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Resting connectivity between salience nodes predicts recognition memory

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Abstract

The resting connectivity of the brain's salience network, particularly the ventral subsystem of the salience network, has been previously associated with various measures of affective reactivity. Numerous studies have demonstrated that increased affective arousal leads to enhanced consolidation of memory. This suggests that individuals with greater ventral salience network connectivity will exhibit greater responses to affective experience, leading to a greater enhancement of memory by affect. To test this hypothesis, resting ventral salience connectivity was measured in 41 young adults, who were then exposed to neutral and negative affect inductions during a paired associate memory test. Memory performance for material learned under both negative and neutral induction was tested for correlation with resting connectivity between major ventral salience nodes. The results showed a significant interaction between mood induction (negative *vs* neutral) and connectivity between ventral anterior insula and pregenual anterior cingulate cortex, indicating that salience node connectivity predicted memory for material encoded under negative, but not neutral induction. These findings suggest that the network state of the perceiver, measured prior to affective experience, meaningfully influences the extent to which affect modulates memory. Implications of these findings for individuals with affective disorder, who show alterations in both connectivity and memory, are considered.

Key words: salience network; memory; resting fMRI

Introduction

Substantial research indicates that affective experiences are associated with a group of brain regions known collectively as the salience network (Seeley *et al.*, 2007; Menon and Uddin, 2010; Touroutoglou *et al.*, 2012). This network, defined by intrinsic (resting state) functional connectivity between the anterior insula and dorsal anterior cingulate, is consistently co-activated in a broad array of psychological phenomena (see Clark-Polner *et al.*, 2016, Figure 2), including stress, pain and exposure to aversive and other salient stimuli (Kober *et al.*, 2008; Hermans *et al.*, 2014). Resting-state functional magnetic resonance imaging (fMRI) studies have shown that the strength of intrinsic connectivity between the nodes of the salience network, measured when participants are at rest, prior to any task designed to alter affective experience, predicts individual differences in self-reported anxiety, as well as subjective arousal ratings associated with viewing affective-inducing images (Seeley *et al.*, 2007; Touroutoglou *et al.*, 2012). Additionally, communication within the salience network can influence peripheral affective responses; resting salience connectivity predicts stress hormone release (Thomason *et al.*, 2011), and salience network connectivity during a stressful Stroop task predicts changes in blood pressure (Gianaros *et al.*, 2008). Recent research suggests

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that the salience network can be divided into two functionally distinct subsystems, defined by their connectivity to either the dorsal or ventral components of the anterior insula. Connectivity within the 'ventral salience network', defined by connectivity to ventral anterior insula (vAI), predicts subjective ratings or arousal and is believed to mediate the affective functions of the salience network. In contrast, connectivity within the 'dorsal salience network' defined by connectivity to the dorsal anterior insula (dAI) predicts executive function, and is believed to mediate the attentional functions of the salience network (Touroutoglou *et al.*, 2012, Figure 1).

Numerous studies of learning and memory have shown enhanced memory for both negative and neutral material learned under conditions of increased subjective and physiological arousal (LaBar and Cabeza, 2006; McGaugh, 2006). Material rated as subjectively arousing is consistently better remembered than neutral material (Bradley *et al.*, 1992; Blake *et al.*, 2001; Sharot and Phelps, 2004). Similarly, increased physiological arousal caused by acute exercise following learning enhances consolidation of both valenced and neutral material (Segal *et al.*, 2012; Weinberg *et al.*, 2014), and both endogenous and exogenous post-training cortisol levels are correlated with subsequent memory performance for both negative (Buchanan and Lovallo, 2001) and neutral material (Andreano and Cahill, 2006). Additionally, encoding-related activation of the amygdala, a key node of the salience network, has been associated with memory success in multiple studies (Canli *et al.*, 2000; Kensinger and Schacter, 2006; Sergerie *et al.*, 2006). This background led us to hypothesize that individuals with greater intrinsic connectivity within the ventral salience network should show enhanced memory, even for neutral material.

