‘Emotional intelligence’: Lessons from lesions

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Abstract

'Emotional intelligence' (EI) is one of the most highly used psychological terms in popular nomenclature, yet its construct, divergent, and predictive validities are contentiously debated. Despite this debate, the EI construct is comprised of a set of emotional abilities—recognizing emotional states in self and other, using emotions to guide thought and behavior, understanding how emotions shape behavior, and emotion regulation—that undoubtedly influence important social and personal outcomes. In this review, evidence from human lesion studies is reviewed in order to provide insight into the necessary brain regions for each of these core emotional abilities. Critically, we consider how this neuropsychological evidence might help to guide efforts to define and measure EI.

Keywords: Human Lesion Method, Emotional Intelligence, Emotion Recognition, Empathy, Affective Theory of Mind, Emotion Regulation.

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Emotional Intelligence (EI)

A longstanding goal in psychology and neuroscience has been to elucidate the mechanisms that enable individuals to interpret and respond to their environment in an adaptive manner. Traditionally, this pursuit has focused on critical cognitive abilities—verbal comprehension, perceptual organization, reasoning, problem solving, etc.—and their integration into a latent underlying construct, often referred to as ‘*general intelligence*’ or ‘*g*’ [1,2]. However, the degree to which general intelligence alone can predict important personal and social outcomes has been called into question, with research suggesting that it is an insufficient predictor of upward social mobility, career success, and creative achievement [3–5]. Accordingly, applied research has recently shifted its focus to the study of “emotional intelligence” (EI), referring to a set of emotional abilities purported to predict success in the real world above and beyond general intelligence. Evidence suggests that high EI is associated with improved mental health [6], better social problem solving [7], superior relationship quality [8], and enhanced academic and job performance [9,10]. As such, educators and consultants have devoted significant efforts to the development of tools to promote EI [11].

EI has been widely adopted in both basic research and applied fields, yet there is a lack of clarity in the field with respect to how EI should be defined and measured. Two of the most influential EI theories are Bar-On’s mixed model and Mayer and Salovey’s integrative model. According to Bar-On’s mixed model, EI is defined as an array of ‘noncognitive abilities,’ which influence an individual’s adaptive success by shaping their interpretation and response to environmental demands and pressures [12]. However,

the use of the term *noncognitive* to define EI is problematic for several reasons, including the fact that emotional abilities must rely upon ‘cold’ cognitive systems (e.g., metacognition in emotional awareness, stimulus-driven attention in emotion recognition, etc.). Additionally, many of the noncognitive abilities incorporated into the mixed model are tangential to the established research literatures on emotion and intelligence, resulting in a heterogenous set of dimensions that are difficult to integrate into a cohesive EI construct [13]. Perhaps most concerning, the mixed model’s divergent validity is weak, with 62% of the variance on its companion Emotional Quotient Inventory (EQ-i) being accounted for by general intelligence and the Big Five personality traits [14]. In the integrative model, Mayer and Salovey [15] define EI as the confluence of a set of emotional abilities that enable individuals to *“carry out accurate reasoning about emotions and the ability to use emotions and emotional knowledge to enhance thought”* [13]. Data from the integrative model’s companion measurement tool [Mayer-Salovey-Caruso Emotional Intelligence Test, MSCEIT; 18] correlate with general intelligence, but variance explained by other measures is reduced relative to the EQ-i (14%), suggesting that the integrative model has preferable divergent validity [14]. Additionally, the MSCEIT is a performance-based measure, whereas mixed models of EI often deploy self-report measures (e.g., EQ-i). In performance-based methods, the goal is to measure how well participants perform tasks and solve problems related to emotions, whereas in self-report methods individuals rate their level of agreement with descriptive statements about their own emotional abilities [17]. The performance-based approach is typically preferred in the domain of intelligence research, as it attempts to objectively isolate maximum performance (i.e., ‘ability’) in a way that is compatible with

the intelligence construct [17]. Thus, for several reasons, empirical research on EI has typically favored Mayer and Salovey's integrative or 'ability-based' model of EI, whereas Bar-On's mixed model and related approaches are more often found in applied fields.

