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Chapter · January 2018

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## **What Neuroscience Can Tell Us about Social Situations: Challenges and Opportunities**

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The Oxford Handbook of Psychological Situations

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Subject: Psychology, Cognitive Neuroscience, Social Psychology Online Publication Date: Dec 2018

DOI: 10.1093/oxfordhb/9780190263348.013.33

### **Abstract and Keywords**

The goal of this chapter is to highlight how neuroimaging techniques can complement behavioral approaches for understanding situations. The chapter describes three situational contexts relevant to applying these techniques to study situational contexts. First, it considers the neuroimaging environment itself as situational context and delineates unique features of this environment that can impact subjective experience. Second, it reviews methodological trends for eliciting situational experiences in a neuroimaging environment, particularly in the domain of interpersonal interactions. Third, it discusses recent neuroimaging evidence suggesting that diverse social situations share common underlying neural responses. The chapter highlights how manipulating an individual's construal of a situation can provide additional insights into the neurobiology of positive and negative situations. Together, neuroimaging approaches can provide one organizing principle for the vast constellation of situations. The hope is to encourage researchers to apply these approaches to gain novel and complementary insights into situational experience.

Keywords: fMRI, social context, evaluative feedback, reward, pain, negative affect

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*There are these two young fish swimming along, and they happen to meet an older fish swimming the other way, who nods at them and says, "Morning, boys, how's the water?" And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes, "What the hell is water?"*

David Foster Wallace, 2005 (as cited in Krajeski, 2008)

The parable about the fish highlights the deceptively simple fact that some of the most obvious and real aspects of our existence, such as the situations in which we find ourselves embedded, are hidden from view and often go unnoticed. Yet these situations powerfully influence our behaviors, thoughts, and feelings as well as our interactions with other people. The parable also captures another important aspect of social situations, namely, that different individuals might construe and experience the same situation in different ways (Funder, 2016). Therefore, one important but difficult avenue to understanding people and predicting their behavior is studying the situations

in which they are embedded (Wagerman & Funder, 2009). Here, we discuss the challenges and opportunities of using brain imaging methodologies to gain traction on situational experiences.

Neuroimaging techniques, including functional magnetic resonance imaging (fMRI), provide the unique opportunity to assess situational experience directly, in real-time, thus reducing biases from self-reports and retrospective recall. Despite offering a complementary lens with which to study situations, brain imaging comes with a unique set of strengths and constraints. Participants are aware that they are being assessed, the procedure can be at times distressing or unfamiliar, and the physical environment imposes limits on the range of possible observable behaviors. The goal of this chapter is to examine three facets related to using neuroimaging techniques to study situational contexts. First, we describe the unique features of the fMRI experimental environment that can impact subjective experiences as well as the physical constraints that may restrict participants' responses. Second, we highlight recent trends and methodological advances that create situational experiences, particularly in the domain of interpersonal interactions. Third, we review recent neuroimaging evidence which suggests that seemingly disparate social situations share underlying neural responses. We highlight how manipulating construal, that is, an individual's perception of a situation, and accounting for individual differences can provide novel insights into the neurobiology of positive and negative situations.

## **Part I: The Neuroimaging Environment as a Situation**

A significant but understudied issue in fMRI research is how contextual features of the fMRI experimental setting may inadvertently influence measured neural activity. Salient features of the fMRI testing context include the confined space of the scanner bore, head restriction, and continuous loud auditory noise (Raz et al., 2005), any of which may induce stress and negative affect. Indeed, MRI procedures have been demonstrated to elicit feelings ranging from minor apprehension to severe panic, to increase cortisol levels, and to activate the sympathetic nervous system in children and adults (Eatough, Shirtcliff, Hanson, & Pollak, 2009; Lueken, Muehlhan, Evens, Wittchen, & Kirschbaum, 2012; Melendez & McCrank, 1993; Muehlhan et al., 2013; Törnqvist, Månsson, Larsson, & Hallström, 2006; Tyc, Fairclough, Fletcher, Leigh, & Mulhern, 1995). The experienced stress during an fMRI experiment can potentially profoundly influence baseline neural activity; the perception of task stimuli, task engagement, and performance; as well as the physiology leading to functional activation patterns (Dantendorfer et al., 1997; Kukulja, Thiel, Wolf, & Fink, 2008). The degree to which the scanner environment influences fMRI data varies with dispositional traits and demographic variables, which, depending upon the study population and design, can lead to inaccurate interpretations of the resulting fMRI data.

Currently, it remains unknown whether alterations in "resting" brain activity reflect heightened reactivity to the experimental context, which can include a combination of acute and diffuse threats; tonic differences in negative affect (Gross, Sutton, & Ketelaar, 1998) or some combination of the two processes (Shackman et al., 2016). Psychometric analyses (i.e., latent state-trait models) indicate that resting-state prefrontal electroencephalogram (EEG, which records electrical activity of the brain) asymmetry reflects the joint contribution of traits and states to a similar degree (Coan, Allen, & McKnight, 2006; Hagemann, Hewig, Seifert, Naumann, & Bartussek, 2005; Hagemann, Naumann, Thayer, & Bartussek, 2002). But as yet, the relative contribution of traits and states to fMRI measures of brain function is not known. As we shall discuss in more detail, most neurophysiological assays are intrusive and can elicit substantial negative affect. Of relevance to the present chapter, MRI data collection requires subjects to lie motionless in a spatially confined, dark tube while being engulfed by loud noise for up to an hour.

Furthermore, MRI-induced negative affect is amplified in individuals with a more negative disposition (Harris, Cumming, & Menzies, 2004). Pattern recognition techniques have recently emerged as a key tool for quantifying the neural organization of emotions in humans. Such techniques have uncovered that emotional states can be decoded from neuroimaging data in the absence of any experimental manipulations. Early findings indicate that individual differences in mood states are associated with the relative incidence of brain states associated with fear, anger, and sadness (Kragel, Knodt, Hariri, & LaBar, 2016). Thus, resting brain activity transiently fluctuates among multiple emotional states and fluctuations depend on emotional status of the individual (Shackman et al., 2016). How this emotional status is impacted by the scan context is a meaningful direction for future research.