To test this hypothesis, we measured ventral salience network connectivity at rest, prior to an associative memory task performed under both high arousal, negative affect induction and neutral affect induction. We predicted that individuals with stronger ventral salience network connectivity would exhibit better recognition memory performance for neutral material encoded while in an aroused, negative affective state than individuals with weaker salience network connectivity. Support for this prediction would demonstrate two novel phenomena: (i) the ventral salience network influences normal memory function and (ii) memory for neutral material is enhanced when individuals with stronger ventral salience network connectivity are in an aroused affective state.

Participants

Forty-one adults, (21 F, 20 M, age $M = 24.24$, s.d. $= 3.5$, range $= 18$–32 years) were included in this experiment. All participants were right-handed native English speakers with normal or corrected-to-normal vision, and none reported any history of neurological or psychiatric disorder. All participants provide informed consent to participate according to the guidelines of Massachusetts General Hospital's Institutional Review Board.

Assessment of pre-scan affective state

Prior to scanning, all participants rated their current affective state in terms of both valence and arousal using the Self-Assessment Manikin (Bradley and Lang, 1994). On the valence questionnaire, participants responded to the question 'How are you feeling right now?' on a 5-point scale, where 5 represented 'Very Good', and 1 represented 'Very Bad'. On the arousal questionnaire, participants responded to the same question on a 5-point scale, where 5 represented 'Very Activated', and 1 represented 'Very Calm'.

Behavioral data acquisition: encoding and retrieval tasks

Participants attended two separate scan sessions, approximately 1 week apart. In one session, participants performed a paired associate memory task under negative affect induction, whereas in the other, the paired associate memory task was performed under neutral affect induction.

The stimulus materials included (i) Interdisciplinary Affective Picture System (IAPS) images employed for the induction component of the experiment (Lang *et al.*, 2008) and (ii) picture–word pairs employed for the memory component of the experiment. IAPS stimuli included 36 high arousal negative valence images (arousal: $M = 5.73$, s.d. $= 0.81$; valence: $M = 2.718$, s.d. $= 0.7$) and 36 low arousal neutral valence images (arousal: $M = 3.3$, s.d. $= 0.9$; valence: $M = 5.39$, s.d. $= 0.76$). Picture–word pairs included 120 face–word pairs and 120 scene–word pairs, all chosen to be affectively neutral. Face stimuli were obtained from the Center for Vital Longevity Face Database (Minear and Park, 2004) and depicted affectively neutral male and female faces from multiple age groups. Scene stimuli were obtained from the IAPS set and were selected to be neutral in valence and arousal. Words were selected from the Medical Research Council Psycholinguistic Database (Coltheart, 1981); all words

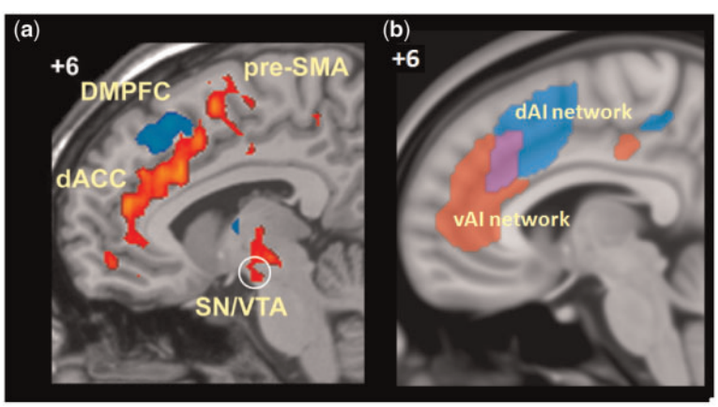

Fig. 1. (a) Salience network (red) as originally defined in Seeley *et al.* (2007). (b) Salience sub-divisions as defined in Touroutoglou *et al.* (2012), showing ventral anterior insula network (red), dorsal anterior insula network (blue) and the overlap between the two (purple). Thresholded at $Z > 0.2$.

were adjectives, selected for high frequency and high concreteness.

