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Resting state functional connectivity correlates of emotional awareness

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ABSTRACT

Multiple neuroimaging studies have now linked emotional awareness (EA), as measured by the Levels of Emotional Awareness Scale (LEAS), with activation in regions of neural networks associated with both conceptualization (i.e., default mode network [DMN] regions) and interoception (i.e., salience network [SN] regions) – consistent with the definition of EA as one's ability to appropriately recognize, conceptualize, and articulate the emotions of self and other in fine-grained, differentiated ways. However, no study has yet tested the hypothesis that greater LEAS scores are associated with greater resting state functional connectivity (FC) within these networks. Twenty-six adults (13 female) underwent resting state functional magnetic resonance imaging, and also completed the LEAS. Using pre-defined functional ROIs from the DMN and SN, we observed that LEAS scores were significantly positively correlated with FC between several regions of both of these networks, even when controlling for differences in general intelligence (IQ). These results suggest that higher EA may be associated with more efficient information exchange between brain regions involved in both interoception- and conceptualization-based processing, which could plausibly contribute to more differentiated bodily feelings and more fine-grained conceptualization of those feelings.

1. Introduction

It is a commonplace clinical observation that there are substantial individual differences in people's awareness of their own emotions. Specifically, some individuals appear to have a greater ability than others to understand, and clearly articulate, the emotions they are feeling. One well-established and validated measure of these individual differences in emotional awareness (EA) is the Levels of Emotional Awareness Scale (LEAS) (Lane et al., 1990; Lane and Schwartz, 1987). As measured by the LEAS, higher EA has been found to correlate positively with many adaptive traits/abilities, including self-reported impulse control (Bréjard et al., 2012), openness to feelings (Lane et al., 1990), emotion recognition ability (Lane et al., 2000, 1996), empathy (Barchard and Hakstian, 2004), and a stable sense of well-being independent of current mood (Ciarrochi et al., 2003). In contrast, lower LEAS scores have been associated with several maladaptive clinical phenomena, such as essential hypertension (Consoli et al., 2010), eating disorders (Bydlowski et al., 2005), post-traumatic stress disorder (Frewen et al., 2008), schizophrenia (Baslet et al., 2009), depression (Berthoz et al., 2000; Donges et al., 2005), borderline personality disorder (Levine et al., 1997), somatoform disorders (Subic-Wrana et al., 2005), a "disorganized attachment style" (Subic-Wrana et al., 2007), impaired insight in the context of cocaine abuse (Moeller et al., 2014), and greater pain in patients with irritable bowel syndrome (IBS) (Lackner, 2005). Thus, EA appears to represent an important individual difference variable associated with both emotional and physical health.

The neural basis of EA has also begun to receive experimental investigation. For example, two different task-based functional neuroimaging studies have demonstrated that higher LEAS scores are associated with greater activity in the dorsal anterior cingulate cortex (dACC) (Lane et al., 1998a; McRae et al., 2008) – a region of the "salience network" (SN; Barrett and Satpute, 2013) implicated in autonomic regulation (Critchley et al., 2003), attention to one's bodily states (Farb et al., 2013), and facilitating the influence of bodily feelings on action selection (Critchley, 2005; Medford and Critchley, 2010). Another study has also shown that, during recall of life-threatening experiences, healthy subjects showed greater activity in the rostral ACC (rACC) as a function of greater scores on the LEAS (Frewen et al., 2008). The rACC, and adjacent parts of the medial prefrontal cortex (MPFC), are known to comprise a significant hub of the "default mode network" (DMN) (Barrett and Satpute, 2013; Buckner et al., 2008; Li et al., 2014; Raichle et al., 2001), which refers to a set of brain regions whose activity is highly correlated at rest and which are thought to play an important role in the process of conceptualization. In combination with the results of other studies of the

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rACC/MPFC (Kalisch et al., 2006; Peelen et al., 2010; Roy et al., 2012; Smith et al., 2014b), we have previously suggested that this region, in conjunction with the rest of the DMN, may play an important role in assigning conceptual significance to bodily feelings (Lane et al., 2015; Smith and Lane, 2015) – and therefore allow such feelings to be understood in explicit emotional terms (e.g., sadness, fear, etc.). This suggestion is also consistent with another study (Tavares et al., 2011), which showed that, while subjects viewed simple animated scenarios with social/emotional content, higher LEAS scores predicted greater neural activity within abstract semantic processing regions (i.e., left anterior temporal cortex), whereas lower LEAS scores predicted more concrete action-oriented brain activation (i.e., in pre-motor cortex).

While the studies described above have examined the association between EA and task-related neural responses, it is notable that no study to date has yet examined the relation between LEAS scores and resting state measures of functional connectivity (FC) in the DMN or SN. Given that DMN regions have themselves been largely characterized using resting state connectivity measures (Buckner et al., 2008), and given the theoretical/empirical work described above supporting a link between EA and DMN regions/functions, there are strong reasons to hypothesize that LEAS scores should predict individual differences in DMN connectivity at rest. Given that EA also involves recognition/articulation of differentiated bodily feeling states, and that the SN is involved in representing bodily percepts (and using them to guide cognition and action selection), there is also reason to predict LEAS scores would be associated with better FC between SN regions. In the present study, we therefore examined the correlations between LEAS scores and individual differences in resting state FC with the hypothesis that higher LEAS scores would be associated with stronger positive connectivity between DMN regions and SN regions, respectively.

