Distributed Neural System for Emotional Intelligence Revealed by Lesion Mapping

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ABSTRACT

Cognitive neuroscience has made considerable progress in understanding the neural architecture of human intelligence, identifying a broadly distributed network of frontal and parietal regions that support goal-directed, intelligent behavior. However, the contributions of this network to social and emotional aspects of intellectual function remain to be well characterized. Here we investigated the neural basis of emotional intelligence in 152 patients with focal brain injuries using voxel-based lesion-symptom mapping. Latent variable modeling was applied to obtain measures of emotional intelligence, general intelligence, and personality from the Mayer, Salovey, Caruso Emotional Intelligence Test (MSCEIT), the Wechsler Adult Intelligence Scale (WAIS), and the Neuroticism-Extroversion-Openness Inventory (NEO-PI-R), respectively. Regression analyses revealed that latent scores for measures of general intelligence and personality reliably predicted latent scores for emotional intelligence. Lesion mapping results further indicated that these convergent processes depend upon a shared network of frontal, temporal, and parietal brain regions. The results support an integrative framework for understanding the architecture of executive, social, and emotional processes, and make specific recommendations for the interpretation and application of the MSCEIT to the study of emotional intelligence in health and disease.

Keywords: emotional intelligence; general intelligence; voxel-based lesion-symptom mapping

INTRODUCTION

Accumulating evidence supports an integrative understanding of the human mind, uncovering the cognitive and emotional foundations of intelligent behavior, and their joint contributions to perception, memory, language, and thought (for reviews, see (Blakemore SJ et al. 2004; Ochsner KN 2004; Barrett LF et al. 2007; Lieberman MD 2007; Adolphs R 2010)). Parallel developments in cognitive neuroscience have motivated new perspectives about the information processing architecture of the mind, breaking away from the classic view that each identifiable function is localized to a single cortical area (reviewed in (Miller EK 2000; Miller EK and JD Cohen 2001; Miller EK and EA Phelps 2010)). One postulate of this approach is that each cortical region has more than one function, and that functions of distinct areas might overlap with one another to support a coordinated architecture for cognitive and emotional processes.

   According to this emergent view, most neural computations should not be thought of as implemented by an individual area, but rather by the interaction and collaboration among multiple areas. Specific brain regions are thought to belong to several intersecting networks based on their structural topology and functional connectivity (Passingham RE et al. 2002). Therefore, the impact of a brain region on behavior depends on its structural and functional connectivity as a member of a broader information processing network. Advances in network theory have shown that regions characterized by a high degree of functional connectivity are important in regulating the flow and integration of information among areas (Guimera R and LA Nunes Amaral 2005; Guimera R et al. 2007; Sporns O et al. 2007). A recent computational study indicates, for example, that the dorsolateral prefrontal cortex (BA 46) in the macaque links multiple functional clusters, supporting an integrative architecture for the coordination of multiple brain systems (Sporns O *et al.* 2007). These developments suggest that connectivity information will be particularly important in understanding a region's role in the coordination of cognitive and emotional processes.

Together with cognitive intelligence, emotional and social intelligence form important components of general intelligence. One of the major differences between the two is that the former is thought to relate primarily to higher order mental processes like reasoning, while the latter focuses more on perceiving, immediate processing and applying emotional and social content, information and knowledge. It has also been suggested that another fundamental difference between the two may be that cognitive intelligence is more cortically strategic in nature, while emotional and social intelligence is more limbically tactical for immediate behavior suited more for survival and adaptation (Goleman D 1995; Bar-On R et al. 2000; Stein S and HE Book 2011). However, thus far these theories are supported more by supposition than by empirical findings.

One of the primary purposes of this study is to investigate whether the neural architecture of emotional and social intelligence is integrated with cognitive intelligence or instead depends on distinct brain systems. Of the neuropsychological patient studies that have examined the neural bases of general intelligence (Basso A et al. 1973; Black FW 1976; Eslinger PJ and AR Damasio 1985; Shallice T and PW Burgess 1991; Bechara A et al. 1994; Duncan J et al. 1995; Burgess PW and T Shallice 1996; Isingrini M and F Vazou 1997; Parkin AJ and RI Java 1999; Blair RJ and L Cipolotti 2000; Kane MJ and RW Engle 2002; Bugg JM et al. 2006; Glascher J et al. 2009; Glascher J et al. 2010; Roca M et al. 2010; Barbey AK et al. 2012), social cognition (Kertesz A et al. 1979; Naeser MA et al. 1982; Alexander MP et al. 1989; Damasio AR 1992; Kertesz A et al. 1993; Caplan D et al. 1996; Bates E et al. 2003; Dronkers NF et al. 2004; Caplan D et al. 2007; Tyler LK and W Marslen-Wilson 2008), and emotion (Bechara A *et al.* 1994; Devinsky O et al. 1995; Rowe AD et al. 2001; Stuss DT et al. 2001), all share one or more of the following features: diffuse (rather than focal) brain lesions, lack of comparison subjects carefully matched for pre- and post-injury performance measures, and exclusive use of cognitive or emotional measures. As a consequence, there has been no comprehensive evaluation of

these processes in a relatively large sample of patients with focal brain damage, and across a broad range of tasks and stimulus material. The absence of such data represents a substantial gap in understanding the cognitive and neural architecture of human intelligence.

A central goal of the present study is to characterize the neural basis of emotional intelligence in a large sample of patients with focal brain injuries ($n = 152$), examining task performance on a comprehensive battery of tests designed to measure: (1) emotional intelligence (Mayer, Salovey, Caruso Emotional Intelligence Test; MSCEIT); (2) general intelligence (fluid ability, crystallized ability, working memory, and processing speed; WAIS-III); and (3) personality (extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience; NEO-PI-R). We investigated the neural substrates of each domain, examining the (i) selectivity of cortical networks for specific domains and (ii) the degree to which these systems engage common networks. We applied confirmatory factor analysis to obtain latent scores of each domain, followed by voxel-based lesion-symptom mapping.