A schematic of the encoding and retrieval procedure for both sessions can be found in Figure 2. Each scan session comprised an affect induction run followed by an encoding run followed by three more induction and encoding runs, in alternating order. During each of the four induction/encoding runs, an affective state was induced by presenting nine images for 6 s each. Immediately following affect induction, participants performed an associative memory encoding task. Each image/word pair was presented for 6 s, and a total of 20 pairs (10 scene/word and 10 face/word) were encoded in a single run. Inter-stimulus interval was jittered around a mean ISI of 6 s, with a total of 99 s of fixation in each 225 s run. To ensure depth of encoding, participants were asked to judge whether the word 'matched' the picture. As picture/word pairs were created randomly, and pairs with an obvious semantic connection were excluded, this judgment was subjective; it was meant to prompt deeper encoding. Next, participants completed a second affect induction and a second run of associative encoding, followed by two more induction and encoding runs, for a total of four runs each.

A retention delay of approximately 10 min followed, during which other scans unrelated to these analyses were performed. After this delay, recognition testing began. Participants were presented with all 80 pairs learned during encoding, as well as 40 novel pairs made up of new words and pictures, and 40 rearranged pairs made of words and pictures seen previously, but not previously associated. Each picture was presented for 6 s, during which time the participant responded by button press whether the pair had appeared during encoding, or whether it was a new or rearranged pair (yes/no).

Approximately 1 week later, the second scan session was performed. Participants returned and underwent an identical procedure with two differences: (i) a new set of words and images were used during encoding and retrieval, and (ii) neutral, rather than negative, affect was induced during induction runs through the presentation of low arousal, neutral valence IAPS images.

In both sessions, all participants completed a brief practice session prior to scanning to familiarize them with the encoding and retrieval procedure; thus all participants were aware that their memory would be tested prior to encoding in both sessions.

Measures of memory performance

Each recognition trial was coded as a hit, miss, false alarm or correct rejection, and recognition accuracy was computed in terms of d', a measure which controls for individual response bias [$d' = z(\text{hits}) - z(\text{FA})$]. This score was computed separately to distinguish between discriminability of previously encoded pairs *vs* novel pairs (d'_{NOVEL}) and discriminability of previously encoded pairs *vs* rearranged pairs ($d'_{\text{REARRANGED}}$). These subscores were computed separately for the sessions under negative and neutral induction.

Assessment of post-scan affective state

Following scanning, participants in completed two more questionnaires assessing their affective state in terms of valence and arousal. The first questionnaire was identical to the pre-scan questionnaire, in which participants responded to the question 'How are you feeling right now?' in terms of valence and arousal. The second questionnaire asked how participants felt during affect induction. Participants were provided with an example from the affect induction (a negative, high arousal image at session 1, and a neutral, low arousal image at session 2), and responded to the question 'How were you feeling when you saw images like this in the scanner?', using the same valence and arousal scales on the self-assessment manikin as used prior to scanning.

MRI data acquisition and preprocessing

Imaging data were collected on a 3T Magnetom Tim Trio system at Massachusetts General Hospital (Siemens, Erlangen, Germany), using a 12-channel phased-array head coil. Structural MRI data were acquired using a T1-weighted 3D MPRAGE sequence [repetition time/echo time/flip angle (FA) = 2200 ms/1.54 ms/7°, resolution = 1.0 mm isotropic; Sample 2: TR/TE/FA = 2530

