RUNNING HEAD: Studying the Brain to Understand Emotion

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

Kimberly S. Chiew, Kathryn C. Dickerson, R. Alison Adcock

Center for Cognitive Neuroscience, Duke University

To appear in: *The Nature of Emotion*, second edition (editors: R. J. Davidson, A.J. Shackman, A.S. Fox, R. C. Lapate)

Corresponding author:
R. Alison Adcock
B203 Levine Science Research Center
Duke University
Box 90999
Durham NC USA 27708
alison.adcock@duke.edu

Emotion is a fundamental driver of human thought and behavior. It colors our everyday experiences – from what we perceive, to what we remember, to how we act in the future. Following one hundred years of research and despite emotion's critical role in our daily lives, characterizing and classifying emotion has remained an elusive goal. Methodologies for probing the mind via study of the brain have advanced greatly over the past two decades, opening new avenues for research inquiry in the cognitive sciences. In this piece, we outline how neuroscience research has played a critical role in advancing our understanding of emotion and outline future directions for using neuroscience research to inform our fundamental knowledge of emotion and its impact on behavior.

Surprisingly, little consensus exists regarding the definition and structure of emotion (Russell & Barrett, 1999), with various working definitions being proposed. Emotion has been defined as a psychological or physiological state indexing occurrences of value (Dolan, 2002); as a syndrome encompassing aspects of thought, physiology, expression, action, and goals (Roseman, 2008); as comprised of autonomic reactions, cognitions, and behaviours (Davidson, Ekman, Saron, Senulis, & Friesen, 1990); and as highly contextualized with affective and cognitive (situational construal) components (Gendron & Barrett, 2009). Common to these and other definitions is the idea that emotion has multiple subcomponents; primary among these are an affective component, manifested through physiological response, and a cognitive component, indexing the relationship between individual and the environment. This general

composition is consistent with the proposed functional role of emotion in physiologically preparing the body for action, facilitating social communication, and influencing cognitive processing in an adaptive fashion (Rolls, 2000).

Given the theorized complexity of the structure of emotion and its fundamental role in adaptive behaviour, much research has been devoted to elucidating its functional architecture. While the value of neuroimaging for understanding mental processes can been questioned (Coltheart, 2006), there are abundant examples of the influence of neuroimaging on psychological theory. For example, Jonides and colleagues (Jonides, Nee, & Berman, 2006) have argued that neuroimaging data can be just as useful as behavioural data. Neuroimaging data can demonstrate dissociations that clarify the nature of psychological constructs, can identify differential source mechanisms of overtly indistinguishable behavioural responses; and can stimulate new psychological theories and hypotheses. Here, we consider how studying the brain can inform the study of emotion within three major domains of inquiry: first, conceptualization and categorization, second, identifying common and distinct neural architecture with the aim of developing new mechanistic hypotheses, and third, utilizing our understanding of brain-based treatments of psychopathology to inform our knowledge of emotion.

Conceptualization and Categorization of Emotion.

As noted above, consensus regarding the conceptualization of emotion has proved elusive. A defining characteristic arising from multiple definitions of

emotion is its nature as a multi-component process. Neuroscience data has been leveraged against the problem of identifying these dissociable components. For example, emotion may include both aspects of hedonic subjective experience (i.e., pleasure or pain) and adaptive motivational goals (i.e., pursuit or retreat); neuroscience research in both animals and humans has identified distinct substrates of these emotion subcomponents. A prominent example is work identifying opioid vs. dopamine systems as respectively underlying behaviours reflecting 'liking' (the subjective experience of pleasure) vs. 'wanting' (motivational drive) (Berridge, 1996; Berridge & Kringelbach, 2008). Identifying the dissociable impacts of hedonic vs. motivational influences on information processing has become an important topic in human affective neuroscience in recent years, examined via psychophysiological and neuroimaging methods (Braem et al., 2013; Chiew & Braver, 2011, 2014; Frober & Dreisbach, 2014) and has extended to characterizing emotional deficits in schizophrenia (Wang et al., 2015). Prior to this line of inquiry the extent to which wanting and liking were indeed distinct constructs was unclear. Understanding that they can be disentangled and are dependent on discrete neurobiological systems has direct clinical implications: For example it is has been proposed that in addiction, the initial reward "liking" response to a drug is later replaced by cravings or "wanting" of the drug, when little positive affect remains (Berridge & Robinson, 2003), offering the promise of novel treatment targets.