MATERIALS AND METHODS

Participant Data

Participants were drawn from the Phase 3 Vietnam Head Injury Study (VHIS) registry, which includes American male veterans who suffered brain damage from penetrating head injuries in the Vietnam War ($n = 152$). All subjects gave informed written consent. Phase 3 testing occurred between April 2003 and November 2006. Demographic and background data for the VHIS are reported in Supplemental Table 1 (see also (Koenigs M et al. 2009; Barbey AK et al. 2011; Koenigs M et al. 2011; Barbey AK *et al.* 2012)). No effects on test performance were observed in the VHIS sample on the basis of demographic variables (e.g., age, years of education, lesion size).

Lesion Analysis

CT data were acquired during the Phase 3 testing period. The axial computed tomography (CT) scans were acquired without contrast in helical mode on a GE Electric Medical Systems Light Speed Plus CT scanner at the Bethesda Naval Hospital. Structural neuroimaging data were reconstructed with an in-plane voxel size of 0.4 × 0.4 mm, an overlapping slice thickness of 2.5 mm, and a 1 mm slice interval. Lesion location and volume from CT images were determined using the interactive Analysis of Brain Lesions (ABLe) software implemented in MEDx, version 3.44 (Medical Numerics) (Makale M et al. 2002; Solomon J et al. 2007). Lesion volume was calculated by manually tracing the lesion in all relevant slices of the CT image in native space, and then summing the trace areas and multiplying by slice thickness. Manual tracing was performed by a trained psychiatrist with clinical experience of reading CT scans. The lesion tracing was then reviewed by an observer who was blind to the results of the clinical evaluation and neuropsychological testing enabling a consensus decision to be reached regarding the limits of each lesion. The CT image of each individual's brain was normalized to a CT template brain image in Montreal Neurological Institute (MNI) space. The spatial normalization was performed with the automated image registration (AIR) algorithm (Woods RP et al. 1993), using a 12-parameter affine fit. Note that both the patient's brain and the CT template brain are first skull-stripped to maximize the efficacy of the AIR registration from native space to MNI space. In addition, voxels inside the traced lesion were not included in the spatial normalization procedure. For each subject, a lesion mask image in MNI space was saved for voxel-based lesion-symptom mapping (Bates E *et al.* 2003). The lesion overlap map for the entire VHIS patient sample is illustrated in Supplemental Figure 2.

Neuropsychological Tests

We administered the Mayer, Salovey, Caruso Emotional Intelligence Test (Mayer JD et al.

2008), the Wechsler adult intelligence scale, third edition (Wechsler D 1997) (WAIS-III), and the

NEO-PI-R (Costa PT, Jr. and RR McCrae 1997) to investigate the common and specific neural

substrates underlying emotional intelligence, psychometric intelligence, and basic personality

traits. Supplemental Table 2 summarizes the employed measures (for further detail concerning

their standardization, reliability, and validity, see (Wechsler D 1997; Mayer JD *et al.* 2008)).

Confirmatory factor analysis

The measurement model for psychometric and emotional intelligence was tested (Supplemental

Fig. 1). Emotional intelligence was measured by the full MSCEIT inventory and psychometric

intelligence was defined by the WAIS-III, which includes measures of fluid/perceptual ability,

crystallized/verbal ability, working memory, and processing speed.

This five factor model produced appropriate fit indices: χ^2 = 344.9, degrees of freedom (DF)

= 199, χ^2/DF = 1.73, RMSEA = 0.07. All correlations among factors are statistically significant (*p*

< 0.000). Nevertheless, the highest correlation was found for crystallized/verbal and emotional

intelligence (r = 0.78).

Computation of scores of interest

Using the imputation function of the AMOS program (Arbuckle J 2006) we obtained latent

scores for the five factors depicted in Fig. 1. The four latent scores derived from the WAIS-III

subtests, along with the scores obtained from the NEO big five scales, were submitted to a

stepwise regression analysis for predicting the latent score derived from the MSCEIT battery.

Results showed that crystallized/verbal intelligence, processing speed, and conscientiousness

significantly contributed to the prediction of emotional intelligence (adjusted R^2 = 0.81, *p* <

0.000). Emotional intelligence unpredicted defined a residual score reflecting its specific

variance. This residual score supported an investigation of the neural basis of emotional

intelligence while removing the variance shared with verbal intelligence, processing speed, and

conscientiousness.

Voxel-based lesion-symptom mapping

These scores were correlated to regional gray and white matter determined by voxel-based

lesion-symptom mapping (Bates E *et al.* 2003). This method compares, for every voxel, scores

from patients with a lesion at that voxel contrasted against those without a lesion at that voxel

(applying a False Discovery Rate correction of $q < 0.05$). Unlike functional neuroimaging

studies, which rely on the metabolic demands of gray matter and provide a correlational

association between brain regions and cognitive processes, voxel-based lesion-symptom

mapping can identify regions playing a causal role in human intelligence by mapping where

damage can interfere with performance.

RESULTS

Emotional intelligence

Figure 1 depicts a summary of lesion mapping results keeping correlation values among

fluid/perceptual intelligence, crystallized/verbal intelligence, working memory, processing speed,

and emotional intelligence, as obtained from the latent variable analysis shown in Supplemental

Figure 1. Results for emotional intelligence removing its variance shared with the other factors

are reported below.

Impairments in emotional intelligence were associated with selective damage to a social

cognitive network (reviewed in (Saxe R 2006)). This network comprised the extrastriate body

area within left posterior temporal cortex, which is associated with perceiving the form of other

human bodies; left posterior superior temporal sulcus, which is involved in interpreting the

motions of a human body in terms of goals; left temporo-parietal junction, which supports the

uniquely human ability to reason about the contents of mental states; and left orbitofrontal

cortex, which is known to support emotional empathy and triadic relations between two minds and an object, supporting shared attention and collaborative goals (Fig. 1).