Akin to a lack of consistency in behavioral research on EI, neuroimaging studies have revealed similarly unclear results. There are six studies that have directly investigated EI on the *Neurosynth* online neuroimaging archive [16¹], and we conducted a miniature meta-analysis using these studies to determine whether any particular brain regions have been *reliably* associated with EI. Regions-of-interest (ROI) were manually constructed based on the relevant neuroimaging tables reported in each paper, and these ROIs were placed on a glass brain to visualize the degree of overlap between the six papers. The resulting figure revealed a striking level of inconsistency in brain regions that have been implicated using traditional measures of EI (**Figure 1A**). Therefore, inconsistencies in both the behavioral and functional neuroimaging data make it difficult to establish the neurocognitive factor structure of EI.

Goals and Structure of the Present Review

The field is in need of a clearer delineation of EI's constituent emotional abilities and some evidence that these abilities rely on a common network of brain regions which would provide support for the assertion that they can be integrated into an overarching EI construct. The present review aims to accomplish these two goals. First, the review is organized according to the four domains of emotional ability that are included in all models of EI: i) recognizing emotional states in the self and in others, ii) using emotions to facilitate thought and behavior, iii) understanding how emotions shape one's own behavior and the behavior of others, and iv) regulating one's own emotions and the

¹ <http://neurosynth.org/analyses/custom/a83a4072-85d4-4fd1/>

emotions of others [19]. By clearly outlining the component emotional abilities that are common to all EI theories, we aim to provide a clear definition of EI that represents a consensus across the various working models of this construct. Second, the review aims to summarize human lesion studies that provide insight into the network of brain regions that are reliably implicated across these component emotional abilities. In the domain of general intelligence, human lesion studies have provided critical evidence that damage to a fronto-parietal network leads to disruptions across a range of higher-order cognitive abilities, providing support for the presence of a core underlying *g* factor [20,21]. Similarly, over the past few decades, research into the impairments and psychosocial consequences of focal brain injuries have helped to elucidate a network of brain regions that appear to be critical across a range of emotional abilities. The first section of this review outlines the key findings from this literature. Then, the next section considers existing methods used to measure EI, and how human lesion studies might inform future research on how to conceptualize and measure EI.

Mapping the Four Component Abilities of EI

i. Recognizing emotional states in self and other.

Emotional awareness.

Conscious recognition of our own feelings, or '*emotional awareness*,' is an important emotional ability, evidenced by the consequences of its dysfunction in individuals with high levels of 'alexithymia,' a subclinical condition primarily defined by impaired emotional awareness [22]. Alexithymia can be acquired in patients with traumatic brain injuries (TBI), with increased alexithymia severity negatively impacting TBI patient outcomes [23,24]. A recent study examined alexithymia levels in a large

sample of patients with focal, penetrating TBI (Vietnam Head Injury Study, VHIS; **Box 1**) in order to establish the brain regions underlying emotional awareness. Patients with substantial damage to the anterior insula (AI) had heightened levels of alexithymia relative to patients with minimal AI damage, patients with no AI damage, and matched control subjects [**Figure 2A**; 25]. Further, the extent of damage to the AI significantly predicted the severity of acquired alexithymia, after controlling for damage to an adjacent region also thought to play a role in emotional awareness [anterior cingulate cortex, ACC; 26]. ACC also appears to play a role in emotional awareness, as cingulotomy patients demonstrate significant reductions in feelings of tension and anger following removal of supracallosal sectors of the ACC [27]. These findings are in agreement with theoretical and neuroimaging work suggesting that the AI integrates ascending signals about the state of one's own body (i.e., interoceptive signals, such as heart rate and skin conductance), which are sent to ACC in order to initiate the selection and planning of motor and non-motor (e.g., change in cognitive set or top-down regulation of sensory processing) responses to emotional events [28]. The conjoint activity of these two regions is thought to play a critical role in the generation of subjective emotional experience [28–30]. In addition, two recent case studies suggest that alternative interoceptive pathways (via somatosensory cortex and the brain stem) can enable some aspects of emotional awareness in patients with AI and ACC damage [31,32].

Lastly, ventromedial prefrontal cortex (vmPFC; including the ventral sector of mPFC, medial orbitofrontal cortex, and perigenual and subgenual anterior cingulate cortex) appears to play a role in emotional awareness as well. Patients with vmPFC

lesions show diminished experience of regret following unfavorable decision outcomes [33], and reduced emotional intensity in day-to-day life [34]. Although vmPFC's role in emotional awareness is a topic of ongoing investigation, based on what is known about this region's involvement in reward processing (see **Box 2**) it is possible that vmPFC computes the reward value of interoceptive states and links them to exteroceptive events [35].