## **General Effects of Stress**

About 30% of subjects undergoing fMRI scanning report stress-related reactions to the scan environment, including apprehension, concern, and sometimes panic (Melendez & McCrank, 1993). Not surprisingly, these reactions have been shown to elevate pre-scan state anxiety (Dantendorfer et al., 1997; Katz, Wilson, & Frazer, 1994) and baseline levels of cortisol, a hormone released under stressful conditions (Kukolja et al., 2008; Muehlhan, Lueken, Wittchen, & Kirschbaum, 2011; Tessner, Walker, Hochman, & Hamann, 2006). Such physiological responses are particularly relevant to fMRI studies because stress hormones are associated with a range of neural functions that are reflected in brain activity (Hsu et al., 2003; Wang et al., 2005) and therefore the measurement itself may generate non-specific effects on the brain that differ across subjects. For instance, cortisol has been shown to correlate with both deactivation in the hippocampus (Pruessner et al., 2008) and activation in the amygdala (van Stegeren et al., 2007), regions implicated in memory consolidation and threat detection. Thus, the responses may change the very phenomena that neuroimagers seek to quantify.

In addition to direct effects of stress on brain function, many indirect consequences of stress may also impact emotional measures. For example, acute stress and anxiety can trigger a variety of physiological changes, including heavy breathing, sweating, heart palpitations, and changes in blood pressure. Physiological noise represents the primary source of noise in the Blood Oxygen Level Dependent (BOLD) fMRI signal (Krüger & Glover, 2001) and consists largely of cardiovascular (Dagli, Ingelholm, & Haxby, 1999) and respiratory-induced fluctuations (Wise, Ide, Poulin, & Tracey, 2004). The physiological effects induced by the scan context may influence neural-metabolic function and cerebral blood flow (Brennan et al., 1988), thereby altering the BOLD signal measured by fMRI. Together, these stress-induced fluctuations in the fMRI signal may contribute to the considerable variation observed in many fMRI responses (e.g., Zandbelt et al., 2008, Plichta et al., 2012) and confound fMRI studies that do not control for these factors.

## **Psychological Effects of Stress and Anxiety**

In addition to effects of stress on baseline levels of brain activity, fMRI-related anxiety can potentially also influence task performance inside the scanner. Modulating effects of arousal on cognition, particularly working memory and attention, are well established and have complex impact on cognitive tasks (de Kloet, Oitzl, & Joëls, 1999; Moran, 2016). In the case of working memory, for example, the majority of studies document impaired working memory following stress (Roosendaal, McReynolds, & McGaugh, 2004; Elzinga & Roelofs, 2005; Schoofs, Preuß, & Wolf, 2008), although some also report protective effects (Henckens, van Wingen, Joëls, & Fernández, 2010; 2011). Thus, an individual's ability to express their latent working memory abilities in the context of an fMRI study may be modulated by scanning-related stress. This can complicate the interpretation of studies that fail to account for perceived stress and state anxiety of fMRI participants.

To understand these effects, neuroimaging is increasingly being used to examine the neural circuits implicated in the activation and modulation of the stress response system. For example, recent work indicates that stress may impair working memory through disruptions in fronto-parietal attentional networks (van Ast, Cornelisse, Meeter, Joëls, & Kindt, 2013). However, counterintuitively, these observed performance deficits were not mediated by increased cortisol levels; in fact within the stress condition, increased cortisol led to improved working memory performance. These counterintuitive results may be explained through research in both rodent (Okuda, Roozendaal, & McGaugh, 2004) and human studies (Elzinga & Roelofs, 2005) that indicate that the influence of stress hormones on cognitive functioning depends on the level of stress-induced emotional arousal. In particular, other systems may moderate the relationship between cortisol levels and cognitive performance; for example, in human working memory, acute sympathetic activation following a naturalistic stressor alters the effects of cortisol on performance (Elzinga & Roelofs, 2005). Given that participants in MRI studies experience a range of stress in response to the scanner environment (Melendez & McCrank, 1993), pre-scan anxiety and cortisol reactivity are likely to have interactive influences on working memory.

While stress related to fMRI testing can impact how participants perform tasks in the scanner, this relationship requires accounting for the interplay between measured stress hormone responses, the context in which they are elicited, and participants' situational perceptions. The complex effects of stress on brain function and behavior cannot be understood simply by measuring a single stress hormone such as cortisol. However, not all labs are equipped for testing these relationships and doing so may misdirect limited resources. We suggest that the imaging field as a whole can stand to benefit from a greater awareness of the extraneous factors that might influence task evoked responses, and we provide some specific recommendations at the end of this section.

## **Auditory Noise**

Another particularly salient characteristic of an fMRI environment is the high level of auditory noise generated by standard fMRI sequences. Together with noise emanating from helium pumps and air circulation systems surrounding the scanner, these noise sources provide a level of auditory interference that is significantly higher than that experienced in a typical behavioral testing environment. While the interference caused by auditory noise is most salient when considering auditory tasks, it may also affect subjects' performance on non-auditory tasks, for example, by increasing demands on attention systems and thus biasing cognitive performance (Hommel et al., 2012). There have been relatively few studies addressing this question directly. Using a continuous functional imaging sequence, Cho and colleagues (1998) had participants perform simple visual (flickering checkerboard) and motor (finger tapping) tasks, with and without additional scanner noise played through headphones. The researchers observed contrasting effects in visual and motor modalities: activity in visual cortex increased with added auditory noise, whereas activity in motor cortex was reduced. Not all studies examining this issue have observed effects of noise in non-auditory tasks: Elliott and colleagues (1999), using participants performing visual, motor, and auditory tasks, observed that scanner noise resulted in decreased activity uniquely during the auditory condition. Nonetheless, the number of instances in which scanner noise has been observed to affect neural activity on non-auditory tasks is significant enough to be mindful of the issue. These studies suggest that a lack of behavioral effect of scanner noise does not guarantee equivalent neural processing, that both increases and decreases in neural activity are seen in response to scanner noise, and that the specific regions in which noise-related effects are observed vary from study to study.

Effects of scanner noise have also been reported in an fMRI task on verbal working memory. Tomasi et al. (2005) had participants perform an *n*-back working memory task. The volume of the scanning sequence was

experimentally manipulated by 12dBA by utilizing different resonant vibration modes of the gradient coil and adjusting the readout frequency. Behavioral accuracy did not differ as a function of noise level. However, although the overall patterns of task-related activity were similar, brain activity differed as a function of noise. The louder sequence produced increased change in BOLD responses in attentional networks and the quieter sequence was associated with decreased BOLD responses (i.e., smaller signal changes) in the anterior cingulate cortex (ACC) and the putamen. These data support the idea that attentional networks may be recruited to compensate for interference due to increased scanner noise (Tomasi, Caparelli, Chang, & Ernst, 2005).

