneralization of fear-related categories. Knowing that the amygdala is associated with positive as well as negative emotions, the authors speculate that a similar overgeneralization can be caused by positive emotions, which could be a future extension of the model.

Modern neural theories of emotion, and its relationship to cognition, have tended toward a network approach rather than localizing emotions to "centers" in the brain.[23,24] In particular, Lisa Feldman Barrett summarizes considerable evidence that there are not specific brain pathways whose activity corresponds linearly to the experience or expression of specific emotions such as happiness, sadness, anger, fear, disgust, or interest.[23] Yet there are still cortical and subcortical regions to which defined functions relating to emotion in general can be roughly attributed, and I believe it is still worthwhile to understand the roles of these interacting regions.

In addition to amygdala and ventromedial prefrontal cortex, the brain's "emotional system" includes the hypothalamus, which is the primary area of the brain for connection with other internal organs such as the heart, endocrine glands, and digestive system. The basolateral nucleus of the amygdala, which receives inputs from sensory cortex, projects to the central nucleus of the amygdala, which in turn projects to the hypothalamus, allowing for autonomic and visceral reactions to sensory stimuli or events.[25]

The nucleus accumbens (nACC), otherwise known as the ventral striatum, is a key area for processing rewards. Some researchers in fact have found a negative correlation between activity in the ventral striatum that is associated with affiliation and non-threatening interactions, and activity in the amygdala that is associated with threatening interactions.[26] Yet stimulation of a pathway from amygdala to nACC stimulates reward seeking[27] and reduces fear.[28]

Yet this same region has also been implicated in motivated actions that may not have a strong emotional component; in other words, in "wanting" without "liking".[29] The large number of dopamine receptors in nACC are involved in motivating behavior leading to rewards, whether natural rewards or artificial rewards such as addictive drugs. Dopamine depletion decreases such motivated behavior without diminishing the facial indications of pleasure, such as reactions to sweet-tasting food.

The distinction between wanting and liking partly mirrors the distinction that MacLean drew between emotional and automatic processes.[7] As in the triune brain schema, both the emotional and automatic systems are necessary for the regulation of behavior, as both are involved in correcting prediction errors that occur in response to unexpected events.[23,30] Like some of the results cited earlier, the results on wanting and liking[29] argue against the binary "emotion versus reason" distinction that is prevalent in popular culture – and until recently, also in science. It also argues against judgmental reactions to people struggling with addictions, whether biochemical or behavioral, which label such people as "emotionally controlled" or "lacking in will power."

The anterior cingulate cortex (ACC) has been implicated in a variety of functions related to emotion and cognition. In the triune brain theory,[7,9] the ACC, which is far more developed in mammals than in reptiles, plays an important role in the emergence of parental and other caring behaviors. The functions of this region are versatile and amplify the inseparability of cognition and emotion in the brain. The ACC performs a comparison of emotional valuations for different behavioral options, valuations located in the ventromedial prefrontal cortex, with which it has extensive connections. ACC therefore tends to become activated under conditions of cognitive dissonance or informational conflicts.[31] Other researchers have shown that representations of negative affect, pain, and cognitive control are close together in the ACC.[32]

The anterior cingulate is sensitive to the difference between actual and desired states of the body. Another area sensitive to that difference is the anterior insula, which like ACC is an evolutionarily old part of the cerebral cortex. The insula is one of the brain regions that is comparatively large in humans relative to other primates. Its functions are not completely known, but it is the only area known to be actively involved both cognitive and emotional aspects of empathy.[33] The results reviewed here on amygdalar connections[14,15] exemplify the considerable influence of emotion on cognition – and thereby on decision making. The next section explores the neuroscience of influences of cognition on emotion.

How much can cognition control or influence emotion?

Starting with Darwin and James in the Nineteenth Century, many psychologists have developed different theories for the order of events necessary for the experience of an emotion. This theorizing led to years of debate in the 1980s between Robert Zajonc[34,35] and Richard Lazarus[36,37] on whether emotions are purely physiological or whether they require a cognitive label to supplement the physiological changes.