Emotion recognition.

In addition to emotional awareness, the ability to recognize the emotions of others is essential to social interaction, and evidence from focal lesion studies has helped to chart the neural bases of emotion recognition. This work has reliably demonstrated that amygdala lesions disrupt the ability to recognize emotional facial expressions [36–38]. There is controversy surrounding whether this emotion recognition function of the amygdala generalizes to other modalities such as prosody. Some groups have found intact emotional prosody recognition in patients with amygdala damage [39], whereas others have shown significant impairments [40]. Bilateral amygdala damage does not seem to impact the *execution* of emotional facial expressions or emotional awareness [41,42], suggesting that this structure plays a specific role in processing emotionally salient exteroceptive stimuli (e.g., observed facial expressions of others). Accordingly, it has been argued that the amygdala acts as an amplifier that biases activity at downstream cortical targets to prioritize processing of salient stimuli [43,44].

One downstream target of the amygdala during emotion recognition appears to be the vmPFC. vmPFC damage negatively impacts the ability to recognize emotional states from both facial stimuli and prosodic cues [45,46]. Interestingly, a recent eye-

tracking study suggests that this impairment is driven by reduced visual attention to the eyes of others [**Figure 2B**; 45,47]. This study suggests that reciprocal interactions between the vmPFC and the amygdala are crucial for detecting and representing motivationally salient stimulus events [45].

Lesion studies have implicated brain regions involved in interoception and emotional awareness as also playing a role in emotion recognition. Specifically, lesion studies have implicated somatosensory cortex, insula, and the ACC in emotion recognition [48–50]. A recent voxel-based lesion-symptom mapping (VLSM) study found that the AI and the ACC play a critical role in emotion recognition across both pleasant and unpleasant emotion categories [50]. These VLSM results were replicated by another study of patients with focal resections of the insular cortex, who demonstrated impaired performance at recognizing facial cues related to fear, happiness, and surprise [51]. Collectively, the finding that brain regions necessary for first-person emotional experience are also necessary for emotion recognition is compatible with the ‘simulation hypothesis’ [i.e., that representing the emotional states of others engages the brain networks involved in representing emotional states in the self, possibly mediated by the activation of the human mirror neuron system; 52]. However, none of these studies specifically looked at emotional awareness and its relation to recognition [c.f., 53], and more work is required to provide stronger evidence for this hypothesis.

ii. Using emotions to facilitate thought and behavior.

Empathy and prosocial behavior.

Whereas emotion recognition is a critical source of incoming social information, it does not necessarily drive behaviors in response to that information (e.g., consider a

hypothetical situation in which an individual recognizes unhappiness on the face of a disliked other—recognition in this case will not necessarily provoke a prosocial behavioral response). Beyond recognition, affective empathy is a catalyst through which another person's emotions can influence and mobilize social behavior. Affective empathy refers to the ability to share the emotional state of another person, and it is a critical source of motivation driving individuals to perform prosocial behaviors intended to benefit the other [54,55]. Diminished affective empathy following brain injury has consistently been observed in patients with ventrolateral prefrontal cortex [vLPFC; 56,57] and insular lesions [57,58]. For example, a sample of 192 patients from the VHIS (**Box 1**) completed the Balanced Emotional Empathy Scale, a 30-item questionnaire designed to measure affective empathy as a single factor, and a VLSM analysis demonstrated significantly reduced emotional empathy in patients with damage to a network of brain regions, including vLPFC, insula, and temporoparietal junction [TPJ; 57]. Involvement of this network in affective empathy is compatible with the 'Self to Other Model of Empathy'. According to this model, empathy relies upon both the ability to match others' emotional states in the self (i.e. emotional contagion, implemented by vLPFC and insula), and the ability to prioritize processing of self- and other-related representations according to context demands and individual goals [i.e., self-other control, implemented by TPJ; 59].

Emotional memory.