## **Special Considerations for Developmental and Clinical Research**

Considerations about how the fMRI scanner context might influence neural responses are particularly relevant for special populations such as clinical patients and children (Shechner et al., 2013). For children, many aspects of participating in an imaging experiment can be challenging and potentially more stressful compared to adults, as their ability to regulate emotions is still developing (Luna, Garver, Urban, Lazar, & Sweeney, 2004; Nelson et al., 2005). Therefore, anxiety caused by the fMRI experiment itself may cloud developmental neuroimaging data, and may do so for some children more than others. Such anxiety may additionally be driven by children's perception of the fMRI experiment. Only a few studies have examined age-related effects of fMRI on behavior, with mixed findings (Eatough et al., 2009; Keulers, Stiers, Nicolson, & Jolles, 2015; Shechner et al., 2013). One such study demonstrated that both younger and older adolescents undergoing fMRI showed anticipatory stress responses, as indicated by elevated cortisol levels and subjectively experienced anxiety. Overall, cortisol output during the fMRI experiment was negatively associated with brain activation, although the location of this association was dependent on age group (Keulers et al., 2015). Another study in adolescent youth observed significant reactivity in three stress-reactive hormones in response to MRI: cortisol, dehydroepiandrosterone (DHEA), and testosterone. Only DHEA levels were related to subsequent scan success (Eatough et al., 2009).

Limited data exist on the relation between anxiety-like symptoms and scan quality in pediatric clinical samples. Shechner and colleagues (2013) investigated psychological reactions to an fMRI scan among children and adolescents with and without anxiety disorders, as well as among healthy adults. Of note, the majority of participants tolerated the MRI well, and no significant differences in distress were observed across the three groups, indicating that on average MRI scans are associated with low levels of psychological distress among healthy and anxious children and therefore tolerable and feasible in widespread use (Shechner et al., 2013). The training procedures in this study undoubtedly contributed to these findings. The majority of participants in this study underwent training in a mock (practice) scanner, which allowed them to acclimate to the scanner environment. Using a mock scanner provides the unique opportunity for participants to experience the physical and auditory environment of the actual MRI scanner prior to data acquisition (Davidson, Irwin, Anderle, & Kalin 2003; Kotsoni, Byrd, & Casey, 2006) and is thus helpful for reducing anxiety (Shechner et al., 2013, but see Eatough et al., 2009) and other developmental and methodological issues such as task noncompliance and motion (de Bie et al., 2010; Perlman, 2012).

Children with Autism Spectrum Disorder (ASD) constitute another vulnerable group and previous literature suggests that 30% of data is lost from scans conducted with ASD participants due to scan motion artifacts (Yerys et al., 2009). Given the high co-morbidity of anxiety disorders in individuals with ASD, it is important to consider whether anxiety might affect fMRI data quality and lead to exclusion biases. In a preliminary study (Pecukonis, Anderson, Sadikova, & Redcay, 2017), investigators analyzed the relation between child and parent-reported anxiety and average scan motion (i.e., frame displacement) during a social interaction fMRI paradigm in children

with ASD. Initial results demonstrated a significant association between average frame displacement and the parent-reported generalized anxiety factor. The findings therefore suggest exercising caution when excluding data from research analyses with clinical samples. Importantly, researchers should be aware of these moderate to strong correlations between participant anxiety and scan motion, as excluding these participants from their dataset may result in a sample that is not fully representative of the ASD population (Pecukonis et al., 2017). If possible, we recommend assessing participants' state anxiety, particularly in pediatric clinical samples, and reporting any correlations with motion parameters.

## Summary

Neuroimaging allows researchers to quantify neural underpinnings of online cognitive and affective processes. However, fMRI studies typically fail to account for any behavioral differences or neuronal activation enhanced or suppressed by an individual's exposure to the fMRI environment. Features of this environment, including pre-scan distress and loud auditory noise, can interact with demographic, dispositional, and clinical traits to influence behavior. This may be particularly relevant for special populations such as patients and children. Some recommendations for future research include (1) tracking which specific factors of the procedure induce distress or anxiety (i.e., by including debriefing questionnaires and/or pre- and post-test state anxiety measures); (2) reporting any between-group differences in anxiety and motion (and their association) in research analyses with clinical samples, and exercising caution when excluding data; (3) determining the usefulness of accounting for individual variability in scanner-evoked stress hormone levels (i.e., by including pre-task levels as nuisance variables into the analyses); and (4) attempting to keep stress levels as low (and equal across measurements) as possible, for example by using an acclimation procedure in a mock scanner prior to the first fMRI session.

## Part II: Methods for Creating a Social Situation

In addition to potentially eliciting stress and anxiety, the scanning environment presents physical constraints on the participant and on the experimenter. These physical constraints do not necessarily impose as many challenges to studying basic cognitive phenomena such as visual attention and working memory. However, the physical constraints make the scanning experience a socially isolated one in which participants lie prone in a dark tube by themselves. Such restrictions impose several roadblocks to studying naturalistic social situations and interpersonal interactions. Yet, there are reasons to believe that individuals treat even the most minimal and pared down social contexts as real (Tamir & Hughes, in press). For example, individuals readily perceive the presence of mental agents even when none exist: Newborns exhibit a strong preference for social stimuli such as faces and face-like arrangements (Johnson, Dziurawiec, Ellis, & Morton, 1991), individuals tend to automatically ascribe intentionality and personality characteristics to moving geometric shapes as they interact on a screen (Heider & Simmel, 1944), and individuals tend to anthropomorphize their cars or computers when they "misbehave" (Waytz et al., 2010). Indeed, people seem to overgeneralize their natural and automatic social proclivities to relatively unnatural or novel contexts, such as pared down or minimalistic social situations (Tamir & Hughes, in press). In other words, people seem to have a "social heuristic" (Rand, 2016), treating even minimal or reduced social interactions as real in the event that there is something meaningful to be learned from such interactions (Tamir & Hughes, in press).

Researchers have capitalized on our innate social proclivities and found ways to circumvent the physical constraints imposed by the scanner environment by creating novel and innovative experimental paradigms that generate real or imagined social interactions. The burgeoning field of social affective neuroscience has used such tasks to begin to illuminate the biological bases of our complex social abilities. Initial neuroimaging investigations of social cognition have focused on the neural underpinnings of our capacity to grasp the mental states and emotions of others. In most such paradigms, participants are required to observe others or think about their mental states, rather than engage in social interaction. This tradition established an important foundation of elemental social abilities (e.g., theory of mind, emotion perception from faces) but may not fully capture the complex processes involved in everyday social interactions (Redcay et al., 2010). This is because, when relating to one another, people are not engaged in a passive process of inference but are rather deeply engaged and motivated perceivers (Hughes & Zaki, 2015; Freeman & Ambady, 2011). More recent work across social affective neuroscience and neuroeconomics builds on this foundation by creating tasks that incorporate elements of active social interaction and manipulate features of the social context (Tamir & Hughes, in press). This work has the potential to speak not only to the neural processes involved in social interaction but also speak to how situational contexts might impact these basic social cognitive abilities. Next, we provide a few examples of such experimental methods and provide evidence that participants experience these situations as real and impactful.