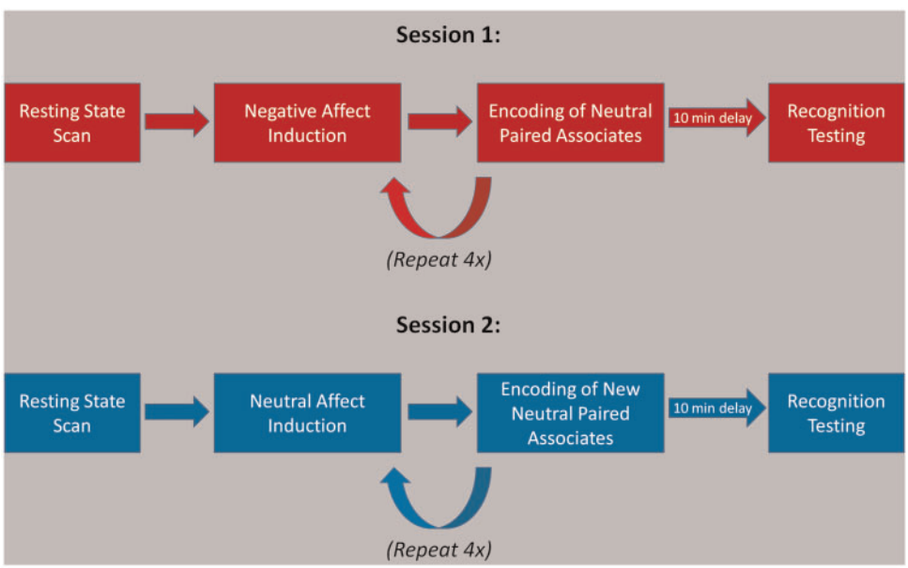

Fig. 2. Overview of experimental procedure.

ms/3.48 ms/7°, resolution = 1.0 mm isotropic]. Slices were acquired horizontally with interleaved acquisition.

Whole-brain resting-state fMRI data were acquired with echo-planar sequence (TR = 5000 ms; TE = 30 ms; FA = 90°). These parameters allowed us to obtain 55 slices and have a spatial resolution of 2.0 mm isotropic voxels. The resting-state scan was 6.40 min long and the data involved one run of 76.8 time points. During all resting-state fMRI runs, participants were directed to keep their eyes open without fixating and to remain as still as possible. Resting-state fMRI runs preceded the task-based fMRI runs.

The resting-state data were preprocessed using a series of algorithms. After removing the first four functional volumes, the following steps were completed: correction for slice-dependent time shifts, correction for head motion with rigid-body transformation in three translation and three rotations, spatial normalization to Montreal Neurological Institute (MNI305) atlas space, resampling to 2 mm isotropic voxels, spatial smoothing using a 6 mm full width at half-maximum Gaussian kernel and a low pass filter to remove frequencies > 0.08 Hz. Any time point whose total motion vector exceeded 5 mm was discarded. We then removed sources of spurious variance and their temporal derivatives from the data through linear regression (six parameters derived from the rigid-body head motion correction, the signal averaged over the whole brain, the signal averaged over a region within the deep white matter and the signal averaged over the ventricles) and the residual blood oxygenation level dependent (BOLD) time course was retained for functional connectivity analysis.

Resting-state fMRI analysis

To examine the intrinsic connectivity within the salience network, we used a hypothesis-driven seed-based resting-state functional connectivity MRI analysis (as previously published in Touroutoglou *et al.*, 2012). A 4 mm spherical region of interest was constructed around a right vAI seed (MNI: 28, 17, −15) found to anchor the ventral salience network in a previous experiment (Touroutoglou *et al.*, 2012). Using this seed, and the resting-state data acquired during the first session, we computed two measures of ventral salience network connectivity previously reported in Touroutoglou *et al.* (2012). First, we computed an average measure of connectivity between vAI and major targets within the ventral salience network, including right frontal pole (22, 54, 28), bilateral pregenual anterior cingulate (R: 2, 36, 16 L: −2, 36, 16) and bilateral ventral putamen (R: 18, 8, −8 L: −18, 6, −8). The Pearson's product-moment correlation, *r*, was computed for each pair, and averaged to produce the vAI–major targets measure. Next, we computed connectivity for a single pair of major nodes of the ventral salience network whose connectivity was the best predictor of subjective arousal in Touroutoglou *et al.* (2012): right vAI and right pregenual anterior cingulate. Additionally, we computed resting connectivity between default mode network (DMN) nodes in the hippocampus (MNI: 21, −6, −18) and posterior cingulate cortex (PCC) (MNI: 3, −51, 39), a measure that has been shown to predict memory in multiple studies (Andrews-Hanna *et al.*, 2010; Wang *et al.*, 2010b; Touroutoglou *et al.*, 2012, 2015).