This network additionally engaged major white matter fiber tracts, including the superior longitudinal/arcuate fasciculus, which connects temporal, parietal, and inferior frontal areas; the superior fronto-occipital fasciculus connecting dorsolateral prefrontal cortex and the frontal pole with the superior parietal cortex; and the uncinate fasciculus, which connects anterior temporal cortex and amygdala with orbitofrontal and frontopolar regions (Fig. 1). The necessity of the social cognitive network for emotional intelligence supports the integration of emotional and social processes at the neural level (Ochsner KN and MD Lieberman 2001; Ochsner KN 2004).

As expected, the neural system for emotional intelligence shared anatomical substrates with networks observed for psychometric intelligence. We focus on the independent predictors of emotional intelligence, as noted above, namely, verbal comprehension/crystallized intelligence (Beta = 0.796, $p < 0.000$) and processing speed (Beta = 0.175, $p < 0.000$). Impaired performance on measures of verbal comprehension was associated with selective damage to a left hemisphere perisylvian language network (reviewed in (Hickok G and D Poeppel 2007); Fig. 2; regions highlighted in yellow). This network is distributed throughout association areas in the left perisylvian cortex, recruiting a ventral pathway that maps sound to meaning (language comprehension) and a dorsal pathway that maps sound to action (language production). The ventral pathway comprised anterior middle temporal gyrus, posterior middle temporal gyrus, and middle posterior superior temporal sulcus. These regions are known to support the process of mapping sensory or phonological representations onto lexical/conceptual representations in language comprehension (Hickok G and D Poeppel 2007). The dorsal pathway engaged the anterior and posterior insula and an area at the parietal-temporal boundary, which are known to contribute to mapping sensory or phonological representations onto articulatory motor representations in language production (Hickok G and D Poeppel 2007). Impaired performance

on measures of verbal comprehension was also associated with damage to white matter fiber tracts that are widely implicated in language processing, including the arcuate fasciculus, which connects temporal, parietal, and inferior frontal areas, and the uncinate fasciculus, which connects anterior temporal cortex and amygdala with orbitofrontal and frontopolar regions (Fig. 2; regions highlighted in yellow). The anatomical extent of this network is consistent with the notion that crystalized intelligence is a complex process that derives from the coordinated activity of several brain regions. Critically, this network shared anatomical substrates with emotional intelligence (Fig. 2; regions highlighted in green), engaging both the dorsal and ventral perisylvian language systems and indicating that emotional intelligence relies upon neural systems for crystallized intelligence.

Deficits in processing speed were associated with damage to a bilateral network of frontal and parietal regions, including white matter fiber tracts that bind these areas into a unified system (Fig. 2; regions highlighted in red). This network shared neural substrates with emotional intelligence (Fig. 3; regions highlighted in pink), recruiting regions within the left dorsolateral prefrontal cortex (BA 9) that support the regulation and control of emotional and social behavior.

Personality traits and emotional intelligence

Computed regression analyses showed that only one of the big five contributed to the prediction of emotional intelligence, namely, conscientiousness (Beta = 0.15, $p < 0.000$). Therefore, we focus on this personality trait. Impairments in conscientiousness were associated with damage to regions of the social knowledge network that are important for the regulation and control of behavior, including the right dorsolateral prefrontal cortex (BA 9), left orbitofrontal cortex (BA 11), and left temporo-parietal junction (BA 22; Fig. 3; regions highlighted in yellow). These regions have been widely implicated in social information processing networks (for a review, see (Saxe R 2006)) and share anatomical substrates with emotional intelligence, suggesting that these constructs may be closely related (Fig. 3; regions highlighted in green).

Residual emotional intelligence scores

Finally, we analyzed the emotional intelligence residual scores removing variance shared with its significant predictors in both the psychometric intelligence and personality domains. Impairment in the emotional intelligence residual score was associated with selective damage to frontal and parietal brain structures that have been widely implicated in social information processing. These regions comprised the right orbitofrontal cortex (BA 10), left inferior (BA 40/39) and superior parietal cortex (BA 7), in addition to major white matter fiber tracts, including the superior longitudinal/arcuate fasciculus, the superior fronto-occipital fasciculus, and the uncinate fasciculus (Fig. 4). The necessity of the social cognitive network for emotional intelligence supports the integration of emotional and social processes by shared neural systems (Ochsner KN and MD Lieberman 2001; Ochsner KN 2004).

DISCUSSION

In this study, we investigated the neural architecture of emotional intelligence and examined the degree to which this network engages systems for key competencies of psychometric intelligence (verbal comprehension/crystallized intelligence, perceptual organization/fluid intelligence, working memory, and processing speed) and personality traits (extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience). We administered tests for measuring these psychological constructs to 152 patients with focal brain injuries and applied voxel-based lesion-symptom mapping to investigate their neural substrates.

We observed a significant effect on emotional intelligence with lesions in white matter sectors including the superior longitudinal/arcuate fasciculus that connect frontal and parietal cortices. Despite its distributed nature, the neural substrates of emotional intelligence were remarkably circumscribed, concentrated in the core of white matter, and comprising a narrow subset of regions associated with social information processing. This finding suggests that

emotional intelligence is supported by mechanisms for the regulation and control of social behavior, and that the communication between areas associated with these abilities is of critical importance.

Orbitofrontal cortex is a central component of this network and has been increasingly implicated in emotional and social cognition (Kringelbach ML 2005). This region is uniquely placed to integrate sensory and visceral motor information to modulate behavior through both visceral and motor systems. This has led to the proposal that orbitofrontal cortex is involved in the integration of bodily signals that help decision making processes and have been termed, for example, 'interoceptive' (Nauta WJ 1971) or 'somatic' markers (Damasio AR 1996). These proposals suggest that orbitofrontal cortex is an important part of the networks involved in emotional and social processing (Nauta WJ 1971; Rolls ET 2000).