The strong influence of emotions on memory is critical to the ability to use emotions to shape thinking and behavior. People have superior memory for emotional events relative to neutral ones, with emotional memories being significantly less likely to

be forgotten over time [60]. Emotional memory is impaired following lesions to the medial temporal lobes (MTL) that encompass the amygdala, hippocampus, and perirhinal cortex [61,62]. Yet, this change in emotional memory following MTL lesions is driven by amygdala damage, as patients with hippocampal lesions and an intact amygdala either show a normative emotional memory enhancement [63], or are impaired on *both* memory for neutral and emotionally salient stimuli [64]. Emotional enhancement in memory consolidation has important social consequences, and patients with amygdala damage end up having a difficult time learning the important traits of others [e.g. trustworthiness, likeability, and competence, **Figure 2C**; 62]. It has recently been argued that the amygdala plays a role in coordinating the enhanced consolidation and recall of emotionally salient information relative to more affectively neutral contextual information [60], similar to the way it amplifies processing of salient information online during emotion recognition tasks [43].

iii. Understanding how emotions shape one's own behavior and the behavior of others.

Understanding how emotions shape our own behavior and the behavior of others is related to an ability known as affective 'Theory of Mind' (ToM), which is a critical milestone in the development of effective social and emotional abilities [65]. Cognitive ToM refers to the ascription of mental states to the self and others, commonly measured by having participants observe or read stories about another individual's behavior, and then asking them to make judgments about their underlying motivations. Hence, affective ToM is the ability to infer that the thoughts and behaviors of others are influenced by underlying *feelings*, and to interpret those feelings by relying upon their

understanding of how emotions shape their own thoughts and behaviors. Multiple human lesion studies have found affective ToM to be impaired in patients with vmPFC lesions [66,67]. For instance, one study found impaired recognition performance on the 'Faux Pas Task' in 30 patients with vmPFC lesions, relative to both patients with damage to other brain regions and healthy controls [66]. Faux pas recognition requires the ability to recognize when someone says something that is inappropriate or insulting in a social context, which requires the ability to ascribe an emotional response to the listener. The results clearly demonstrated that vmPFC patients, particularly left vmPFC patients, were significantly less able to correctly recognize social faux pas relative to patients with damage to other brain regions and healthy controls [**Figure 2D**; 66]. Prefrontal involvement in faux pas recognition appears to be restricted to medial sectors, as another study replicated the finding that vmPFC damage disrupts faux pas recognition performance, but this ability was preserved in patients with dorsolateral PFC damage [68]. Patients with bilateral amygdala lesions are also impaired on faux pas recognition [69], but the precise role of this region and its network-level interactions with vmPFC that might support affective ToM are currently unclear (see **Outstanding Questions**).

iv. Emotion regulation.

The last emotional ability central to the EI construct is emotion regulation, which refers to the set of operations involved in modulating ongoing emotional responses in accordance with individual or social goals. This ability is critical to mental health and social functioning, as emotion regulation deficits have been linked to aggressive behavior, anxiety, and depression [70]. Such affective psychopathologies are commonly

attributed to dysfunctional emotion regulation, including an overreliance on maladaptive strategies (e.g., avoidance of anxiety-provoking situations, or suppression of emotional facial expressions in such situations), and diminished use of adaptive strategies [e.g., acceptance of negative feelings, or reappraisal of such feelings to give them a less aversive interpretation; 70]. Signs of dysfunctional emotion regulation have been observed in individuals with acquired brain injury, particularly patients with vmPFC lesions [71,72]. For example, patients with vmPFC damage (specifically, patients with medial orbitofrontal cortex damage) demonstrate significantly greater electrophysiological responses (P3 component) to emotionally-salient stimulus events relative to non-brain-injured controls, and fail to attenuate these responses over time [Figure 2E; 73]. This impaired regulation of emotional responses has significant social consequences for vmPFC patients: they reject offers to share money with greater frequency than controls [74], are rated highly on several traits that hinder social rapport [e.g., irritability, inappropriate affect, etc.; 76], and fail to monitor and regulate the emotional states of others [e.g., reduced frequency of apologies; 75]. Additionally, vlPFC and amygdala lesions have also been found to disrupt emotion regulation abilities [77,78]. These findings are compatible with an extensive functional neuroimaging literature suggesting that network-level interactions between vlPFC, vmPFC, and amygdala are involved in successful emotion regulation [e.g., 79].

