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Relationship between individual differences in functional connectivity and facial-emotion recognition abilities in adults with traumatic brain injury

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ABSTRACT

Although several studies have demonstrated that facial-affect recognition impairment is common following moderate-severe traumatic brain injury (TBI), and that there are diffuse alterations in large-scale functional brain networks in TBI populations, little is known about the relationship between the two. Here, in a sample of 26 participants with TBI and 20 healthy comparison participants (HC) we measured facial-affect recognition abilities and resting-state functional connectivity (rs-FC) using fMRI. We then used network-based statistics to examine (A) the presence of rs-FC differences between individuals with TBI and HC within the facial-affect processing network, and (B) the association between inter-individual differences in emotion recognition skills and rs-FC within the facial-affect processing network. We found that participants with TBI showed significantly lower rs-FC in a component comprising homotopic and within-hemisphere, anterior-posterior connections within the facial-affect processing network. In addition, within the TBI group, participants with higher emotion-labeling skills showed stronger rs-FC within a network comprised of intra- and inter-hemispheric bilateral connections. Findings indicate that the ability to successfully recognize facial-affect after TBI is related to rs-FC within components of facial-affective networks, and provide new evidence that further our understanding of the mechanisms underlying emotion recognition impairment in TBI.

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1. Introduction

Among the many sequelae of traumatic brain injury (TBI), difficulties in social functioning are major predictors of overall outcome, posing a challenge for patients and clinicians (Morton and Wehman, 1995; Spikman et al., 2013). Several studies have linked overall social and communication impairment to the ability to successfully identify others' emotions from their facial expressions (Knox and Douglas, 2009; McDonald and Flanagan, 2004; Pettersen, 1991; Watts and Douglas, 2006), suggesting that poor interpersonal skill might be attributed—at least partially—to deficits in emotion perception and interpretation. Emotion recognition abilities show marked individual differences both within healthy (Germine and Hooker, 2011; Palermo et al., 2013; Tamamiya and Hiraki, 2013) and brain injury populations (Babbage et al., 2011; Rigon et al., 2016b; Rosenberg et al., 2014). Indeed, among groups of individuals with TBI that would otherwise be defined as homogeneous (i.e., as "moderate", "severe", or "moderate-severe" (Malec et al., 2007)), great variability in facial-affect recognition skills has been reported (Rigon et al., 2016b; Rosenberg et al., 2014), leading to a considerable challenge for clinicians attempting to predict deficit profiles and long-term interpersonal outcomes.

Successful treatment of social impairment represents an additional challenge: as traditional rehabilitation strategies have shown little success in improving social competence following TBI (McDonald et al., 2008; Ylvisaker et al., 2005), current research has attempted to develop complementary treatments that, instead of simply targeting and training a specific impaired behavior, focus on the additional improvement of the functionality of large-scale brain networks mapping onto cognitive, affective or motor functions through brain stimulation and lifestyle interventions (Barbey et al., 2015).

Several studies have attempted to link facial-affect recognition skills with site of focal brain lesions (e.g., frontal or medial temporal lobe

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lesions), with mixed results (Green et al., 2004; Martins et al., 2012; Spikman et al., 2012). However, recent work suggests that a better understanding of individual differences in TBI populations might be achieved by adopting a view of brain function as the product of functional communication between nodes of integrated networks, and not only of the structure of a specific brain region (Barbey et al., 2015). Indeed, TBI is a condition characterized by widespread axonal damage leading to disconnection within and between regions included in brain networks supporting different cognitive processes (Adams et al., 1982; Graham et al., 1988; Sharp et al., 2014). Structural connectivity following TBI has traditionally been examined using diffusion tensor imaging (DTI), which provides a way to assess integrity and directionality of white matter tracts traveling between nodes of a given brain network (Hulkower et al., 2013; Kennedy et al., 2009; Sharp and Ham, 2011). However, in the past decade several studies have employed resting state functional connectivity (rs-FC) measured with functional magnetic resonance imaging (fMRI) to investigate integrity of brain networks in TBI populations (Arenivas et al., 2014; Bonnelle et al., 2011; Marquez de la Plata et al., 2011; Palacios et al., 2013; Rigon et al., 2016a; Sharp et al., 2011). Rs-FC measures the correlation between fluctuations in the hemodynamic fMRI signal between regions throughout the brain that form large-scale brain networks (Biswal et al., 1995; Fox et al., 2005). A growing body of work supports a relationship between the functionality of these intrinsic networks assessed at rest and cognitive (e.g., executive functioning, processing speed, personality variable) and behavioral (e.g., tasks-modulation) processes in both healthy and clinical populations (Cox et al., 2012; Ham and Sharp, 2012; Hampson et al., 2006; Seeley et al., 2007).

