Afterword: *What is the added value of studying the brain for understanding emotion?*

Alexander J. Shackman

Department of Psychology, Neuroscience and Cognitive Science Program, and Maryland Neuroimaging Center, University of Maryland, College Park, MD USA

Regina C. Lapate

Department of Psychology and Helen Wills Neuroscience Institute, University of California, Berkeley, CA USA

Address Correspondence to:
Alexander J. Shackman (shackman@umd.edu)
3123g BPS
Department of Psychology
University of Maryland, College Park, MD 20742 USA

As detailed in many of the essays scattered throughout this volume, the last two decades have witnessed the widespread adoption of powerful new tools for interrogating the brain and new areas of multidisciplinary research focused on identifying the neural circuitry underlying emotional states and traits. But what is the 'added value' of studying the brain for understanding the nature of emotion? Can affective neuroscience really provide insights that go beyond the reach of more traditional measures— behavior, ratings, and peripheral physiology (Bradley & Lang, 2000)? This is not an abstract or purely rhetorical question. As Johnstone reminds us, skeptics have questioned whether neuroscience can provide conceptually important evidence or adjudicate between alternative theoretical models (e.g., Coltheart, 2013) and millions of research dollars have been spent on the assumption that it can.

All of the authors agree that studying the brain is important for establishing the nature, as well as the biological bases, of emotion. Johnstone, for example, argues that neuroscience is necessary (but not sufficient), for developing a deep understanding of emotion. Berridge and Levenson emphasize that neuroscientific data can unveil critical, but otherwise hidden, features of emotion. Pessoa notes that in biology, *function follows structure*; therefore, understanding the neural realm constrains plausible explanations in the psychological realm. He wryly notes that, "because emotion is the by-product of a complex biological system, investigators ignore the brain at their own peril. Overall, progress without understanding the brain will be too slow, and likely insufficient."

Several authors emphasized the value of neurobiological methods for fractionating emotional and motivational states into their more elementary constituents, for carving nature at her joints (see also Adolphs, *in press*). One of the most fundamental conceptual claims in affective science concerns the

distinction between emotional reactivity and regulation. In nature, reactivity and regulation are challenging to tease apart using behavioral or self-report methods because they are rapid, overlap in time, and can occur automatically, outside of conscious awareness (e.g., Goldsmith & Davidson, 2004; see also Van Reekum & Johnstone's response to Question 7). Yet, as Johnstone notes, mechanistic studies in rodents and neuroimaging studies in human have provided compelling evidence that emotional reactivity and regulation reflect partially separable neural circuits.

The precise relationship between feelings and other aspects of emotion, such as expressive behaviors and autonomic activity, has long been contentious among emotion theorists (Adolphs, 2013; LeDoux, 2015). Levenson marshals data drawn from studies of patients with pseudo-bulbar affect (PBA), a relatively common neurological disorder characterized by sudden and uncontrollable laughter or crying (Brooks, Crumpacker, Fellus, Kantor, & Kaye, 2013). From a basic science perspective, PBA is particularly interesting because these emotional signs are often uncoupled from patients' subjective experience. They may laugh in response to tragedy or weep in response to a joke. As Levenson notes, this dissociation provides support for models in which the behavioral and autonomic components of emotion reflect mechanisms (or what he terms 'modules') separate from those that generate emotional feelings.

Berridge describes one of the most surprising and theoretically significant discoveries to emerge from studying the brain, namely, the idea that reward is not a single, indivisible thing, but instead can be split into two processes: 'wanting' and 'liking.' 'Wanting' reflects the degree of appetitive motivation, craving, and desire that a reward elicits. 'Liking,' on the other hand, reflects the hedonic pleasure and positive affect—the yumminess—elicited by reward contact and consumption. 'Wanting' and 'liking' are