## **Social Decision Making**

The neural and psychological mechanisms underlying social interactions have been examined through different theoretical and methodological lenses. For example, researchers interested in studying social interactions in the context of decision making have drawn from game theory and behavioral economics (for reviews, see Bhanji & Delgado, 2014; Ruff & Fehr, 2014; Rangel & Hare, 2010). Given the highly social environments in which we live, some of our most important decisions are made in the context of social interactions and are in part determined by the decisions of other people (Reis, 2008; see also Asendorpf, this volume). These decisions extend from the relatively commonplace, such as choosing a movie to watch with friends, to the more consequential, such as deciding which job to accept. Research that draws from behavioral economics seeks to understand situations in which people interact with one another. Although deceptively simple, these tasks require participants to make choices with other people that are informed by complex reasoning about the motivations and intentions of their interaction partners. Game-theoretical experiments have been used to model a variety of different social exchanges, such as bargaining behavior (e.g., the ultimatum game; Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003; Tabibnia, Satpute, & Lieberman, 2008), cooperative and competitive behavior (e.g., the trust game, public goods game, prisoner's dilemma; Delgado, Frank, & Phelps, 2005; Hughes, Ambady, & Zaki, 2017; King-Casas et al., 2005), and altruism and vicarious reward (e.g., charitable donation; Genevsky, Västfjäll, Slovic, & Knutson, 2013; Harbaugh, Mayr, & Burghart, 2007; Mobbs et al., 2009; Morelli, Sacchet & Zaki, 2015). These tasks are used to measure the influence of selfishness, mutual reciprocation, and prosocial motivation, as well as the inferred motives of interaction partners (e.g., via reputation, past experience, or social knowledge such as group membership). Critically, the payoffs across these varied tasks depend upon the combination of the player's choice and interaction partner's choice, and are made incentive-compatible by making a subset of choices count toward the payoff for participation.

Several neuroimaging studies demonstrate that participants in these social exchanges experience them as real and impactful. For example, reward-related structures in the brain, such as the striatum and ventromedial prefrontal cortex (vmPFC), track a social partner's decision to cooperate or not cooperate as well as to reciprocate or not reciprocate cooperation (Hughes et al., 2017; King-Casas et al., 2005; Rilling et al., 2002). In this way, brain



activity seems to encode not just tangible rewards like food, wine, and money, but also more abstract social rewards such as positive feelings of affiliation garnered by mutual cooperation. Similarly, players in these games seem to be highly motivated to maintain fairness norms by punishing defectors, even when doing so comes at a financial cost to the participant (e.g., De Quervain, Fischbacher, Treyer, & Schellhammer, 2004). Finally, players tend to reject unfair offers, even when accepting such offers would be the financially rational choice. Participants report greater negative emotion in response to such inequity. Brain activation in the insula—a region involved in autonomic arousal and pain—increases as the unfairness of the offer increases and correlates with rejection of unfair offers (Sanfey et al., 2003; Rilling et al., 2004). Critically, this pattern of results is observed if participants believe they are interacting with a human partner, but not when interacting with a computer making random choices.

Taken together, research that uses game-theoretical paradigms provides one avenue with which to study social exchange situations in a neuroimaging environment. The tasks used are tightly controlled and provide intuitive and quantitative proxies for complex social behaviors in both humans and animals (e.g., prosocial behavior), which can then be used to model every trial of brain activity during the task. The findings from this body of research suggest that participants treat these pared down social interactions as real and react positively to mutual cooperation and negatively to inequity and nonreciprocity.

## Virtual Social Interactions

Another lens through which to study social interactions is to examine how individuals use naturalistic interpersonal cues from other people to make sense of social situations. Most of this work examines component processes of interpersonal interactions (e.g., emotion understanding, shared attention, thinking about other people's mental states), despite increasing behavioral evidence that these processes may function differently in interactive social contexts. (Gallotti & Frith, 2013; Rice & Redcay, 2016). Standard neuroscience approaches have identified neural activity patterns in response to simplified versions of social stimuli such as static images of facial expressions (Ekman & Friesen, 1976; Tottenham et al., 2009), affectively valenced photographs such as the International Affective Picture System (IAPS; Bradley & Lang, 2007), and scripted imagery of social events (Frewen et al., 2010) to emulate social experience. While effective and reliable at eliciting social emotions (i.e., Michalska et al., 2017), such static stimuli are not fully representative of social encounters in the real world. Several possible differences between processing real-time interpersonal interactions and offline components of social behaviors have been proposed, including basic differences in visual motion and other perceptual parameters (de Borst & de Gelder, 2015) and a greater demand on mentalizing systems for live interactions (Rice & Redcay, 2016). Others suggest that live interactions are more rewarding (Schilbach et al., 2010, 2013), provide unique sources of information (Kuhl, 2011), and capture more attention (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012) possibly due to increased arousal (Okita, Bailenson, & Schwartz, 2007), compared to static or video images. Despite the obvious practical challenges, neuroimaging paradigms may be especially well-suited to dissociate these possibilities and to identify the many implicit, ongoing processes hypothesized to underlie live social interaction.

Because of the possibility of *actually* interacting with another person, truly social interactions demand a level of interdependence between people that has not been adequately captured in traditional computer-based social tasks (Laidlaw, Risko & Kingstone, 2016). Several differences have been noted. For instance, one study found that when being interviewed, interviewees look more to the face and less to the background in a real-life condition, where the interviewer is physically present and makes eye-contact, as compared to a video of the interviewer (Freeth,

Foulsham & Kingstone, 2013). In other words, participants interacting with a live person are better able to attribute an interviewer's eye contact as a signal to return their gaze. Another study asked participants to walk over a university campus to buy coffee while wearing a mobile eye tracker that recorded what they saw from a first-person perspective. The videos were then played back to other participants, whose eye movements were examined while looking on the screen (Foulsham, Walker & Kingstone, 2011). Eye-gaze fixations toward other pedestrians occurred frequently both in the real world and the laboratory, however pedestrians close to the walker were fixated more often when they were viewed on the screen than in the real world. Thus, in real life people tended to look *away* from an approaching person, whereas in the lab they readily stared at them as they approached. In other words, when interacting with real people, individuals adapt their looking behavior consistent with social norms: they look away when they are in the proximity of strangers and want to avoid interacting with them (Foulsham et al., 2011) and they look toward people who they are actively interacting with (Freeth et al., 2013). Non-interactive laboratory paradigms cannot fully incorporate such dynamics and thus may not adequately capture how the social brain functions in live social interaction. Truly interactive paradigms that simulate social interaction with contingent responding of the interaction partner are better suited to emulate the inherent reciprocity of our everyday interactions (Schilbach et al., 2010, 2013).