Another important issue in the science of emotion is investigating how different emotion states relate to one another. A central question in the emotion

literature is whether emotion states – happiness, sadness, disgust, surprise and more – should be differentiated from one another as distinct entities, as predicted by categorical theories (Ekman & Cordaro, 2011; Panksepp, 1992), or differ on a smaller number of common underlying factors, as predicted by dimensional theories (Lindquist, 2013; Russell, 1980). Recent research (Kragel & Labar, 2013, 2015) has begun to tackle this issue using multivariate analytical approaches to characterize patterns of psychophysiological and neural data during the experience of different emotions. Given the complex, multi-componential nature of emotion, Kragel and LaBar argue that a multivariate approach incorporating multiple dependent variables may be the most appropriate analytical approach to characterizing different emotional experiences. Analysis of biological activity revealed that a valence/arousal dimensional account was insufficient in characterizing psychophysiological and neural substrates of emotion; these were best characterized by a category account. Specifically, patterns of autonomic and neural activity were not necessarily more similar or overlapping when comparing emotions thought to be more similar on dimensions of valence and arousal, as a dimensional account would predict. It is difficult to imagine such a fine-grained analysis of the organization of emotion without access to the quantifiable patterns of biological activity underlying emotional states.

Using Neural Commonalities and Dissociations to Generate New Mechanistic Hypotheses.

In addition to clarifying the structure and organization of emotions, comparing neural data across different conditions or experiments can isolate processes underlying individual mental phenomena. For example, neuroimaging studies have revealed that emotion regulation, the process by which one wholly or partially alters the nature, magnitude and duration of emotional responses (Gross & Thompson, 2007), engages brain areas previously associated with non-emotional cognitive control, including the prefrontal cortex and anterior cingulate (Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner & Gross, 2005). This finding was notable in sparking a wealth of research on emotion regulation using a cognitive neuroscience approach, allowing parallels to be drawn between emotional and non-emotional regulation. This effort has yielded increased understanding of regulatory cognitive processes including contextual change, attentional redeployment, and response modulation (Ochsner, Silvers, & Buhle, 2012). Importantly, these insights into common mechanisms of regulation emerged from and specifically inform ideas about the origins and modulation of emotional experience.

Conversely, brain data can provide evidence for the dissociability of mental processes. For example, neuroimaging research from our laboratory has provided evidence for the dissociability of rewarding and punishing motivational influences on learning, indicating that positively and negatively valenced information is processed by independent mechanisms, as opposed to leveraging common, valence-independent affective mechanisms (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Murty, Labar, & Adcock, 2012;

Murty, LaBar, Hamilton, & Adcock, 2011). Specifically, we have shown that reward-motivated learning engages mesolimbic dopamine systems and promotes functional connectivity between the dopaminergic midbrain and hippocampus; this increased connectivity predicts successful memory formation under reward motivation (Adcock et al., 2006). In contrast, we found that punishment-motivated learning was associated with increased amygdala activity and increased connectivity to the parahippocampal cortex, supporting memory formation without midbrain involvement (Murty et al., 2012). Critically, these data together suggest that motivated learning can occur with or without dopaminergic involvement, dependent on the motivational context. This demonstration of biological dissociability enriches characterizations of valence, suggesting that a one-dimensional definition of valence is overly simplistic, and raises further questions about the mechanistic impact of these systems on memory modulation - cohering with work suggesting that emotions are best represented as categories rather than dimensions (as previously described) (Kragel & LaBar, 2015). These neuroimaging findings spurred a new behavioural hypothesis about valence specific effects on encoding which we confirmed in a subsequent study: using a novel, human version of the rodent Morris water maze (hippocampal-dependent learning), we observed memory benefits under reward, but not punishment motivation (Murty et al., 2011). This example illustrates how neural data has played an important role in moving the field forward, generating and refining new research questions for future work.

Leveraging the Neuroscience of Psychopathology to Study Emotion.

Deficits in emotional functioning are a defining feature of many forms of human psychopathology: they are a hallmark of anxiety and mood disorders but also associated with a wide range of other diagnostic conditions (Keltner & Kring, 1998). Consequently, basic research on emotional processes has advanced scientific understanding of psychopathology (Kring, 2010), but conversely, findings from psychopathology have also advanced affective science. At a fundamental level, all interventions for psychopathology alleviate emotional dysfunction through manipulation of biological systems. Pharmacological interventions manipulate neuromodulator systems at the receptor level (such as GABA, serotonin, and norepinephrine), while learning-based psychotherapy alters neural activity via network plasticity (Flack & Laird, 1998; Linden, 2006). Direct perturbation of the central nervous system through methods like electroconvulsive therapy, transcranial stimulation, and deep brain stimulation may also help patients for whom pharmacological and/or therapy treatments have failed, although the neural mechanisms by which such stimulation improves emotional functioning remain unclear (Cusin & Dougherty, 2012).