2. Materials and methods

2.1. Participants

Twenty-six adults (13 female; mean age = 23.12 ± 4.03) were recruited from the general population via flyers and internet advertisements to participate in the present study. Participants did not have any history of psychiatric or neurological disorders (assessed via a phone screen questionnaire based on criteria within the Diagnostic and Statistical Manual for Mental Disorders, 4th addition; DSM-IV-TR), and all provided written informed consent prior to participation. All participants received a nominal financial compensation for participation. The research protocol of the present study was also reviewed and approved by the Institutional Review Board of the University of Arizona.

2.2. Procedure

Upon completing the informed consent process, participants were taken to the magnetic resonance imaging (MRI) scanner at the University of Arizona where they underwent a resting state functional scan (see Neuroimaging Methods below). After completing the resting state functional scan, participants were escorted back to the lab, seated at a laptop, and asked to complete an on-line version of the LEAS (www.eleastest.net) that makes use of a validated automatic scoring program (Barchard et al., 2010).

LEAS. The LEAS presents participants with 2–4 sentence descriptions of 20 social situations, where each situation includes 2 people. The situation descriptions are designed to elicit four types of emotion (sadness, happiness, anger, and fear) at 5 levels of complexity. One situation is presented on each electronically presented page, followed by two questions: "How would you feel?" and "How would the other person feel?" Separate response boxes are provided for typing in the answers to each question. Participants are instructed to type their responses into these boxes, and they are asked to use as much or as little space as needed to answer. The only rule given is that they must use the word "feel" in their responses.

Scores reflecting EA level are assigned based on the words participants provide in their responses. The lowest scores (Level 0) are given to words that do not refer to feelings. Level 1 scores are given to words that refer to physiological sensations (e.g., "tired"), whereas level 2 scores are given to words referring to feeling-related actions (e.g., "punching") or simple valence discriminations (e.g., "bad," "good") that have inherent avoidance- or approach-related content. Level 3 scores are assigned to words referring to single emotion concepts (e.g., "happy," "sad"). Level 4 scores are given when at least 2 words from level 3 are used (i.e., when they convey greater emotional differentiation than either word alone). For each item, the self- and other-related responses are scored separately (i.e., with a value of 0–4). A "total" score is also given for each of the 20 LEAS items; this score reflects the higher of the self- and other-related scores, unless a score of 4 is given for both. In this case, a total score of 5 is given for the item, so long as the self- and other-related responses are sufficiently differentiable (for more detail, see Lane et al., 1990).

General Intelligence. Intelligence quotient (IQ) was measured with the two-subtest form (FSIQ-2) of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Pearson Assessment, Inc., San Antonio, TX; Wechsler, 2011). This was done in order to control for general intelligence when examining FC correlates of LEAS scores.

2.3. Neuroimaging methods

Neuroimaging was performed within a 3T Siemens Skyra scanner (Siemens, Erlangen, Germany) with a 32-channel head coil. T1-weighted structural images (3D MPRAGE) were acquired (TR/TE/flip angle = 2.1 s/2.33 ms/12°) covering 176 sagittal slices (256 × 256) with a slice thickness of 1 mm (voxel size = 1 × 1 x 1). Functional T2*-weighted scans were acquired over 32 transverse slices (2.5 mm thickness; matrix: 88 × 84). Each volume was collected with an interleaved sequence (TR/TE/flip angle = 2 s/25 ms/90°). The voxel size of the T2* sequence was 2.5 × 2.5 × 3.5 mm (i.e., with a 40% slice gap, allowing collection of 300 vol within a 10-min acquisition time). The field of view (FOV) was 240 mm.

2.4. Resting-state preprocessing

The publicly available CONN functional connectivity toolbox (version 16.a; https://www.nitrc.org/projects/conn), in conjunction with SPM12 (Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm), was used to perform all preprocessing steps (using CONN's default preprocessing pipeline), as well as subsequent statistical analyses, on all collected MRI scans. In this preprocessing pipeline, raw functional images were slice-time corrected, realigned (motion corrected), unwarped, and coregistered to each subject's MPRAGE image in accordance with standard algorithms. Images were then normalized to Montreal Neurological Institute (MNI) coordinate space, spatially smoothed (8 mm full-width at half maximum), and resliced to 2 × 2 × 2 mm voxels. The Artifact Detection Tool (ART; *http://www.nitrc.org/projects/artifact_detect/*) was also used to regress out scans as nuisance covariates in the first-level analysis exceeding 3 SD in mean global intensity and scan-to-scan motion that exceeded 0.5 mm. These were added in addition to covariates for the 6 rotation/translation movement parameters.

2.5. Functional connectivity analysis

Using a standard seed-driven approach, FC analyses were performed using the default FC processing pipeline in the CONN toolbox (for details, see Whitfield-Gabrieli and Nieto-Castanon, 2012). In this processing pipeline, physiological and other spurious sources of noise were estimated with the aCompcor method (Behzadi et al., 2007; Chai et al., 2012; Whitfield-Gabrieli et al., 2009); they were then removed together with