Several innovative interactive methodologies have recently been developed to map the neurobiological bases of social interaction in more naturalistic contexts inside the fMRI scanner, while still maintaining rigorous experimental control. For instance, one set of studies, examining non-evaluative and contingent social interaction has focused on joint attention. Such studies employ gaze-contingent stimuli together with anthropomorphic virtual characters to create interactive and socially responsive stimuli (e.g., Koike et al., 2016; Oberwelland et al., 2016; Schilbach et al., 2010). A participant in one of these studies either initiates or responds to a shift in gaze (e.g., Wilms et al., 2010), allowing researchers to distinguish the effects of reciprocated and rejected shifts of joint attention. The experimental setup enables participants to experience their own eye-movements influencing and interacting with the gaze behavior of another person (Schilbach et al., 2013). These "interactive" paradigms frequently recruit motivation and reward circuitry (Pfeiffer et al., 2014; Redcay et al., 2010; Schilbach et al., 2010; but see Redcay et al., 2012), including the ventral tegmental area, substantia nigra, amygdala, orbitofrontal cortex (OFC), insula, anterior cingulate cortex, and ventral striatum (Haber & Knutson, 2010). Interactive joint attention episodes also more reliably recruit the MPFC, known to be important in processing intent (Amodio & Frith, 2006) implying that in interactive scenarios, participants engage in mentalizing behaviors that might not be relied upon as much in non-interactive tasks.

## **Evaluative Feedback from Social Interactions**

Another feature of social interactions is the potential to receive personally relevant feedback from interaction partners in real time. Feedback can take the form of explicit reports about one's trustworthiness, likability, attractiveness, or other features of one's personality, or it can take the form of behaviors that carry personal significance, such as if a peer decides whether to engage in interpersonal interactions. These and other forms of real-time evaluative feedback are rich sources of social knowledge because they provide information both about oneself and about one's interaction partners. Increasingly, neuroimaging research has begun to create real or ostensible social interactions while participants undergo fMRI to peek at the underpinnings of how people process evaluative social feedback.

A growing number of studies examining how people process evaluative feedback in interpersonal interactions have focused on the experience of social reward and subjective value from ostensible social partners. In several such

studies, photographs of the participants are ostensibly evaluated by peers, and participants are then shown this feedback while undergoing fMRI scanning. This research finds that receiving positive social feedback about one's personality, likability, and attractiveness from peers recruits activity in reward-related brain structures including the ventral striatum (e.g., Izuma, Saito, & Sadato, 2008; Hughes, Leong, Shiv & Zaki, 2018; Morelli, Torre, & Eisenberger, 2014). Related work provided participants with real feedback from peers following face-to-face interactions or speed dating interactions and found similar reward-related brain activity following positive versus negative feedback about personality and attractiveness (e.g., Korn, Prehn, Park, Walter, & Heekeren, 2012; Cooper, Dunne, Furey, & Doherty, 2013). These kinds of feedback are consequential, leading people to revise their views of themselves (Hughes & Beer, 2013; Korn et al., 2012) and their impressions of the individuals that provided them with feedback (Hughes et al., 2018). An elegant set of developmental studies mirror these findings across development (e.g., Guyer et al., 2012; Jarcho et al., 2016). For instance, in the "Chatroom Task" (Guyer et al., 2008; 2009; 2014) children rate the likeability of social partners based on photographs and are told that they will be similarly evaluated by peers. During the fMRI session, children predict and learn how they were perceived by each peer. Ventral striatum activation was increased for positive vs negative peer feedback (Guyer et al., 2011, with age-related increases in ventral striatum activation when anticipating evaluation (Guyer et al., 2009). Not all feedback is experienced as rewarding by all children. In the "Virtual School Task" (Jarcho et al., 2016) children believe they are chatting with peers who are either predictably nice, predictably mean, or unpredictable. The researchers found that children who were socially shy in early childhood showed greater activity in brain regions implicated in processing salience and distress (dorsal ACC, and bilateral insula), during the anticipation and receipt of feedback from unpredictable peers. These findings imply that it's not only the feedback that matters, but also the personality traits of both interaction partners.

Building on this work, a new study employed a social-interactive fMRI paradigm with middle school-aged children to examine both the desire to initiate interaction with a peer and the enjoyment of the ensuing interaction (Rice-Warnell, Sadikova, & Redcay, 2018). In this study, children were led to believe that they were chatting online with a peer about their likes and hobbies, when in reality the peer was a computer program. On each trial, children engaged in a social bid to the peer, by revealing a like or hobby (e.g., letting the peer know "I like soccer"), and then received a reply about the peer's interest in that subject (e.g., the peer replying "Me too"). To separate effects of contingency from social context, the authors also included a non-social computer control that responded contingently. To assess the intrinsic reward of mutual social engagement, social engagement was contrasted with non-engagement instead of disagreement. Neuroimaging data indicated increased recruitment of the ventral striatum for the peer vs computer both when initiating interaction and when receiving replies. Peer replies also increased activation in brain regions reliably linked with social cognition, including MPFC and right temporoparietal junction (TPJ). Of note, within these social cognitive regions, the difference between peer and computer activation increased with age. The paradigm provides converging evidence that social engagement is intrinsically rewarding and can be successfully probed within the scanner context.

## **Social Exclusion**

Central among mechanisms that have evolved to support social behavior is the ability to detect and respond to diverse signals of social inclusion and social exclusion. The paradigm most commonly used to probe social exclusion with fMRI is the Cyberball game (Eisenberger 2015a, 2015b; Williams & Jarvis, 2006). Participants believe they are playing a game of "catch" over an internet connection with two other players via avatars, whereas the actions of these players are in fact pre-programmed to include or exclude the participant. The game is particularly well suited for neuroimaging paradigms, as it allows for flexible modification of social interactions

without having to rely on live characters (i.e., Eisenberger, Lieberman, & Williams, 2003). At the start of the game, each avatar catches approximately one third of the time and throws a ball approximately one third of the time. In the “inclusion” condition, the participant catches and throws the ball approximately one third of the time. In the “exclusion” condition, the participant is ostracized as the other two avatars throw the ball back and forth. Notably, while in many studies participants believe that human participants control the two other avatars with whom the participant is playing catch, telling participants that the avatars in the Cyberball game are controlled by a computer does not actually change the effects of ostracism (Zadro, Williams, Richardson, 2004). Research using this paradigm finds a reliable relationship between self-reported distress during social exclusion and BOLD responses in brain regions associated with affective and pain processing (e.g., dorsal ACC; dACC, insula; Eisenberger et al., 2003; 2007), the implications of which will be discussed in more detail in Part III of this chapter.

