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Editorial overview: Interactions between Emotion and Cognition

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Mara Mather is Professor of Gerontology and Psychology at the University of Southern California. She received her Ph.D. from Princeton University and completed college and postdoctoral training at Stanford University. Her research is on the affective/cognitive neuroscience of aging, examining how age-related changes in brain function and structure impact cognition and emotion. She and her colleagues identified older adults' positivity effect in attention and memory and she was instrumental in elucidating its mechanisms. She and her colleagues developed the first model that account for how arousal can simultaneously enhance processing of high salience stimuli while suppressing less salient stimuli and the first brain model to posit that local cortical excitation levels help determine the effects of norepinephrine on perceptual and cognitive processing. She has received the Distinguished Scientific Award for Early Career Contribution to Psychology from the American Psychological Association, a National Institutes of Health K02 Career Development award and an Alexander von Humboldt Foundation Research Fellowship.

Emotion and cognition are intertwined processes that have many interacting dimensions. Questions about how they interact have led to many fascinating lines of research and debates within the field. Even the question of whether they are distinct is a debated question, and one that is represented by diverse perspectives in this special issue. This volume of Current Opinion in Neurobiology illuminates the latest advances in understanding how emotion influences cognition and how, in turn, cognitive processes influence emotion, with an emphasis on the brain mechanisms involved.

The experience of emotion depends on signals from the body. Thus, when discussing emotion–cognition interactions, one must take into account how signals from the body influence cognitive processes. Recent research reveals that fluctuations in body signals can lead to moment-to-moment fluctuations in attention and cognition, as well. Critchley and Garfinkel review how changes in cardiac signals during the phases of each heart beat influence perception, memory, motor action and decision-making. For instance, timing visual detection task trials to the systole phase of the heart beat improves performance. Mather and Thayer review findings that heart rate variability is associated with better emotional well-being and propose that oscillations in heart rate (especially the large amplitude oscillations induced by slow paced breathing) increase functional connectivity within brain networks associated with emotion regulation and modulate faster oscillations in brain activity. Such mechanisms could help explain emotional and cognitive benefits of meditative practices that involve slowed breathing. A critical conduit of messages between the heart and the brain is the vagus nerve. Poppa and Bechara provide an update to the influential somatic marker hypothesis and the role of the 'body-loop' in decision-making, focusing on the critical role of the vagus nerve in brain–body communications.

Focusing within the brain itself, Pessoa reviews the role of large-scale brain networks in emotion–cognition interactions. He makes the case that brain networks are dynamic and that emotional states affect not only the degree of correlated activation with a network, but also the network organization itself. This occurs because networks are dynamic coalitions of brain regions that coordinate to meet specific needs. In particular, Pessoa argues that the representation of emotion in the brain is not confined to any one region or system, but instead arise from functionally integrated systems that allow for intermixing of information from bodily signals with information related to perception and cognition. Preckel *et al.* make the case that there are two distinct brain networks involved in social aspects of emotion–cognition relationships. They argue that socio-affective and socio-cognitive processes are separable both behaviorally and neurally. On the affective side, empathy

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Fanselow received his B.S. degree from Brooklyn College (1976). Then he pursued a PhD degree at the University of Washington (1980), studying under Robert Bolles. Following his graduate training he held Assistant/Associate Professorships at Rennselaer Polytechnic Institute and Dartmouth College. In 1987, Dr. Fanselow moved to UCLA where he is now Distinguished Professor in both the Psychology and Psychiatry Departments. He currently holds the Staglin Family Chair in Psychology and is Director of the Staglin Center for Brain and Behavioral Health. His work has always focused on fear asking questions ranging from its evolutionary function, to the organization of behavior, to its neural basis.

involves sharing others' emotions whereas on the cognitive side, theory-of-mind processes enable cognitive understanding of others' thoughts and intentions. The authors argue that although these processes rely on independent brain networks, they are both required in complex social situations. Marsh reviews data indicating that empathy for another experiencing a particular emotion is accompanied by activation of the sensory system involved in the shared experience rather than a specific empathy network. So for example, empathizing with someone in pain activates the brain matrix associated with experiencing pain. She discussed similar findings in nonhuman animals as well arguing that subcortical structures are key promoters of empathy. Mentalizing, which allows theory of mind, is seen as distinct from empathy.