To assess the influence of ventral salience connectivity, affect induction (negative *vs* neutral) and type of retrieval task (d'_{NOVEL} *vs* $d'_{REARRANGED}$) on recognition memory performance, vAI–pgACC connectivity was entered into a multiple regression analysis including induction and retrieval type as dummy-coded variables. An identical regression analysis was also performed using the 'major targets' measure of the ventral salience network.

In a subsequent analysis intended to distinguish the influence of DMN connectivity from connectivity of the salience network, a measure of default mode connectivity between two major nodes, the hippocampus and PCC, was added to the multiple regression analysis described above. The interaction between ventral salience connectivity and hippocampus–PCC connectivity was also included.

Results

Effects of picture viewing on self-reported affect

Average ratings in response to question 1 (How are you feeling right now?) and question 2 (How were you feeling when you saw images like this in the scanner?) are shown in Figure 3. Question 1 ratings were compared before and after scanning in both sessions using paired *t*-tests. Question 2 ratings were compared between the first and second sessions by the same method. For question 1, participants reported significantly more unpleasant (negative valence) after scanning compared to before scanning in the negative induction session [$P = 0.012$, $t(40) = 2.646$, $d = 0.613$, Figure 2a]. The difference between pre- and post-scan measurements, however, was non-significant [$P = 0.183$, $t(40) = 1.36$, $d = 0.4$]. During the second (neutral induction) session, pre- and post-scan measurements of affect did not differ significantly in terms of either valence [$P = 0.304$, $t(40) = 1.044$, $d = 0.17$] or arousal ($P = 0.221$, $t = 1.24$, $d = 0.21$). In response to question 2, participants rated their experience as significantly more negative [$P < 0.0001$, $t(40) = -8.48$, $d = -2.68$], and

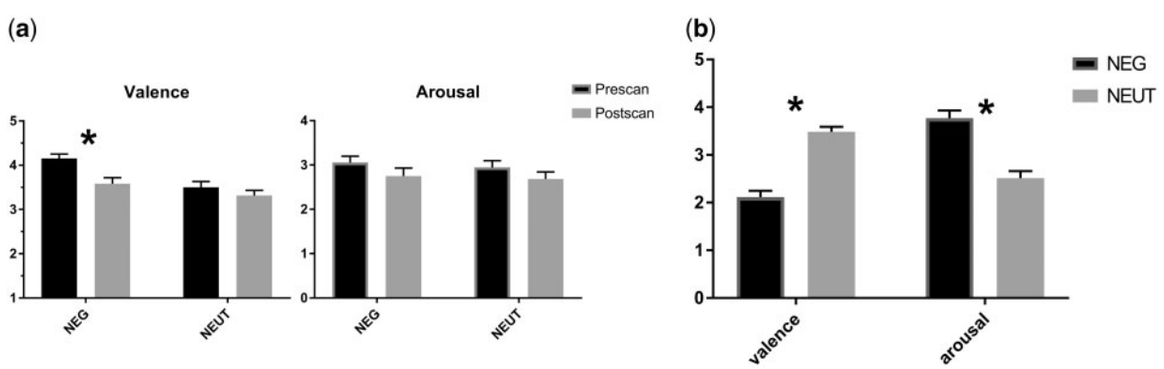

Fig. 3. (a) Average ratings of experienced valence and arousal before *vs* after the scan session, under negative and neutral affect induction conditions. *$P < 0.05$. (b) Average ratings of valence and arousal experienced during affect induction, for negative *vs* neutral induction. **$P < 0.0001$.

their arousal experience as significantly stronger [$P < 0.0001$, $t(40) = 5.114$, $d = 1.8$] while viewing images during the negative induction compared to neutral induction.