Although the Cyberball paradigm has several advantages (e.g., ecological validity), it has been criticized in terms of experimental control. For example, Somerville, Heatherton, and Kelley (2006) have argued that the task confounds social distress with violation of expectation; that is, participants expect to be thrown the ball, but during the exclusion condition they are not. To address this issue, Somerville et al. (2006) designed a task that independently manipulated social expectation and social distress within a social evaluation task. As predicted, dACC responses were elicited when participants’ expectations differed from the feedback they received. In contrast, responses in ventral ACC (vACC), a region associated with processing valence and reward, was associated with the difference between positive and negative feedback. Moreover, neural responses to positive versus negative feedback in vACC correlated with individual differences in self-esteem (Somerville, Kelley, & Heatherton, 2010). Individuals with lower self-esteem showed the largest difference in activation to positive versus negative feedback, suggesting that the valence of feedback might be more salient to these individuals.

Taken together, this research demonstrates the potential of examining more naturalistic and ecologically-valid social interactions and their consequences in the context of neuroimaging experiments. People react to pared down, minimalistic, and virtual interpersonal feedback and interactive decisions as though they are real, even within the confines of the fMRI scanning environment. People experience positive outcomes in these situations as subjectively valuable, and negative outcomes as aversive and even painful.

## **Part III: Construals Influence the Experience of Positive and Negative Situations**

Individuals frequently describe experiencing pleasure in situations associated with social connection and affiliation, and pain in situations involving rejection, isolation, or loss. In fact, much like even the most basic organisms, humans are fundamentally driven to approach situations that bring about pleasure and avoid situations that bring about pain. The fact that people tend to divide the world into “pleasurable or painful,” “positive or negative,” or “good or bad” suggests that valence might be one useful and potentially natural joint at which to carve the vast constellation of situations. However, human beings are quite a bit more complex than basic organisms, and as such our construal of situations critically determine whether such situations are experienced as pleasurable or painful (Funder, 2016; Tamir & Hughes, in press).

Human neuroimaging techniques, including fMRI, have begun to shed light on how complex social situations might modulate brain systems involved in encoding pleasure and pain. More recent work has extended beyond cataloguing social situations as pleasurable or painful by examining how our construal of such situations and individual difference variables determine whether situations are experienced as pleasurable or painful. In the following sections, we highlight recent advances that suggest potential similarities between the experience of basic rewards and more complex social rewards on one hand, and the experience of physical pain and more complex social and emotional pain on the other. In particular, we suggest that information from a neural level of analysis provides a complementary lens with which to examine people's natural reactions to complex social situations, and how these experiences might interact with individuals' construals and personality variables.

## **Neuroimaging Research on Positive Situations and Experiences**

Research across behavioral neuroscience, neuroeconomics, and cognitive neuroscience have characterized mechanisms associated with a slew of positive experiences and reward. Researchers have characterized a mesolimbic system and mapped interconnections between midbrain structures (e.g., ventral tegmental area, substantia nigra) and their connections with striatum (e.g., nucleus accumbens, caudate) and areas of cortex (e.g., medial prefrontal cortex) that underpin motivation and reward (Berridge, 1996; Haber & Knutson, 2010). For example, striatum activation responds to cues that predict a likely reward (e.g., the ringing of a bell before a meal) as well as to the experience of various rewards (e.g., receiving juice, wine, tasty foods, and money; Knutson et al., 2001; Delgado et al., 2000; Schultz et al., 1997).

However, as highly social beings our lives are inherently intertwined with other people, and situations that provide opportunity for social connection are also experienced as pleasurable or subjectively valuable. Indeed, a wealth of social rewards also recruits the same mesolimbic reward system as primary rewards (Bhanji & Delgado, 2014; Izuma et al., 2008; Ruff & Fehr, 2014). This observation led to the suggestion that this system might serve as a "common currency valuation system," allowing individuals to integrate across different features of positive experience (e.g., magnitude, individual preferences, social vs. nonsocial situations) into a subjective value signal that allows individuals to compare disparate positive experiences to each other (Chib et al., 2009; Grabenhorst & Rolls, 2011; Kable & Glimcher, 2007). Therefore, activity in the mesolimbic system might not only indicate the presence or absence of positive experiences, but also assign a subjective "value" to such experiences. For example, striatum activity seems to be "dose-dependent," increasing in activation along with the magnitude of a particular reward (e.g., food, wine, money) and with motivational states (e.g., hunger and satiety; Gottfried et al., 2003; Peters & Büchel, 2010). Taken together, the existence of a common valuation system in the brain provides a common metric that cuts across many diverse and disparate positive situations. Next we briefly review research that describes (1) diverse social situations that nonetheless share common underlying ingredients and (2) individual differences, construals and motivational states that modulate the subjective value of diverse positive situations.

Research on social reward began by examining the brain's response to happy or attractive faces (e.g., Spreckelmeyer et al., 2009; Cloutier, Heatherton, Whalen, & Kelley, 2008; O'Doherty et al., 2003) or thinking about loved ones (e.g., Acevedo, Aron, Fisher, & Brown, 2011; Bartels & Zeki, 2004; Hughes & Beer, 2012). For example, participants' subjective ratings of attraction to pictures of faces correlate with activity in striatum (e.g., O'Doherty et al., 2003; Cloutier et al., 2008). Tasks that ask participants to either think about their romantic partner (as compared to strangers or non-close others) or consider the positive attributes vs. negative attributes of their romantic partners recruit activity in striatum (e.g., Acevedo et al., 2011; Hughes & Beer, 2012).

Unsurprisingly, construals and individual difference variables affect striatum sensitivity to attractive or liked others. For example, men show larger striatum responses to happy and attractive faces than women (e.g., Spreckelmeyer et al., 2009; Cloutier et al., 2008). This finding is consistent with work showing that men will work harder, wait longer, and pay more money to view pictures of attractive opposite sex-faces than women (Hayden, Parikh, Deaner, Platt, 2007; Wilson & Daly, 2004). Individual differences in attachment style also modulate reward-related brain activity to happy faces. For example, individuals with avoidant attachment styles show reduced striatum activation in response to happy faces, which is consistent with preferences for distant and detached social connections of avoidantly anxious individuals (Vrtička, Andersson, Grandjean, Sander, & Vuilleumier, 2008). Finally, what people find attractive or subjectively valuable is often influenced by individual motivations and norms. For example, people tend to conform to the preferences of other people to align themselves and affiliate with them. When presented with ostensible normative preferences from peers, participants shift their preference for faces, and these shifts in preference are accompanied by activity in reward-related regions, including striatum and medial prefrontal cortex (Zaki et al., 2011). Together, these and other findings exemplify the tendency for differences in construal and motivation to influence pleasurable or positive experiences as well as neural sensitivity to such experiences in reward-related brain systems.