A growing body of evidence further supports the functional division of orbitofrontal cortex into orbital and medial sectors (for a review, see (Kringelbach ML 2005)). A large meta-analysis of the existing neuroimaging data was used to show that activity in the medial orbitofrontal cortex is related to the monitoring, learning and memory of the reward value of reinforcers, whereas lateral orbitofrontal cortex activity is related to the evaluation of punishers, which can lead to a change in ongoing behavior (Kringelbach ML and ET Rolls 2004). Further studies have since confirmed the role of the medial orbitofrontal cortex in monitoring affective properties in olfaction (Anderson AK et al. 2003; Rolls ET et al. 2003), gustation (Small DM et al. 2003), and for somatosensory (Rolls ET *et al.* 2003) and multimodal stimuli (de Araujo IE et al. 2003). These findings support the observed role of medial orbitofrontal cortex in emotional intelligence, indicating that this region is computationally necessary for monitoring affective properties of social and environmental stimuli. The involvement of lateral orbitofrontal cortex in the evaluation of punishers (Kringelbach ML and ET Rolls 2004) elucidates the role of this region in executive function, suggesting that it is necessary for evaluative processes in goal-directed behavior and

decision making (Barbey AK et al. 2009). The findings reported here indicate that the orbitofrontal cortex plays a central role in the coordination of social and affective systems, providing a nexus for sensory integration and contributing to a fronto-parietal network for goal-directed behavioral control.

The neural system for emotional intelligence shared anatomical substrates with specific facets for psychometric intelligence, engaging perisylvian language areas (Fig. 2; highlighted in green) and regions within the left anterior cingulate cortex (BA 32) and superior longitudinal fasciculus also implicated in processing speed (Fig. 2; highlighted in pink). These findings are consistent with the observed pattern of correlations between these factors (Fig. 1) and further suggest that emotional intelligence depends on mechanisms for social processing and crystallized intelligence. In addition, we found that emotional intelligence engaged brain regions implicated in conscientiousness, recruiting areas within the left orbitofrontal cortex (BA 10), anterior insula (BA 13), and inferior temporal cortex (BA 37) (Fig. 3; highlighted in green). This result further indicates conscientiousness, or the degree of organization, persistence, control, and motivation in goal-directed behavior, is a central feature of emotional intelligence.

Finally, we investigated the neural systems underlying emotional intelligence residual scores removing variance shared with its significant predictors in both the psychometric intelligence and personality domains. When compared to the neural system observed for emotional intelligence at the latent variable level, we see that the residual factor engages common and distinctive brain regions (Figs. 4 and 5). Common regions include right dorsolateral PFC, left posterior superior temporal sulcus, and left temporo-parietal junction (Fig. 5; highlighted in green), while distinct areas reflect engagement of perisylvian language areas for emotional intelligence at the latent variable level (Fig. 5; highlighted in blue) and recruitment of the right precentral gyrus and left superior parietal cortex for the residual emotional intelligence factor (Fig. 5; highlighted in yellow).

Conclusion

Historically, cognitive and emotional processes have been viewed as separate constructs.

Research in the past two decades, however, has increasingly shown that such a view may be

limited and that, if we are to understand how complex behaviors are carried out in the brain, an

understanding of their interactions is indispensable. The present study provides

neuropsychological patient data to suggest that emotional and crystalized intelligence recruit

shared neural systems for the integration of cognitive, social, and affective processes. Whereas

many behaviors might be reasonably well characterized in terms of cognitive–social interactions

such that cognitive and social processes are partly separable, often true integration of cognitive

and social processes takes place, blurring the distinction between these domains (Barbey AK *et

al.* 2009). We propose that one fruitful way to refine our understanding of their integration will

involve a more quantitative analysis of structural and functional brain connectivity, with particular

emphasis on the involvement of the observed social knowledge network.

One of the most important implications of the current findings is that the complex cognitive

processes that subserve social competence engage neural processes specialized for social

information. The findings of the present study suggest that emotional and social intelligence has

neural roots, which may be associated with these known basic mechanisms of the brain.

Impairment of these mechanisms may manifest itself in low levels of emotional intelligence,

which comprises a wide array of emotional and social competencies, which can have an ill

effect on one's ability to effectively cope with daily demands. Such impairment may include a

decrease in one's ability to: (i) be aware of and express oneself; (ii) function interpersonally; (iii)

manage and control emotions; (iv) generate positive affect required in achieving personal goals;

and (v) cope with the immediate situation, make decisions and solve problems of a personal

and interpersonal nature.

The data presented in this article are consistent with the view that behavior is a product of the orchestration of many brain regions and that the aggregate function of these areas supports emotional and cognitive processes. As the functional neuroanatomy of this network is further elucidated, we should try to understand the temporal dynamics that underlie its functions, and the structural and functional changes that occur during development. On a timescale of milliseconds, neuroimaging techniques such as magnetoencephalography (MEG) could be used to elucidate the precise role of this system in cognitive, social, and emotional processes. The directionality and timing of neural activity between regions of the social knowledge network is not clear but could potentially be addressed with MEG by using sensitive measures such as Granger Causality (Granger CWJ and H Hatanaka 1969).

On a longer, developmental timescale, it would be interesting to investigate the role of this network in learning and, in particular, in the consolidation of learning. One hypothesis is that the rate of improvement in learning depends on emotional and motivational influences (Cattell RB and RB Cattell 1987) and therefore on changes in functional activity in structures known to be involved in social and emotional processes, such as the orbitofrontal cortex. This approach will be particularly important in understanding goal-directed social behavior and cases of learning that depend on temporal and occipital brain structures that are initially set up through top-down interactions with frontal and parietal regions.