Lesion-mapping the brain bases of EI

Human lesion studies have clearly identified a core network of brain regions that are reliably implicated across a range of emotional abilities, including amygdala, anterior insula, anterior cingulate cortex, and ventromedial prefrontal cortex (Figure 1B). A

critical outstanding issue is whether measures designed to directly assess *EI* are also impaired in individuals with damage to these regions. In this vein, several recent lesion-mapping studies have investigated the neural basis of EI, measured using the MSCEIT [16]. For example, Krueger and colleagues found that vmPFC damage critically impaired the ‘strategic’ factors of the MSCEIT, referring to one’s abilities to understand and regulate emotional responses in the self and others [80]. In addition, Barbey and colleagues recently used a combined latent variable and VLSM approach to first confirm the hierarchical factor structure of the MSCEIT, and then to elucidate the network of brain regions involved in EI. This work found that EI scores on the MSCEIT are reduced following damage to a distributed network, including vmPFC, vlPFC, insula, ACC, as well as several other parietal and temporal brain regions [81,82]. The fact that lesion-mapping studies of the MSCEIT implicate a network of brain regions broadly consistent with studies that focus on its constituent emotional abilities provides preliminary support for the presence of an overarching EI construct.

How Can Human Lesion Evidence Inform Research on EI?

Problems with existing EI assessment tools

Before considering how human lesion studies might inform efforts to define and measure EI, it is important to reconsider existing EI assessment tools. The most widely used measures of EI are Bar-On’s EQ-i [12] and Mayer and Salovey’s MSCEIT [16]. The EQ-i is a self-report EI measure that is suggested to have good internal and test-retest reliability [split-half reliability = 0.86; test-test reliability = 0.85; 12]. However, the self-report nature of the EQ-i runs counter to the conventional wisdom in the intelligence field, wherein this approach is generally avoided in order to prevent the unwanted

influence of self-serving bias in participant responses [17]. Instead, most general intelligence assessment tools ask participants to perform some sort of behavioral task designed to probe a given function as quickly and accurately as possible, and use objective measures (e.g., accuracy, reaction times, etc.) to operationalize the corresponding cognitive ability. This 'performance-based' approach is adopted in the MSCEIT, a tool which also demonstrates strong internal and test-retest reliability [0.91, 0.86; 16]. Worryingly, self-report and performance-based measures of EI demonstrate poor convergent validity, with studies often finding a nonsignificant correlation between EQ-i and MSCEIT total scores [14,83]. In addition to issues of convergent validity, these scales demonstrate problems with divergent validity, and are significantly predicted by established measures including Wechsler's full-scale IQ and the Big Five personality traits [14,84].

Despite issues with convergent and divergent validity, a key argument put forth in favor of measuring EI as a complement to IQ and the Big Five is that it has good predictive validity for important social and personal outcomes. EI has been found to predict empathy, psychological well-being, life satisfaction, success in negotiation, and interpersonal relationship quality [85]. Perhaps the largest literature on EI is in the areas of educational and industrial/organizational psychology, with several studies suggesting that EI predicts academic and workplace success [9–11,86]. However, the utility of EI for predicting success at the workplace has been called into question based on a lack of empirical evidence [87], and meta-analyses have suggested that EI has modest predictive validity for both academic ($\rho=0.23$) and workplace ($\rho=0.30$) outcomes [88,89].

Therefore, the convergent, divergent, and predictive validities of current methods for defining and measuring EI have recently been called into question.

Neurocognitively-informed methods for studying EI.

Despite criticisms leveled against common EI theories and assessment tools, the clinical literature on emotional dysfunction in brain-injured patients is clear: the emotional abilities that comprise EI are *crucial* for day-to-day personal and social functioning. For example, impaired emotional awareness following brain injury has been associated with increased suicidal ideation, increased anxiety sensitivity, and reduced social relationship quality [24,90,91]. Similarly negative outcomes are observed in patients with impaired emotion regulation abilities following a TBI, including increased anxiety and depression, and disrupted social interaction skills [71,75]. Thus, emotional abilities appear to play a role in enabling adaptive day-to-day social and personal functioning, which is compromised in brain-injured patients with impaired emotional abilities. This suggests that EI, if measured effectively, might be associated with important outcomes in the real world that could motivate targeted intervention strategies to improve EI.