To date, a wealth of studies have found abnormalities in both white matter integrity (Hulkower et al., 2013; Sidaros et al., 2008) and patterns of rs-FC in several large-scale brain networks in TBI populations (Rigon et al., 2016a; Stevens et al., 2012), as well as correlations between these measures and behavioral performance (Bonnelle et al., 2011; Ham et al., 2014; Sours et al., 2014; Rigon et al., 2016c). However, only one study has explored the relationship between white matter integrity and facial-affect recognition ability in individuals with moderate-severe TBI: Genova and colleagues (Genova et al., 2015) found that performance on emotion recognition tasks was positively correlated with fractional anisotropy of the inferior fronto-occipital and inferior longitudinal fasciculus, which connect visual regions with temporal and prefrontal areas involved in affective processing and decision making. Although no work has examined the relationship between rs-FC and facial-affect recognition abilities, a recent study by Neumann and colleagues compared blood oxygen level-dependent (BOLD) response during an emotion-labeling task between individuals with TBI and a matched comparison group (Neumann et al., 2015). The authors reported that individuals with TBI who had facial-affect recognition impairment showed less activation in the fusiform gyrus during an emotion-labeling task than those in the comparison group. This finding suggests that deficits in facial-affect recognition secondary to TBI might be related to functional abnormalities in specific brain areas associated with processing faces. However, participants with TBI who did not have facial affect recognition impairments also had lower scores than the comparison group, albeit not significantly, suggesting that changes in the fusiform gyrus alone might not explain all of the variance in affect recognition among adults with TBI. Given that structural disconnection is the hallmark of TBI, it is likely that functional disconnection between regions involved in the perception and interpretation of facial affects also plays a role in impaired facial-affect processing.

The current study aims to expand the work carried out to date on the structural and functional neural correlates on emotion recognition impairment following TBI by adopting a large-scale network perspective and by focusing on the neural mechanisms related to inter-individual differences within TBI individuals. Our analysis combines behavioral data (Rigon et al., 2016b) and rs-FC, measured using fMRI, in a sample of adults with moderate-severe TBI. Out of the scanner participants completed a dynamic emotion-labeling task. Our analysis focused on rs-FC within a set of brain regions that have been consistently found to be involved in processing facial affect as reported by a recent meta-analysis (Sabatinelli et al., 2011) (See Table 1). We hypothesized that there would be (A) differences between individuals with TBI and healthy comparison participants in rs-FC within regions involved in processing facial affect, and (B) an association between inter-individual differences in emotion recognition skills and rs-FC within regions involved in processing facial affect.

2. Methods

2.1. Participants

Twenty-eight participants with TBI and twenty normal healthy comparison participants (HC) were recruited for this experiment. Individuals with TBI were recruited among the community of the University of Iowa. All individuals with TBI were in the chronic phase of their injury (>6 months), and they had sustained a moderate-severe brain injury. TBI severity was determined through a combination of medical records

Table 1
ROI coordinates for the facial affect processing network.

ROIs	Original coordinates			Modified coordinates			Role in facial affect processing
Axis	*x*	*y*	*z*	*x*	*y*	*z*	
Medial prefrontal cortex	4	47	7				Emotional/reward processing
Right inferior frontal gyrus	42	25	3				Processing of emotional stimuli
Left inferior frontal gyrus	−42	25	3				
Right middle frontal gyrus	48	17	29				Emotion regulation
Left middle frontal gyrus	−42	13	27				
Superior frontal gyrus	−2	8	59				
Right amygdala	20	−4	−15	22	−8	−14	Multimodal emotion processing, perception of arousing stimuli, facial identification
Left amygdala	−20	−6	−15	−26	−10	−14	
Right middle temporal gyrus	53	−50	4				Discrimination of expressive faces
Left parahippocampal gyrus	−20	−33	−4				Basic perception of human faces (increased activation for emotional than for neutral faces)
Right parahippocampal gyrus	14	−33	−7	18	−38	−8	
Right fusiform gyrus	38	−55	−20	38	−56	−16	
Left fusiform gyrus	−40	−55	−22	−40	−56	−18	
Right posterior fusiform gyrus	38	−76	−16				
Left posterior fusiform gyrus	−40	−78	−21	−42	−74	−18	

Original coordinates were reported by Sabatinelli et al. (2011), and reflect the activation peak for the contrast emotional faces > neutral faces obtained by a 100 studies activation likelihood estimation analysis. Coordinates are reported in mm and in standard MNI space. Coordinates were modified when maintain the original peak would result in a 7 mm-radius seed partially overlapping with cerebrospinal fluid, taking care that the newly centered seed would still include the original peak. ROI = Region of Interest. When no values are reported in the 'Modified coordinates' column the original coordinates were used. The "Role in Facial Affect Processing" column was compiled according to the interpretations of the meta-analysis findings of Sabatinelli et al.

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