From a clinical perspective, understanding cognitive and emotional deficits in patients with brain damage may facilitate the design of appropriate assessment tools and rehabilitation strategies, with potential improvement in patients' cognitive abilities and daily living. Our findings identify specific tests of the MSCEIT and WAIS that may be targeted in clinical investigations to assess the functioning of the social knowledge network, particularly, emotional intelligence tests of the MSCEIT and crystalized intelligence measures of the WAIS. These findings support

predictions about the nature and significance of cognitive impairments that may result from damage to specific brain networks (Fig. 1).

Many neurological disorders and mental illnesses are characterized by profound deficits in emotional and cognitive behaviors, including epilepsy, Alzheimer's disease, autism and schizophrenia. Outstanding questions concerning these and many other debilitating conditions center on advancing our knowledge of how emotional and cognitive processes interact in both normal and abnormal circumstances. Understanding the neural mechanisms underlying these conditions will ultimately require a broader assessment that examines the functional organization of emotional and cognitive systems, and their interactive role in high-level processes. The reported finding contribute to this emerging research program by elucidating the role of the social knowledge network in the coordination of cognitive, social, and affective processes, demonstrating that this system provides an integrative neural architecture for key competencies of human intelligence.

ACKNOWLEDGEMENTS

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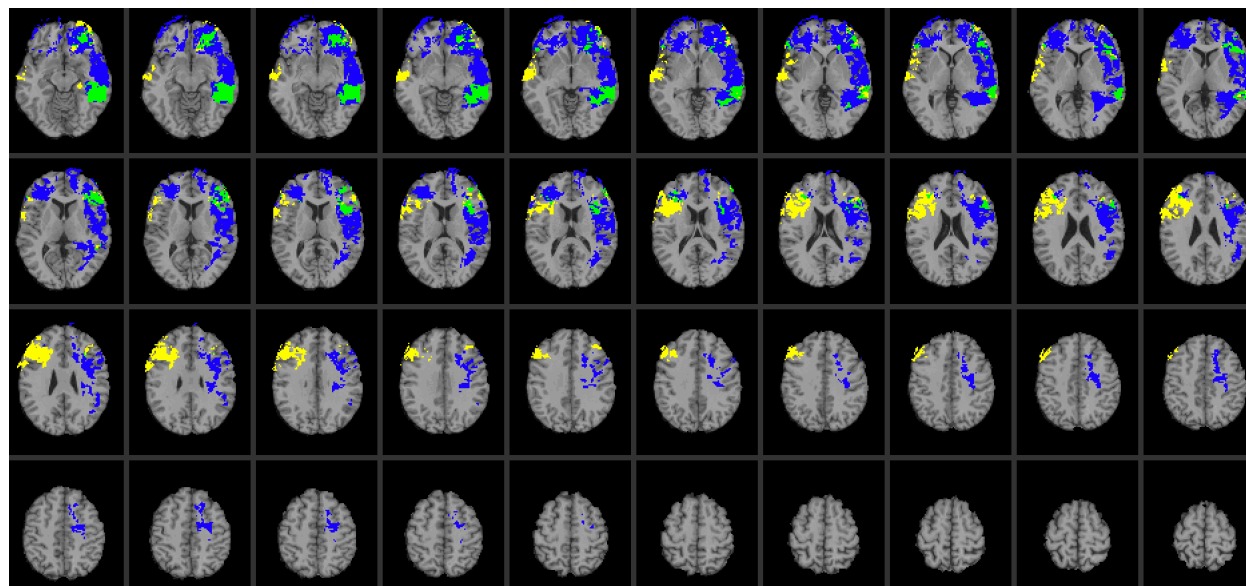
FIGURES