Recognition memory for material encoded under negative and neutral induction

Repeated measures ANOVA including induction (negative *vs* neutral) and memory type (novel *vs* rearranged) indicated significant effects of both induction [$P = 0.023$, $F(40) = 5.575$] and memory type [$P < 0.001$, $F(40) = 27.9$], but no significant interaction between those factors [$P = 0.153$, $F(40) = 2.12$]. Recognition memory was greater for neutral material encoded under negative induction compared to neutral induction for both memory measures. However *post hoc* testing only indicated a significant difference for d'_{NOVEL} (Figure 4).

Intrinsic salience network connectivity, mood induction, and memory

Results of the multiple regression analysis showed that a model including pgACC–vAI connectivity, induction and memory type significantly predicted recognition performance ($r = 0.311$, $P = 0.009$). No main effects of any of the factors included were significant in this model (vAI–pgACC: $\beta = 0.074$, $P = 0.59$; induction: $\beta = -0.006$, $P = 0.941$; memory type: $\beta = -0.01$, $P = 0.898$). However, the interaction between vAI–pgACC connectivity and induction was significant ($\beta = 0.233$, $P = 0.042$).

To further investigate this interaction, bivariate correlation values were computed for both memory measures under both negative and neutral induction. A significant correlation was found between vAI–pgACC connectivity and both d'_{NOVEL} ($r = 0.395$, $P = 0.012$) and $d'_{\text{REARRANGED}}$ ($r = 0.412$, $P = 0.008$) under negative induction. No significant relationships between connectivity and memory were detected under neutral induction (d'_{NOVEL}: $r = 0.075$, $P = 0.647$; $d'_{\text{REARRANGED}}$: $r = 0.157$, $P = 0.333$). These findings are summarized in Table 1. Scatterplots of the significant correlations are depicted in Figure 5. As four *post hoc* correlation tests were performed, the significance threshold was adjusted by Bonferroni correction to $P < 0.0125$. Both correlations under negative induction meet this threshold.

When the identical regression analyses were performed using the major targets measure of connectivity rather than pgACC–vAI, this model also significantly predicted memory performance ($r = 0.331$, $P = 0.003$). However, in this case, the interaction between vAI connectivity to major ventral salience targets and induction was non-significant ($\beta = 0.801$, $P = 0.424$). Similar to the previous analysis, the effects of induction ($\beta = 0.007$, $P = 0.931$) and memory type ($\beta = -0.01$, $P = 0.897$) were also non-significant; however, the effect of vAI–major target connectivity approached significance ($\beta = 0.25$, $P = 0.066$).

Resting salience connectivity and memory, controlling for default mode connectivity

Results of the multiple regression model including hippocampus-PCC connectivity in addition to the factors included in the

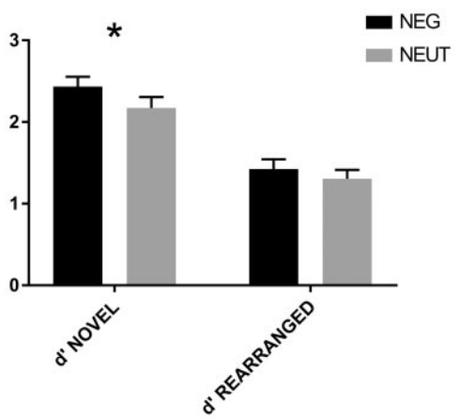

Fig. 4. Recognition performance under negative *vs* neutral affect induction. *$P < 0.01$.

Table 1. Correlation values for right ventral anterior insula–right pregenual anterior cingulate cortex under negative and neutral induction

	d'_{NOVEL}	$d'_{\text{REARRANGED}}$
Negative	0.395*	0.412*
Neutral	0.075	0.157

*, $P < 0.05$.