Zajonc argued that humans share basic emotions with other animals and, like other animals, react too quickly to emotional stimuli for cognitive processes to be involved: an example being a rabbit reacting to fear of a snake. Zajonc argued further that, emotions must come before cognition because emotions are inescapable; that is, one can control the expression of an emotion but cannot control the feeling itself. Also, emotions are hard to describe verbally. Lazarus, on the other hand, argued for the primacy of cognition based on his own studies whereby an unpleasant film was shown to different groups of participants with different accompanying soundtracks. One group of participants were constantly reminded of the harmful consequences of events in the film, while another group were induced to feel an intellectual detachment toward those events. The participants who heard the soundtrack about harmful consequences had a stronger emotional reaction to the film. On this basis, Lazarus argued that even if emotions are outside the control of the conscious mind, they carry within them a meaning based on achievement or nonachievement of goals.

Contemporary psychologists, relying on more sophisticated neuroscience than was available in the 1980s, tend toward a synthesis of Zajonc's and Lazarus' views. There is general acceptance that emotions are evolutionary adaptations shared with other mammals, although psychologists are divided on whether or not it is useful to break down emotions into a few primary types.[23,24,38] Yet several investigators have found that pleasantness ratings of food or food odors are influenced by the words used to describe the food, and that the pleasantness ratings correlate with activations in several brain regions including the ACC and VMPFC (but not the insula).[39]

Recent fMRI studies on the amygdala support the existence of "pre-cognitive" emotion, and thus partly support the Zajonc outlook. Amygdala activation can occur in response to fearful faces even when those faces are quickly followed by other visual stimuli, so quickly that the subjects do not consciously remember the fearful faces.[40] Yet the results of Pessoa and his colleagues on visual displays with both faces and bars[6] show that amygdalar activation can also be influenced by cognition and attention, partly supporting the Lazarus outlook. Other authors emphasize that not all experiences of a given emotion are alike, and they can run the gamut from reflexive reactions to instances of detailed cognitive processing.[41]

Emotions are hard to control, as Zajonc suggested, but not completely inescapable. Other researchers instructed participants in their fMRI study to consciously try to reduce the fear they felt about a fear-inducing face.[42] This conscious effort succeeded in reducing the amygdala's response to the face.

The neural pathways by which cognition and attention influence emotion are numerous, even if they are not always active. The connections between amygdala and VMPFC are reciprocal, even if there are fewer pathways from VMPFC to amygdala than the reverse.[15] Also, there are pathways to emotion-related areas from areas implicated in short-term memory and attention, such as from the dorsolateral prefrontal cortex to VMPFC when attention is paid to the pleasantness of a taste.[39,43] The pattern of attentional control is different from when a participant is paying attention to the physical qualities of the food being eaten.

These forms of attentional influence on emotions are an example of the ubiquitous design whereby one level in the brain biases attentional competition between inputs at a different level in the brain. In computational models with this design[20,39,44], the top-down influence is not purely inhibitory: it inhibits or excites bottom-up representations selectively as suited for the current task. This mixture of effects suggests that rational influences on emotion are not purely suppressive or restraining, but include enhancement of the kind of enthusiasm that motivates constructive behavior along with suppression of destructive or inappropriate emotionality.

Conclusions: Theories of emotion and social implications

There has been a wide range of theories about what emotions consist of and how to classify them.[45] One popular approach, known widely as basic emotions theory, posits that there are a limited number of genetically programmed emotions – happiness, sadness, interest, fear, anger, and disgust are the ones generally agreed on – and that all affective experiences are built on combinations or variations of these basic emotions.[46]

Basic emotions theory is appealing for its simplicity and intuitive credibility. Yet efforts to find specific locations in the brain whose activity correlates with each of the basic emotions have come to grief, and the idea of brain regions as modules for specific emotions (e.g., the amygdala as a fear module) have fallen out of favor due to the complexity of the data from neuroscience. Yet there has been partial success at mapping patterns of activities in specified brain networks that are active when participants are induced to experience specific emotions.[47]

Several authors have developed neurological theories of emotion that differ subtly in emphasis but all involve complex interactions among brain regions. Barrett[23] describes her theory as *emotion construction*; that is, developing emotion-related categories among patterns of neurological activity. She describes the theory as follows:

> The brain continually constructs concepts and creates categories to identify what the sensory inputs are, infers a causal explanation for what caused them, and drives action plans for what to do about them. When the internal model creates an emotion concept, the

eventual categorization results in an instance of emotion.[23] (p. 13)