Figure 1. Summary of lesion mapping and structural equation modeling results (*n* = 152).
The statistical map is thresholded at 5% false discovery rate. In each map of the cortical
surface, the left hemisphere is on the reader's left.
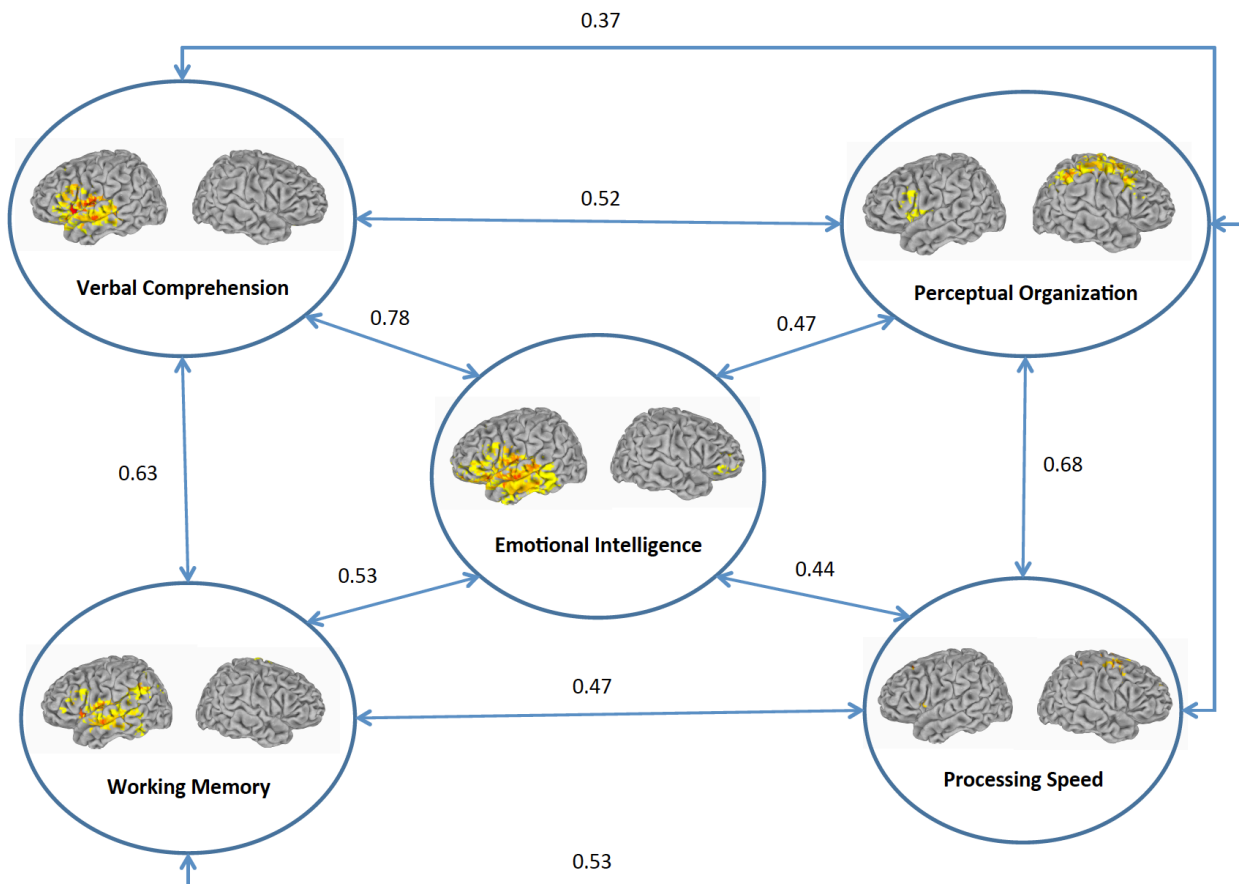
Figure 2. Voxel-based lesion-symptom mapping of emotional intelligence, verbal comprehension, and processing speed. Lesion overlap map illustrating common and distinctive brain regions for emotional intelligence (blue), verbal comprehension (yellow) and processing speed (red) (n = 152). Overlap between emotional intelligence and perceptual organization is illustrated in green. Overlap between emotional intelligence and processing speed is illustrated in pink. Overlap between perceptual organization and processing speed is illustrated in orange. Overlap between all conditions is illustrated in white. The statistical map is thresholded at 5% false discovery rate. In each axial slice, the right hemisphere is on the reader's left.
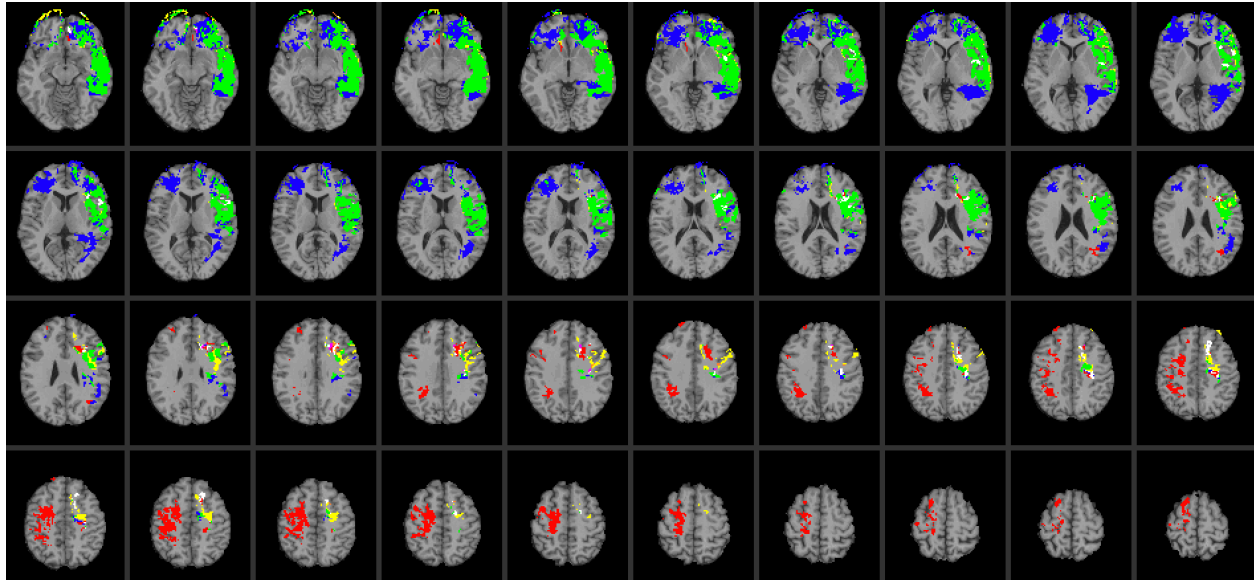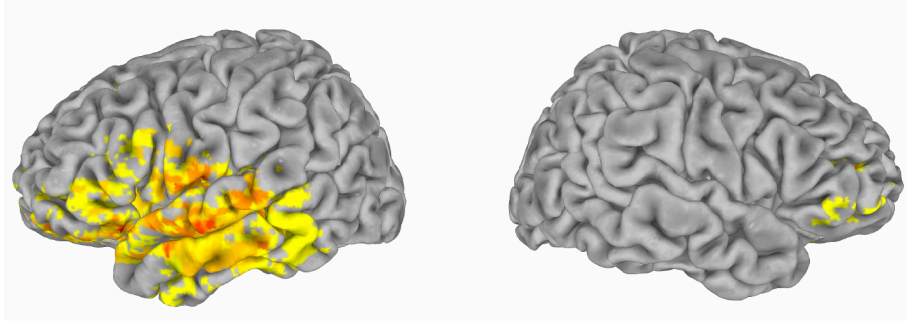
Figure 3. Voxel-based lesion-symptom mapping of emotional intelligence and conscientiousness. Lesion overlap map illustrating common and distinctive brain regions for emotional intelligence (blue) and conscientiousness (yellow) (*n* = 152). Overlap between emotional intelligence and conscientiousness is illustrated in green. The statistical map is thresholded at 5% false discovery rate. In each axial slice, the right hemisphere is on the reader's left.
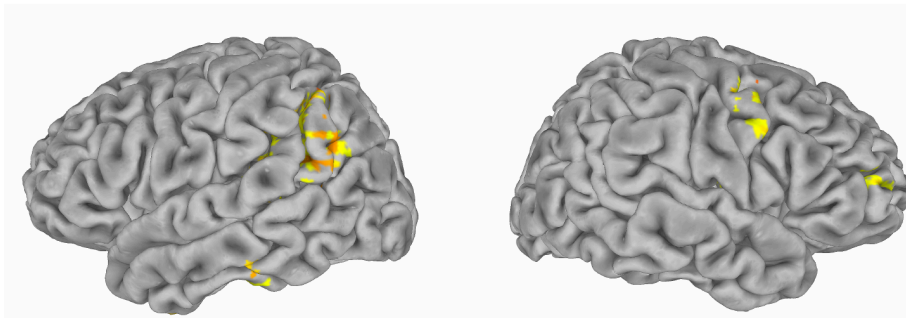
Figure 4. Voxel-based lesion-symptom mapping of latent (a) and residual (b) emotional intelligence scores (*n* = 152). The statistical map is thresholded at 5% false discovery rate. In each map of the cortical surface, the left hemisphere is on the reader's left.