People also enjoy learning good things about themselves from others. People generally wish to feel good about themselves, a motivation that deems positive feedback about the self particularly rewarding. Research shows that striatum and medial prefrontal responses increase when people receive positive feedback about their personalities or social standing from peers (e.g., Izuma et al., 2008; Korn et al., 2012; Somerville et al., 2010; Zink et al., 2008), feel understood by other people (Morelli et al., 2014), and learn that other people like them and want to meet them (e.g., Cooper et al., 2013; Hughes et al., 2018).

However, people differ in their individual motivations to be liked or feel good about themselves, variables which influence the construal of feedback. For example, individuals with low self-esteem might experience positive feedback as more unexpected and valuable than individuals with high self-esteem (vanDellen et al., 2011). Interestingly, individual differences in self-esteem modulate reward-related brain activity in medial prefrontal cortex in response to positive versus negative feedback (Somerville et al., 2010). Other research found that receiving positive feedback from peers was experienced as valuable and associated with increased striatum activation to the extent that individuals liked the source of the feedback (Hughes et al., 2018). In this study, male participants received feedback about their attractiveness from women. Striatum activation increased in response to positive feedback, but *only* when such feedback came from more important, well-liked targets and not from disliked targets. Moreover, this striatum response to feedback predicted an increase in subsequent attraction to the well-liked targets, providing a mechanism for a positive feedback loop for perpetuating more motivationally meaningful interactions. These and other findings suggest that whether positive feedback is experienced as valuable critically pivots on individual motivations and construals of feedback itself, or the sources of such feedback.

Finally, individuals inherently value and seek out opportunities to cooperate with others (Rand & Nowak, 2013; Zaki & Mitchell, 2013). Fairness and cooperation bolster social connections between people and provide opportunities to affiliate and bond with others. Research that uses behavioral economics methods (see previous discussion in Part II) finds that reward-related activity in the striatum increases when receiving rewards from cooperative decisions (e.g., King-Casas et al., 2005; Rilling et al., 2002). Moreover, winning a reward by cooperating with a partner results in larger increases in striatum activity than winning an equivalent reward alone or in a non-social context (e.g., by cooperating with a computer; Rilling et al., 2002; Sanfey et al., 2003). This and

other research on vicarious and shared rewards suggests that individuals value the experience of cooperation above and beyond the monetary rewards that might result from such cooperation (Tabibnia & Lieberman, 2007).

Of note, the value that people place on cooperation is modulated by individuals' construals of the situation and their interaction partners. For example, people tend to cooperate more frequently and exhibit larger striatum responses with their friends than with strangers, even in contexts where friends and strangers reciprocate equally (Fareri, Chang, Delgado, 2012). In other contexts, the value people place on cooperation can conflict with long-standing parochial preferences (Balliet, Wu, & De Dreu, 2014). That is, trust and cooperation often break down across group boundaries when individuals are required to interact with members of other groups (Brewer, 1999; Levine, Prosser, Evans, & Reicher, 2005). In these contexts, cooperation with ingroup, but not outgroup members produces reward-related activity in striatum (Hughes et al., 2017; Hackel et al., 2017). Thus, the inherent social value placed on cooperation often hinges on our construals of the situation, for example across varied intergroup and interpersonal contexts.

Taken together, the work reviewed highlights commonalities across diverse positive social experiences and suggests a common fabric that cuts across them. Although often considered unique, a vast array of positive social situations are bound together by underlying subjective value mechanisms and reward-related brain activity. Signals in the striatum, medial prefrontal cortex, and other mesolimbic brain structures play a central role in signaling the social value of situations and experiences, and motivate social behavior toward such experiences. Activity in these brain networks is also modulated by the construal of social and interpersonal contexts that might critically increase or decrease the inherent value individuals place in these experiences, allowing for a flexible evaluation of the social world. Overall, these findings highlight one potential key with which to unlock hidden commonalities across diverse social situations.

## **Neuroimaging Research on Negative Situations and Experiences**

### **Contextual effects on physical pain**

Physical pain is the most basic and universal negative experience. We all know what it feels like to stub our toe, burn our hand, or get a sudden cramp. Acute pain is reported at some time by virtually all adults in the world, across the span of social class, ethnicity, and race. It is the single most frequent complaint brought to a physician's office in North America (Osterweis et al., 1987). The brain regions and neural pathways that are involved in perceiving pain, or nociception, are highly conserved in animals from rodents to humans and reliably activated by changes in the intensity of noxious input (Apkarian, Bushnell, Treede, & Zubieta, 2005). Traditionally, pain has been considered a true perception of the bodily state. However, current accounts demonstrate that the context in which noxious stimuli are received greatly influence how much pain is experienced. These accounts show that pain in humans is modifiable not only by the intensity of a stimulus, but also by top-down cognitive and psychosocial contexts (Benedetti, Mayberg, Wager, Stohler, & Zubieta, 2005; Michalska et al., under review; Wager & Atlas, 2015). At the neural level, pain is widely thought to emerge from a distributed pain processing network (PPN), whose inputs include sensory (e.g., periaqueductal gray, secondary somatosensory cortex), as well as affective (e.g., dorsal-posterior insula, anterior insula) and evaluative (e.g., dorsal anterior cingulate cortex, dACC) processes (Wager et al., 2013).

Using a variety of brain-mapping technologies, there is mounting evidence that various forms of instruction, such as stimulus expectancies and placebo effects, influence currently available brain markers of nociception. For instance, expectations about upcoming pain cause neurobiological changes in the PPN independent of noxious

stimulus intensity. One study employed conditioning and verbal information to induce expectations about noxious heat intensity as a function of auditory tones (Atlas, Bolger, Lindquist, & Wager, 2010). The key manipulation in this study was the effect of auditory cues predicting either low or high heat stimulation on a matched, medium, heat stimulation condition. Adult participants reported feeling more pain after the high cue than the low cue even though the heat stimulus was identical between those conditions. Correspondingly, almost all brain regions that showed differential responses as a function of temperature also showed congruent differential responses as a function of cues predicting either low or high heat stimulation. Expectancy effects on these regions were in turn mediated by anticipatory responses in ventral striatum and medial OFC; regions that have been studied in the context of value-based learning in both appetitive and aversive domains across humans and animal models (Atlas et al., 2010). These data, and those from other studies, show that nociceptive brain regions are modulated by expectations (Tracey, 2010; Atlas & Wager, 2014; Salomons, Johnstone, Backonja, & Davidson, 2004; Salomons, Johnstone, Backonja, Shackman, & Davidson, 2007). Recently, this work has been extended behaviorally to healthy and anxious children (Michalska et al., 2018), demonstrating that participants across age and anxiety symptoms show robust expectancy effects on the experience of thermal pain. While neural measures were not collected in this recent study, data suggest that pain modulation may not depend on the maturation of prefrontal cortex, as robust modulation was found throughout development. Rather, modulation might instead depend on subcortical processes linked with learning and endogenous pain modulation, although more work is needed (Wager & Atlas, 2015).