In this light, the contentious debate surrounding the validity of EI appears to be misguided. Instead, in our view, research should shift towards empirically validating the hypothesized component structure of emotional ability outlined in the present review (i.e., perceiving emotions in self and other, using emotions to guide thinking and behavior, understanding how emotions influence our own and others' behavior, and regulating emotional responses in self and other). The data from human lesion studies implicate a consistent network of brain regions—including amygdala, vmPFC, insula, and

ACC—across multiple component emotional abilities (**Figure 1B**). These brain regions are part of an ‘emotion network’ that is frequently identified in functional neuroimaging studies of human emotion [see **Outstanding Questions**; 92]. The involvement of a core network of brain regions across distinct emotional domains is compatible with the suggestion of a general overarching EI. However, this hypothesis needs to be evaluated through careful experimentation. Such work could address two crucial questions to help advance this field: Is EI distinct from, or integral to, general cognitive ability? And, to what extent can EI be summarized by a single underlying factor?

Regarding the first question, early theories of emotional and social intelligence attempted to distinguish these abilities from cognitive intelligence [15,93]. Yet, this degree of functional separation seems untenable. Indeed, recent advances in psychology and neuroscience have reliably suggested that emotion and cognition are very much integrated in the brain, combining to shape goal-directed behavior [81,94,95]. For instance, a recent VLSM study suggested that many of the brain regions involved in EI overlapped with those implicated in general intelligence, with a strong behavioral association between the two measures [81]. This suggests that the relationship between emotional and general intelligence may in fact be enmeshed, with EI measuring individual differences in one’s ability to integrate emotions into cognitive operations (e.g., using reward valuations to drive the items held in working memory, using inhibitory control to regulate aversive emotional reactions, etc.).

Regarding the second question, despite agreement that EI is likely made up of several component abilities [12,16], the extent to which these abilities are inter- or independent needs to be established. At present, it is unclear whether all of the

emotional abilities summarized in the present review can be integrated into a single underlying EI variable—i.e., resembling an EI continuum across the general population (**Figure 3A**). Alternatively, such work might instead reveal that EI is a heterogeneous blend of several contributing variables, in which case researchers might be better served measuring individual differences in multidimensional EI space (**Figure 3B**). These questions of whether cognitive and emotional intelligences are integrative or dissociable, and whether EI exists on a continuum or a multidimensional space, would have tremendous applied value, enabling consultants, educators, and medical practitioners to build EI assessment tools and training programs with improved convergent, divergent, and predictive validities.

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Figure Captions

Figure 1. (A) Areas of activation associated with various EI scores from previous functional neuroimaging studies (<http://neurosynth.org/analyses/custom/a83a4072-85d4-4fd1/>). **(B)** Core brain regions implicated in multiple emotional abilities by human lesion studies.

Figure 2. (A) Anterior insula damage is linked to significant impairments in emotion recognition in the self [Figure adapted from 25], and **(B)** amygdala and vmPFC damage are linked to impaired recognition of others' emotions, perhaps due to reduced orienting toward the eyes [Figure reproduced with permission from 45,47]. **(C)** Emotional memory enhancement is diminished in patients with amygdala damage, resulting in an impaired ability to learn the personality traits of others in amygdala patients. In contrast, this ability is preserved in a patient with medial temporal lobe damage but an intact amygdala [Figure reproduced with permission from 56]. **(D)** vmPFC patients also have difficulty understanding the emotional mental states of others, as evidenced by reduced Faux Pas recognition accuracy [Figure reproduced with permission from [66]. Lastly, **(E)** patients with medial orbitofrontal cortex (OFC, a region within vmPFC) damage demonstrate impaired regulation of electrophysiological responses to aversive somatosensory stimulation relative to control participants [Figure reproduced with permission from [73].

Figure 3. Schematic representations of **(A)** a two-dimensional continuum view of EI, and **(B)** a multi-dimensional EI space comprised of at least four component emotional abilities.

Appendices

Appendix I – Glossary.

Alexithymia: A subclinical condition characterized by diminished conscious access to one's own emotional states, and difficulty describing one's emotions to others. Can be either 'developmental'—as in individuals with comorbid alexithymia and autism spectrum disorders—or 'acquired'—as in patients with traumatic brain injury.

Emotional awareness: The conscious experience of discrete emotional states (also referred to as 'feelings').

Emotional Intelligence (EI): A set of core 'emotional abilities' that enable individuals to interpret and respond to the emotional states of themselves and others in order to adaptively shape thought and behavior.