(a) Emotional Intelligence (Latent Factor)

(b) Emotional Intelligence (Residual Factor)

Figure 5. Voxel-based lesion-symptom mapping of emotional intelligence (latent) and emotional intelligence (residual). Lesion overlap map illustrating common and distinctive brain regions for emotional intelligence latent (blue) and emotional intelligence residual (yellow) (*n* = 152). Overlap between these factors is illustrated in green. The statistical map is thresholded at 5% false discovery rate. In each axial slice, the right hemisphere is on the reader's left.
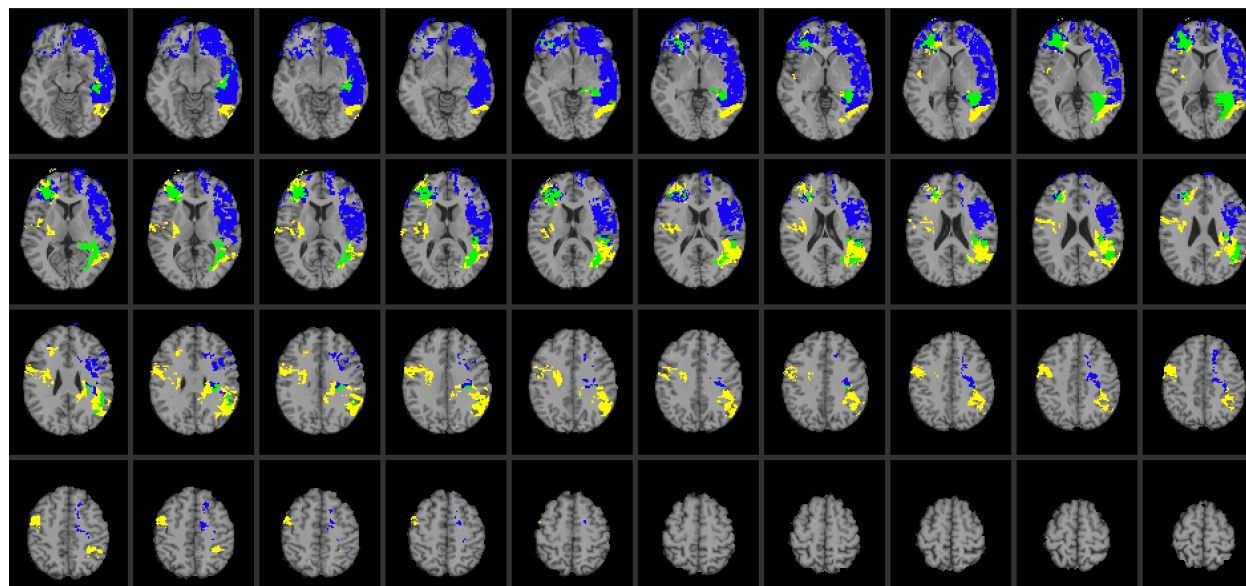
SUPPLEMENTAL TABLES

Supplemental Table 1. Demographic and background data. Note: "Age" refers to age at the time of Phase 3 evaluation. "Sex" refers to the percentage of male veterans. "Years of education" refers to the total number of years of education the veterans completed.

Demographic Data	Patient Group
Age	58.13
Sex (% male)	100.00
Years of education	15.00
Total percent volume loss (cm^3)	3.19

Supplemental Table 2. Description of the administered tests.

Test	Description
Emotional intelligence	
Perceiving Emotions: Faces	The ability to perceive emotions in oneself and others
Perceiving Emotions: Pictures	The ability to perceive emotions in oneself and in objects, art, stories, music, and other stimuli
Using Emotions: Sensations	The ability to generate, use, and feel emotion as necessary to communicate feelings
Using Emotions: Facilitation	The ability to generate, use, and feel emotion as necessary to employ them in other cognitive processes
Understanding Emotions: Blends	The ability to understand emotional information, to understand how emotions combine and to appreciate such emotional meanings
Understanding Emotions: Changes	The ability to understand emotional information, to understand how emotions progress through relationship transitions, and to appreciate such emotional meanings
Managing Emotions: Emotion	The ability to be open to feelings, and to modulate them in oneself
Managing Emotions: Social	The ability to be open to feelings, and to modulate them in oneself and others so as to promote personal understanding and growth
Working memory (WAIS-III)	
Arithmetic	Participant hears numerical problems in story format, performs mental arithmetic, and responds orally
Digit Span	Participant hears a sequence of digits and repeats them initially forwards and then backwards
Letter-Number Sequencing	Participant hears a sequence of alternating digits and letters and then rearranges the items, first repeating the digits in numerical order, followed by the letters in alphabetical order
Verbal comprehension/Crystallized intelligence (WAIS-III)	
Vocabulary	Participant generates verbal definition for words pronounced by the examiner
Similarities	Participant indicates how two items, presented orally, are the same
Information	Participant verbally answers factual oral questions
Comprehension	Participant verbally answers factual oral questions
Perceptual organization/Fluid intelligence (WAIS-III)	