A related phenomenon is placebo analgesia, in which the belief that one is receiving an effective analgesic treatment can reduce pain (Colloca, Flaten, & Meissner, 2013). Placebo effects on pain are controlled by the endogenous opioid system and typically accompanied by reduced activity in the PPN (Meissner et al., 2011; Wager & Atlas, 2015; Wager & Fields, 2013, although see Geuter, Eippert, Attar, & Büchel, 2013). Such effects are paralleled by increased activity in another set of brain regions, including dlPFC, OFC, and vmPFC (Benedetti et al., 2005; Eippert et al., 2009; Meissner et al., 2011; Colloca et al., 2010; Petrovic et al., 2010; Wager & Atlas, 2015). These areas are thought to be involved in the maintenance of beliefs, the representation of value, and the regulation of nociceptive processing (Fields, 2004; Loggia, Mogil, & Bushnell, 2008; Tracey, 2010). More recently Wager and colleagues (2011) have demonstrated that the effectiveness of a placebo response can be reliably predicted from the pattern of neural activity.

## **Contextual Effects on Social Pain**

In the same way that physical pain is experienced as aversive, most, if not all of us, can attest to the fact that as highly social beings, human beings also experience some social situations as aversive. These include witnessing pain in others (Lamm, Decety, & Singer, 2011; Michalska, Kinzler, & Decety, 2013), social rejection (Kross, Berman, Mischel, Smith, & Wager, 2011; Eisenberger, 2015b), and negative interpersonal feedback (Somerville et al., 2006, 2010). All these experiences share underlying components with physical pain, although social and nociceptive experiences may not in fact share exact pain-specific processes, but rather reflect some nonspecific features of arousal and attention (Iannetti, Salomons, Moayedi, Mouraux, & Davis, 2013; Woo et al., 2014).

Evidence in humans suggest at least some overlap between nociceptive and empathic pain (Decety & Michalska, 2010; Michalska et al., 2013). Witnessing others in pain can create or intensify signs of nociceptive pain and individuals with congenital insensitivity to nociceptive pain exhibit blunted responses to empathic pain (Danziger, Prkachin, & Willer, 2006). Neuroscientists have further demonstrated that brain structures, such as anterior insula and parts of the cingulate cortex, commonly respond when humans experience nociceptive and empathic pain (see



Lamm et al., 2011 for a meta-analysis). Brain responses to others' pain in AI and ACC correlate with subjective experiences of pain empathy (Kanske, Böckler, Trautwein, & Singer, 2015) and willingness to take on burdens to reduce others' pain (Hein, Silani, Preuschhoff, Batson, & Singer, 2010). Finally, brain responses to empathic pain diminish after placebo analgesia (Rütgen et al., 2015). Just as with physical pain, here too we see modulation of the PPN by psychosocial contexts. For instance, attitudes toward outgroup members moderate neurological resonance to out-group pain: lamentably, participants exhibit less engagement of pain networks when viewing outgroup members (Decety, Echols & Correll, 2010; Xu et al., 2009).

Several influential fMRI studies have also indicated that physical pain and social rejection activate some common brain networks, raising the possibility that the neural response to social rejection co-opts components of the well-established physical pain signature in the brain (Eisenberger, 2012). Cues of rejection have reliably been shown to activate a network of so-called "social pain" regions that overlaps with the neural response to nociceptive stimulation and primarily includes the dACC and the anterior insula. Recent more fine-grained analysis techniques have argued that the observed overlapping activity is more likely to arise from distinct neural representations that are co-localized at the gross anatomical level (Woo et al., 2014). Nonetheless, while common activation does not necessarily imply identical shared neural representations, it remains plausible that the overlap reflects common regulatory responses to general aversive events. This view is supported by pharmacological findings. For instance, effects on rejection experience of pain medications like acetaminophen (Mischkowski, Crocker, & Way, 2016) suggest that similar neurochemical responses to pain and rejection (e.g., endogenous opioids) may be related to nonspecific neurochemical pathways for aversive affective states. More provocatively, emerging research argues that the classic social pain network in the human brain, centered on the dACC and AI, shows similar patterns of sensitivity to signals of social inclusion as it does to social rejection (Dalgleish et al., 2017). If replicated, such findings will have strong theoretical implications for our understanding of the role of this neural network in social cognition, consistent with the idea of a dedicated system that gauges the implications of all pertinent social information with respect to an individual's social inclusion status.

## **Conclusion and Future Challenges**

Our goal in this chapter was to illuminate both the unique opportunities and inherent limitations of taking a neuroimaging approach to the study of situational influences on human behavior. As social and developmental neuroscientists, we believe that neuroimaging provides a valuable complementary level of analysis to behavioral approaches to understanding social situations. Neuroimaging provides the unique opportunity to assess situational experience directly, in real-time, and to potentially identify mechanistic overlap between psychological processes typically considered distinct. Nonetheless, several challenges remain. Most prominently, neuroimaging studies of positive and negative situations in humans rely on well-controlled manipulations collected under unnatural and constrained conditions. Most of these manipulations are only mildly rewarding or aversive when compared to the kinds of rewards and stressors encountered in daily life. Therefore, addressing the fundamental questions raised in this chapter requires integrating assays of brain function with measures of positive and negative affect assessed under more naturalistic conditions (Laidlaw, Foulsham, Kuhn, & Kingstone, 2011; Perez-Edgar, McDermott et al., 2010; Pfeiffer, Vogeley, & Schilbach, 2013) or in real-world settings (e.g., Berkman & Falk, 2013; Henrich et al., 2001, 2006). We hope to encourage researchers to harness these approaches to build an interdisciplinary science that can unlock new insights into understanding situational experience and its neural, developmental, and psychological roots.

# Acknowledgments

We thank Alexander Shackman for helpful comments on the manuscript.

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