exceedingly difficult to tease apart with behavioral or self-report methods (Havermans, 2011) in part because, as Berridge notes, "Ordinarily in life, when you like something, it is natural to also want it. And when you say you want something, that almost certainly means you expect to like it too. Liking and wanting seem [like] two sides of the same coin." Drawing on more than two decades of mechanistic work in rodents (Berridge & Kringelbach, 2015; Kringelbach & Berridge, 2012), Berridge reviews evidence that 'wanting' and 'liking' are neurobiologically dissociable. 'Wanting' critically depends on dopaminergic projections coursing from the brainstem to the nucleus accumbens. In contrast, 'liking' reflects tiny (~1mm^3 in the rat) 'hotspots' nestled within the accumbens and neighboring regions of the ventral striatum. In rodents, stimulation of these hedonic hotspots with opioids or cannabinoids—the endogenous neurochemicals underlying the pleasures of heroin and marijuana—selectively amplifies facial expressions of 'liking' without altering 'wanting' (i.e., willingness to work for reward).

Most of the authors emphasized the value of neurobiological methods for revealing deep similarities between seemingly disparate psychological constructs. One of the most fundamental conceptual distinctions is the distinction between emotion and cognition. Subjectively, we often experience cognition and emotion as fundamentally different. Emotion is saturated with feelings of pleasure or pain and manifests in readily discerned changes in the body, whereas cognition often appears devoid of substantial hedonic, motivational, or somatic features. These differences in subjective experience and peripheral physiology have led many theorists to treat emotion and cognition as categorically distinct mental faculties, presumably reflecting dissociable neural circuitry. Yet, as Pessoa emphasizes, there is growing evidence that emotion and cognition reflect, at least in part, shared substrates (see Question 8). Along similar lines, Berridge highlights evidence that even emotional states with opposing valences—like desire (i.e., 'wanting') and dread—can reflect shared substrates and Johnstone reviews work indicating

that the endogenous opioid system plays a critical role in functions as varied 'liking,' analgesia, and placebo effects.

Berridge and Johnstone remind us that the conceptual distinctions (e.g., 'liking' vs. 'wanting') and mechanistic insights afforded by affective neuroscience are practically important. Many models of emotional states and traits are descriptive and superficial—not explanatory (e.g., Epstein, 1994; Funder, 1994). As a consequence, they do not provide any clues about what to do when emotions become maladaptive. Developing a more complete understanding of the mapping between the brain (structure), the emotional mind (function), and behavior would inform the development of more effective interventions for a range of emotional disorders, including depression, anxiety, and substance abuse.

Finally, several authors highlight the challenges of this enterprise. As Levenson notes, "sophisticated methodologies for measuring brain activity cannot compensate for weak experimental designs." In this regard it is noteworthy that the English word *emotion* derives from the Latin *emovere*, "to shake, displace, or agitate" (Maxwell & Davidson, 2007). Yet, as Levenson notes, the most common imaging modalities (e.g., fMRI) are highly sensitive to motion and physiological artifacts, which precludes the assessment of naturalistic responses to intense emotional challenges. He warns us about the dangers of inadequate statistical power (Button et al., 2013a, 2013b; Nichols et al., 2017; Poldrack et al., 2017) and limited verification of the target emotional state (Shackman et al., 2006) and advocates for a renewed focus on neurological patient models (Adolphs, 2016), which can readily accommodate naturalistic responses to more intense emotional challenges. Berridge reminds us that some of these challenges can be overcome by integrating measures of brain function with more objective on-line read-outs of emotional valence (e.g., measures of the expressive muscles of the face; Goldin, McRae, Ramel, & Gross, 2008; Heller, Lapate,

Mayer, & Davidson, 2014; Shackman et al., 2006). Johnstone also highlights the need to combine measures: "Even the most beautifully modeled neural circuit means little unless [it is] related to other meaningful measures of emotion—expressive, physiological, behavioral and subjective." Emotion, like other psychological phenomena, is thought to reflect the coordinated activity of distributed neural circuits (Shackman, Fox, & Seminowicz, 2015; Fox & Shackman, *in press*) and both Johnstone and Pessoa emphasize the importance of transitioning from 'localization strategies' (i.e., mapping emotions to isolated brain regions) to a more network-based focus.

In summary, while there is certainly no shortage of challenges, it is clear that affective neuroscience has already provided important new insights into the nature and the mechanistic origins of emotion— insights that could not have been achieved using other kinds of tools.

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