In this theory the anterior cingulate cortex and insula, as parts of the brain's salience network, play major roles in attention regulation in the service of bodily regulation. Pessoa[24] emphasizes the role of functionally integrated systems that include both cortical and subcortical parts of the brain. He cites other work critical of cognitive scientists who overemphasize the role of the cerebral cortex -- another example of the rationalist bias in science -- and pointing to the equal importance of subcortical components of these systems.[48] The amygdala is one of the hubs of neural activity in these functional systems, and its connections with prefrontal and other areas of cortex should be considered a relationship of mutuality rather than of "lower" versus "higher." Specifically, "the amygdala appears to extract the affective significance of stimuli, and the prefrontal cortex guides goal-directed behavior".[49] Stephen Grossberg and his colleagues developed the *CogEM* (for cognitive, emotional, and motor) model to describe interactions between the thalamus, cortex, and amygdala that calculate and act on emotional values of stimuli and events.[17,30,50,51] This model is described as follows:

The CogEM model proposes how emotional centers of the brain, such as the amygdala, interact with sensory and prefrontal cortices — notably ventral, or orbital, prefrontal cortex — to generate affective states, attend to motivationally salient sensory events, and elicit motivated behaviors. Activating the feedback loop between cognitive and emotional centers is predicted to generate a cognitive-emotional resonance that can support conscious awareness of events happening in the world and how we feel about them.[50] (p. 504).

All of these neurological theories see emotion as nearly inseparable from thought and behavior, and as an integral part of the decision process. Along the same lines, the historian William Reddy[45] reviews anthropological findings[52,53] suggesting that non-Western cultures typically do not see "emotion" as a category of experience separate from "thought." So where did the Western dichotomizing of emotion and cognition arise? It came from the Enlightenment period of the Seventeenth and Eighteenth Centuries, with influence from ancient Greek philosophers such as Aristotle. The Enlightenment and its attendant scientific and technical advances have improved the expectancy and quality of life for a large part of the human race. Yet a heritage of that period of history has been the general cultural tendency to disparage our natural human emotional capacities as the more "primitive" and inferior opposite of reason.

The understanding of emotion and cognition from neuroscience supports the non-Western view. Neuroscience suggests that while emotion sometimes opposes thoughtful decision making, it is incorrect to consider emotion in general as opposite and inferior to reason.[1] Rather, emotion and cognition are complementary functions, and both are necessary for effective decision making, a meaningful life, and good interpersonal relationships.

My book argues that the prevailing cultural memes regarding emotion and reason are not only unscientific but harmful, and need to be reevaluated if neuroscience is to be applied to solving global societal problems.[2] The excesses of reason, to the neglect of people's emotional ties to communities, have led to technology changing faster than the human mind can adapt to it, with the effect being further alienation of large numbers of people from community ties. Also, if reason is regarded as superior to emotion, this gives a pretext for ranking people who are regarded as more rational (usually, heterosexual white males) over other people who are regarded as more emotional (usually, women, people of color, and homosexuals).

The political psychologist Drew Westen[54] discusses the difficulty that some well-meaning people, including candidates for political office, have in getting across their message to others. These are people who typically rely on facts and evidence to argue for social programs or for their own candidacies. Yet often these people lack emotional appeal to their audiences, and fail to demonstrate they care about their listeners' lives and their values. This leaves the field open for unscrupulous and narcissistic demagogues to appeal to the fears of voters and then impose authoritarian rule if they get elected. Westen points out that appeals for policy programs need to be based on understanding the emotional as well as the rational brains of the people they are seeking to win over. He adds that emotional appeals need not be appeals to fear; rather, they can be appeals to our "better angels": our desire for a society where people take care of one another, where health, education, and safety both at home and work are enhanced.

The neuroscience of emotion, cognition, and decision making teaches us that different functions of our minds are not controlled by separate modules but are deeply interacting at all levels of the brain. Progressive movements in psychiatry and psychotherapy, informed by progress in neuroscience, do not try to make reason triumph over emotion in the individual. Rather, they aim to synthesize our emotional and rational selves into what one author called the "wise self."[55,56] The mental health of societies as well as individuals depends on fostering this perceived unity of emotion and reason.[2]

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