Just as “knocking out” a gene can help clarify that gene’s function in an intact organism, investigating the nature of emotion dysfunction in psychopathologies, particularly at the neurobiological level may help to clarify healthy emotion function. Focusing on function permits a transdiagnostic perspective: many different psychopathologies (e.g., depression, anxiety, schizophrenia) may all express a single emotional deficit (e.g., anhedonia).

Understanding common neurobiological abnormalities (e.g., dopamine dysregulation) across these diverse diseases may also illuminate the biological mechanisms of emotion. In addition, understanding neurobiological causes of emotional disorders can highlight how emotion interacts with other cognitive functions. Neuroscience research has shown that emotion can modulate a wide range of psychological functions, ranging from the classic “attentional blink” phenomenon, (Schwabe et al., 2011), to memory (Adcock et al., 2006; Dolan, 2002; Kensinger & Corkin, 2004; Murty et al., 2011) and decision-making (Bechara, Damasio, & Damasio, 2000) in both health and disease.

Conclusion

For almost one hundred years, behavioural observations were the primary empirical data used to investigate emotion. Neuroscience research has already accelerated the pace of progress of emotion research, as follows: firstly, just as multivariate (vs. univariate) statistical approaches permit consideration of a fuller range of variables and their relationships to one another, integration of behavioural and neuroscience approaches can clarify the structure and organization of emotion in a nuanced and quantified way inaccessible to the study of overt behaviour alone. Secondly, neuroscience has facilitated the identification of commonalities and dissociations in underlying mechanisms, driving development of new hypotheses. Thirdly, given that emotion dysfunction is central to many forms of psychopathology, consideration of brain dysfunction and brain-based interventions can help us to understand mechanisms of healthy

emotion as well as disease. Like all mental processes, emotion is emergent from biological activity; thus, consideration of its physical structure and function is necessary for a comprehensive understanding of emotion and, ultimately, the human mind.

References

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., & Gabrieli, J. D. (2006). Reward-motivated learning: mesolimbic activation precedes memory formation. *Neuron, 50*(3), 507-517. doi: 10.1016/j.neuron.2006.03.036

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cereb Cortex, 10*(3), 295-307.

Berridge, K. C. (1996). Food reward: brain substrates of wanting and liking. *Neurosci Biobehav Rev, 20*(1), 1-25.

Berridge, K. C., & Kringelbach, M. L. (2008). Affective neuroscience of pleasure: reward in humans and animals. *Psychopharmacology (Berl), 199*(3), 457-480.

Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends Neurosci, 26*(9), 507-513.

Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (2013). Affective modulation of cognitive control is determined by performance-contingency and mediated by ventromedial prefrontal and cingulate cortex. *J Neurosci, 33*(43), 16961-16970. doi: 10.1523/JNEUROSCI.1208-13.2013

Chiew, K. S., & Braver, T. S. (2011). Positive affect versus reward: emotional versus motivational influences on cognitive control. *Frontiers in Psychology, 2*(279), doi:10.3389/fpsyg.2011.00279.

Chiew, K. S., & Braver, T. S. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cogn Affect Behav Neurosci, 14*(2), 509-529.

Coltheart, M. (2006). What has functional neuroimaging told us about the mind (so far)? *Cortex, 42*(3), 323-331.

Cusin, C., & Dougherty, D. D. (2012). Somatic therapies for treatment-resistant depression: ECT, TMS, VNS, DBS. *Biol Mood Anxiety Disord, 2*(1), 14. doi: 10.1186/2045-5380-2-14

Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A., & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology. I. *J Pers Soc Psychol, 58*(2), 330-341.

Dolan, R. J. (2002). Emotion, cognition, and behavior. *Science, 298*(5596), 1191-1194.

Ekman, P., & Cordaro, D. (2011). What is meant by calling emotions basic. *Emot Rev, 3*(4), 364-370.

Flack, W. F., & Laird, J. D. (1998). *Emotions in psychopathology: theory and research*. Oxford: Oxford University Press.