An interesting question that surfaced in several papers was to what extent are emotion and cognition separable processes. Kindt argued that cognitive and emotional expression are quite different. Emotional expression drives behaviors while cognitive memory does not. The cognitive aspect of emotion involves memory for specific events and their relationships such as the expectancy of an aversive outcome. This cognitive memory can recognize discrepancies or prediction errors and this can open a susceptibility window for changing emotion. Thus one can present reminders of events that do not produce fear behaviors but allow the emotional memory to be reconsolidated. Marsh's distinction between empathy and mentalizing is similar. With mentalizing one cognitively recognizes another's feelings, while empathy is actually sharing the emotional experience. Marsh's view is that empathy arises from phylogenetically old subcortical systems and that this is one reason that some form of empathy is shared by many species. Fanselow also indicates that fear is an emotion that automatically drives phylogenetically programmed responses over flexible behaviors. Furthermore, the experiential aspect of fear functions to inhibit cognitive systems that support more flexible behavior. This is one reason that anxiety disorders can have such maladaptive influences. Moscarello and Maren argue that to overcome fear one must find ways to promote flexible behaviors in the face of fear. LeDoux argues for a more radical departure from this idea that emotion and cognition are separable but interacting processes. For him emotion is one form of cognition; fear is the cognitive experience that comes from a variety of threatening events. He views behavioral defenses and autonomic changes as a product of a survival circuit that has little to do with emotional experience. At a more mechanistic level, Scult and Hariri point out that genetic polymorphisms often influence the connectivity in brain-wide networks that support both emotional and cognitive processes.

Clore *et al.* return to this distinction between cognition and emotion. They point out that how emotion influences cognition can be observed because affective reactions can be separated from their objects. Affect generated by one object can be mistakenly attributed to another object, and Clore *et al.* argue that 'affect is always experienced as being about what is mentally accessible at the time'. They also review findings that positive affect serves as a go signal for currently accessible thoughts and mental processes whereas negative affect serves as a stop signal. In contrast with Clore *et al.*'s approach of examining valence as something that can be separated from whatever elicited it, Miskovic and Anderson argue that valence and sensory processing are tightly integrated, with valence representations existing even within sensory brain areas. They suggest that affective valence may be as fundamental to perception as sensory qualities, allowing perception to elicit approach or withdrawal actions without the need for top-down processes to construct the affective response.

In contrast with these bottom-up influences on emotional perception, top-down processes have been a major focus within the emotion regulation literature, as a key emotion–cognition interaction is the implementation of attention and other cognitive processes to regulate emotion. Ghafur *et al.* address the issue that people do not always engage optimal emotion regulation strategies and propose that emotion regulation decisions could be improved by orienting attention and increasing action readiness. This framework leads to some concrete suggestions for interventions to improve the likelihood of successful emotion regulation in everyday life. Moscarello and Maren argue that, in the case of fear, emotional regulation depends on the development of cognitive flexibility in the face of strong emotion. For example, extinction of fear relies on discriminating contexts that are truly dangerous from those that are safe. Likewise, control over fear-elicited behavior requires fear to be reduced so that adaptive behaviors can replace automatic defensive behaviors. This occurs through coordinated hippocampal and prefrontal cortical influences on the amygdala and striatum. Yee and Braver address the question of how motivation influences brain networks involved in cognitive control. They posit that motivation triggers dopamine release in prefrontal cortex that facilitates task performance and reduces the costs of cognitive control and suggest that simultaneous PET-fMRI methods could be used to test these interactions.

From the perspective of emotion regulation research, older adults are a fascinating population to study, as despite the challenges of getting older, older adults tend to experience relatively less negative affect than younger adults. Much recent research has been devoted to try to understand this phenomenon. Carstensen and DeLiema review the literature on the age-related positivity effect, or an age-by-valence interaction in which older adults favor positive stimuli relatively more than negative stimuli compared with younger adults. They review the surprising nature of the effects that do not fit with standard expectations in which an age effect should be associated with cognitive decline.

The effects of emotion on memory are well known and McGaugh reviews evidence indicating how emotion enhances memory, particularly its longevity. This enhancement, while most studied with respect to the episodic memory associated with the emotional event, is observed for gist information and even false memories. As pointed out by Okon-Singer, one reason for this impact of emotion on memory is the way in which emotional changes attention. Anxious individuals and those at risk for anxiety disorders have attention biases toward irrelevant threats. These attention biases are related to imbalanced prefrontal-limbic-sensory circuits. Emotion interacts with cognitive processes not only at the time that emotion is experienced, but during the consolidation of the event. McGaugh points out that this is mediated by a very general mechanism. The arousal that accompanies emotional experiences, regardless of their valence, causes release of norepinephrine, which according to McGaugh, augments the consolidation of information acquired prior to the experience. Payne and Kensinger argue that stress responses during learning trigger a cascade of neurochemical events that lead the sleeping brain to selectively enhance emotional memory consolidation.

Episodic memory processes are essential not only for reconstructing past events, but also for imagining or predicting future events. Levine *et al.* make the case that, as with episodic memory more generally, remembering and predicting emotion rely on similar processes and show similar patterns of accuracy and bias. They point out many interesting features of emotional memories and predictions, such as that emotional intensity is represented more accurately than other aspects of emotional experience, and that people typically feel more intense emotions when anticipating the future than when remembering the past. These tendencies and biases have important implications for decision making, which often relies on predictions about future emotions.

Together, the chapters reveal that research on the interactions of emotion and cognition are diverse and dynamic. This is not surprising given that emotion and cognition reflect two of the most important and complex functions of the brain. As new techniques and theories develop it is likely that this excitement and debate will last well into the years ahead. We hope that these essays provide a look into that future.