Emotional Quotient Inventory (EQ-i): A self-report emotional intelligence (EI) inventory that accompanies the Bar-On mixed model of EI [11]. This test includes 133-items that yield five primary scales with 15 total sub-components: i) intrapersonal scale (self-regard, emotional self-awareness, assertiveness, independence, and self-actualization), ii) interpersonal scale (empathy, social responsibility, and interpersonal relationships), iii) adaptability (reality testing, flexibility, and problem solving), iv) stress management (stress tolerance, and impulse control), and v) general mood (happiness, and optimism).

Iowa Gambling Task (IGT): A decision-making task that is sensitive to vmPFC patient deficits. Participants select between four decks of cards, two of which have a high probability of losses coupled with a low probability of large rewards (disadvantageous net loss decks), whilst the other two have a high probability of small rewards and a low probability of losses (advantageous net win decks). Patients with vmPFC damage select from the disadvantageous decks more often than controls [96].

Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT): A performance-based measure of emotional intelligence (EI) that is a companion to the Mayer and Salovey integrative model of EI [91]. The test consists of four sections of two tasks each, designed to assess each of the capacities of the integrative model (i.e., perceive emotions, understand emotions, use emotions, and manage emotions) to attain one overall EI score. The MSCEIT can also be broken down into two area scores: experiential EI (comprised of the ability to perceive emotional states in the self and others, and the ability to use emotions to facilitate thought and behavior), and strategic EI (comprised of the ability to understand emotions and their changes in oneself and others, and the ability to manage emotion efficiently and effectively).

Ventromedial prefrontal cortex (vmPFC): Ventromedial sectors of prefrontal cortex. Also includes medial orbitofrontal cortex, and perigenual and subgenual anterior cingulate cortex.

Vietnam Head Injury Study (VHIS): A large, prospective study of brain-injured combat veterans and non-brain-injured control participants (see Box 1).

Voxel-based lesion-symptom mapping (VLSM): A univariate analysis technique for determining what brain regions are causally involved in a given function on a voxel-by-voxel basis. Useful for identifying distributed patterns of brain regions as opposed to the traditional region-of-interest based approach.

Appendix II – Box 1. The Vietnam Head Injury Study (VHIS).

The Vietnam Head Injury Study (VHIS) is a long-term prospective study of the functional impact of focal brain injuries [97]. Spanning four phases completed over 40 years, large numbers of Vietnam war veterans with focal, penetrating traumatic brain injuries (TBI; Phase I, 5 years post-injury: $N=1221$; Phase II, 15 years: $N=520$, Phase III, 35 years: $N=182$; Phase IV, 40+ years: $N=133$) as well as non-brain-injured veterans completed a vast array of clinical and experimental tasks. For example, during Phase III of the VHIS patients and controls completed the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT), enabling researchers to identify the network of brain regions that appear to be critical to this ability-based measure of EI (see section **Lesion-mapping the brain bases of EI**).

Box 2. Reward-guided decision-making.

A topic related to EI that is critical for the ability to utilize emotional states in order to guide thought and behavior is reward valuation and adaptive decision-making. The importance of this ability is underscored by the consequences of impaired reward-guided decision-making in patients with vmPFC lesions. Specifically, vmPFC patients often demonstrate apathy, compulsivity, impulsivity, and social-inappropriateness, and these symptoms are driven by impairments in computing the anticipated reward value of events and regulating behavioral responses [98–100]. Reward valuation and decision-making are often probed using the Iowa Gambling Task (IGT), during which participants decide between two high-risk decks of cards that include infrequent large rewards with frequent losses, and two low-risk decks that include frequent small rewards and infrequent losses. Patients with vmPFC lesions are more likely than healthy controls to continually pull from the high-risk decks, which is an inappropriate strategy given that it eventually leads to a net loss [96,101]. In addition to the IGT, the reversal-learning task is also sensitive to the effects of vmPFC lesions. In this task, stimulus-reward pairings are learned over an initial acquisition phase, then these pairings are reversed during a second phase and participants must adapt and change their response tendencies to maximize net reward [102]. vmPFC patients are significantly impaired on such tasks [101,103–105], suggesting that this region is not only involved in representing reward valuations, but also in learning and updating valuations based on experience [106].

A

Reis et al. 2007
Kreifelts et al., 2010
Koven et al., 2011
Takeuchi et al., 2013

Pan et al., 2014
Tan et al., 2014

B

1. vmPFC
2. Amygdala
3. Insula
4. Supracallosal ACC

Figure 3