Frober, K., & Dreisbach, G. (2014). The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control. *Cogn Affect Behav Neurosci, 14*(2), 530-547. doi: 10.3758/s13415-014-0259-x

Gendron, M., & Barrett, L. F. (2009). Reconstructing the Past: A Century of Ideas About Emotion in Psychology. *Emot Rev, 1*(4), 316-339.

Gross, J. J., & Thompson, R. A. (2007). Emotion regulation: conceptual foundations. In J. J. Gross (Ed.), *Handbook of emotion regulation* (pp. 3-24). New York: Guilford Press.

Jonides, J., Nee, D. E., & Berman, M. G. (2006). What has functional neuroimaging told us about the mind? So many examples, so little space. *Cortex, 42*(3), 414-417; discussion 422-417.

Keltner, D., & Kring, A. M. (1998). Emotion, social function, and psychopathology. *Review of General Psychology, 2*(3), 320-342.

Kensinger, E. A., & Corkin, S. (2004). Two routes to emotional memory: distinct neural processes for valence and arousal. *Proc Natl Acad Sci U S A, 101*(9), 3310-3315. doi: 10.1073/pnas.0306408101

Kragel, P. A., & Labar, K. S. (2013). Multivariate pattern classification reveals autonomic and experiential representations of discrete emotions. *Emotion, 13*(4), 681-690. doi: 10.1037/a0031820

Kragel, P. A., & LaBar, K. S. (2015). Multivariate neural biomarkers of emotional states are categorically distinct. *Soc Cogn Affect Neurosci*. doi: 10.1093/scan/nsv032

Kring, A. M. (2010). The future of emotion research in the study of psychopathology. *Emot Rev, 2*(3), 225-228.

Linden, D. E. (2006). How psychotherapy changes the brain--the contribution of functional neuroimaging. *Mol Psychiatry, 11*(6), 528-538. doi: 10.1038/sj.mp.4001816

Lindquist, K. A. (2013). Emotions emerge from more basic psychological ingredients: a modern psychological constructionist model. *Emot Rev, 5*(4), 356-368.

Murty, V. P., Labar, K. S., & Adcock, R. A. (2012). Threat of punishment motivates memory encoding via amygdala, not midbrain, interactions with the medial temporal lobe. *J Neurosci, 32*(26), 8969-8976.

Murty, V. P., LaBar, K. S., Hamilton, D. A., & Adcock, R. A. (2011). Is all motivation good for learning? Dissociable influences of approach and avoidance motivation in declarative memory. *Learn Mem, 18*(11), 712-717.

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. (2002). Rethinking feelings: an FMRI study of the cognitive regulation of emotion. *J Cogn Neurosci, 14*(8), 1215-1229.

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends Cogn Sci, 9*(5), 242-249.

Ochsner, K. N., Silvers, J. A., & Buhle, J. T. (2012). Functional imaging studies of emotion regulation: a synthetic review and evolving model of the cognitive control of emotion. *Ann N Y Acad Sci, 1251*, E1-24. doi: 10.1111/j.1749-6632.2012.06751.x

Panksepp, J. (1992). A critical role for "affective neuroscience" in resolving what is basic about basic emotions. *Psychol Rev, 99*(3), 554-560.

Rolls, E. T. (2000). Precis of The brain and emotion. *Behav Brain Sci, 23*(2), 177-191; discussion 192-233.

Roseman, I. J. (2008). Motivations and emotivations: approach, avoidance, and other tendencies in motivated and emotional behavior. In A. J. Elliot (Ed.), *Handbook of approach and avoidance motivation* (pp. 343-366). New York: Psychology Press.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*(6), 1161-1178.

Russell, J. A., & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: dissecting the elephant. *J Pers Soc Psychol, 76*(5), 805-819.

Schwabe, L., Merz, C. J., Walter, B., Vaitl, D., Wolf, O. T., & Stark, R. (2011). Emotional modulation of the attentional blink: the neural structures involved in capturing and holding attention. *Neuropsychologia, 49*(3), 416-425. doi: 10.1016/j.neuropsychologia.2010.12.037

Wang, J., Huang, J., Yang, X. H., Lui, S. S., Cheung, E. F., & Chan, R. C. (2015). Anhedonia in schizophrenia: Deficits in both motivation and hedonic capacity. *Schizophr Res*. doi: 10.1016/j.schres.2015.06.019