Block Design	Participant arranges multicolored blocks to match a model design
Matrix Reasoning	Participant selects from an array of pictured items the abstract shape that completes the visual-spatial pattern
Picture Completion	Participant identifies the missing element in a series of pictures
Picture arrangement	Participant arranges pictures in a coherent sequence to tell stories
Object assembly	Participant rearranges puzzle pieces to form familiar objects
Processing speed (WAIS-III)	
Digit Symbol Coding	Participant codes items based on a table that contains digits paired with symbols
Symbol Search	Participant performs a visual search to identify whether a target item is present among a set of symbols
Personality (NEO-PI-R)	
Extraversion	Participant completes a personality inventory that is designed to measure the quantity and intensity of energy directed outwards into the social world
Agreeableness	Participant completes a personality inventory that is designed to measure the kinds of interactions an individual prefers from compassion to tough mindedness
Conscientiousness	Participant completes a personality inventory that is designed to measure the degree of organization, persistence, control, and motivation in goal-directed behavior
Neuroticism	Participant completes a personality inventory that is designed to identify individuals that are prone to psychological distress
Openness to experience	Participant completes a personality inventory that is designed to measure the active seeking and appreciation of experience for their own sake

FIGURES

Supplemental Figure 1. Confirmatory factor analysis for the intelligence factors (*n* = 152). Regression weights for the specific measures are depicted on the right for clarity.
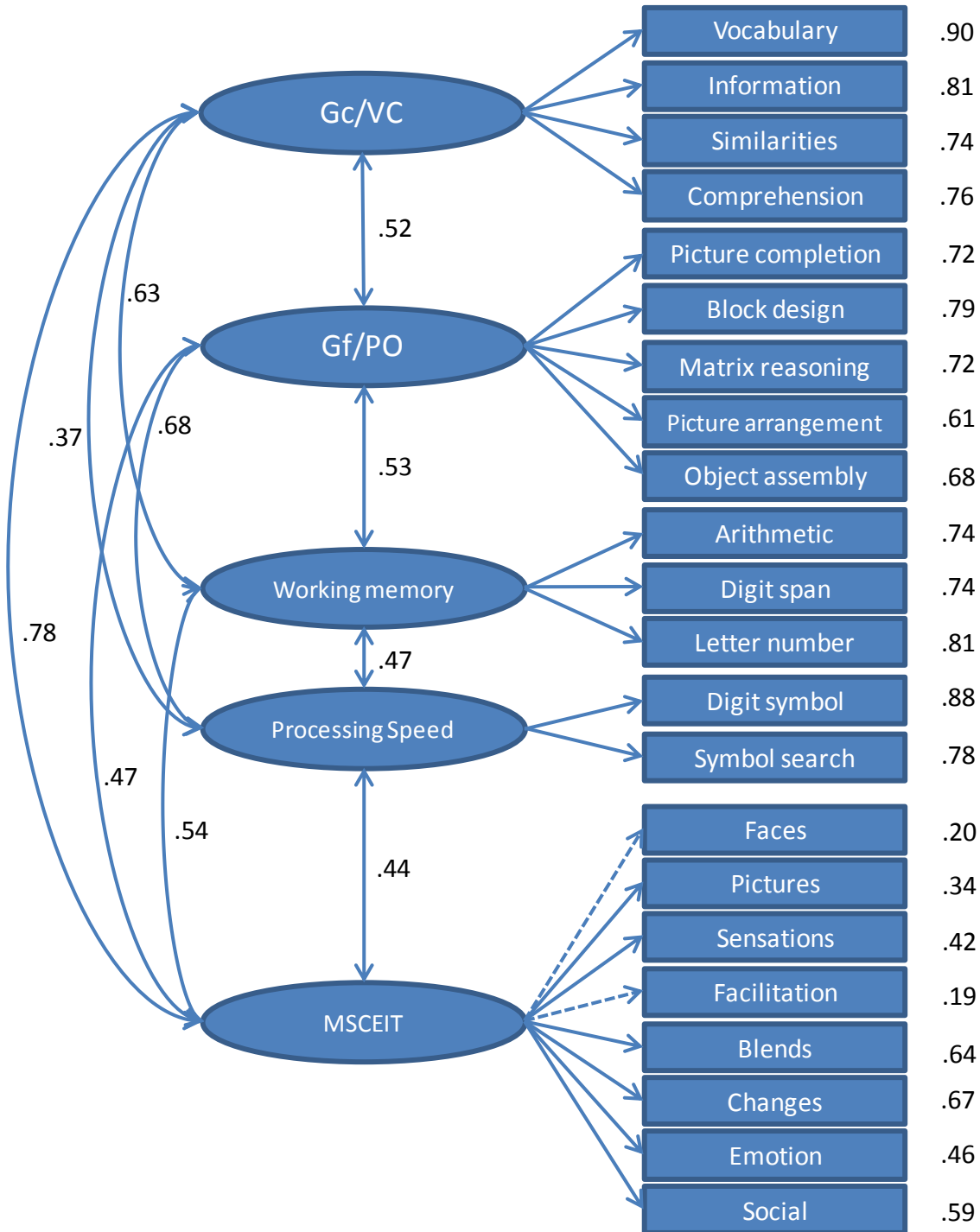
Supplemental Figure 2. Lesion overlap map illustrating the number of patients with brain lesions to a particular voxel. In each axial slice, the right hemisphere is on the reader's left. To ensure sufficient statistical power for detecting a lesion-deficit correlation, our analysis only included voxels for which 4 or more patients had a lesion.