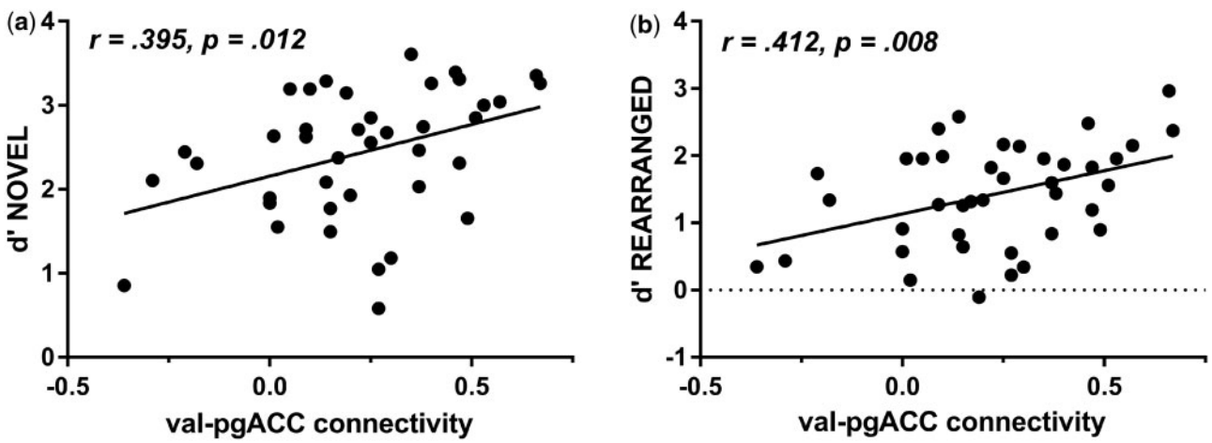

Fig. 5. Intrinsic salience network connectivity predicts memory for neutral material encoded while participants were induced into an aroused, negative mood state. Scatterplots show the relationships between ventral anterior insula–pregenual anterior cingulate cortex intrinsic connectivity at rest prior to task performance and (a) d'_{NOVEL} and (b) $d'_{\text{REARRANGED}}$ ($P < 0.05$, Bonferroni corrected).

analysis above also showed that this model significantly predicted memory ($r = 0.327$, $P = 0.015$). This model showed that the interaction between vAI–pgACC connectivity and mood induction remained significant ($\beta = 0.219$, $P = 0.048$), whereas the effect of hippocampus–PCC connectivity approached significance ($\beta = 0.149$, $P = 0.069$). The interaction between vAI–pgACC connectivity and hippocampus–PCC connectivity showed no relationship with d' ($\beta = -0.009$, $P = 0.915$).

Discussion

This study demonstrates that individual differences in the intrinsic connectivity of key salience network nodes, measured prior to either affect induction or encoding, are related to memory performance for neutral material learned under negatively arousing conditions. Individuals with greater connectivity between salience nodes exhibited superior recognition of neutral material learned under negative affect induction. Although it is well known that material learned under arousing conditions is better remembered, these findings show that individual variability in the enhancement of neutral memory by affect can be explained in part by individual differences in the intrinsic connectivity of the brain's affective circuitry. Thus, the enhancement of memory by affect depends not only on external stimuli that provoke arousal responses but also on the intrinsic functional network properties of the perceiver's brain.

These findings add a critical dimension to a growing literature demonstrating that the intrinsic connectivity of the salience network predicts both cognitive and affective functions. Previous studies have indicated that greater default mode connectivity is associated with better memory (Touroutoglou *et al.*, 2015; Wang *et al.*, 2010a,b), and that salience connectivity is associated with greater subjective and physiological arousal (Gianaros *et al.*, 2008; Thomason *et al.*, 2011; Touroutoglou *et al.*, 2012). This study is the first, however, to demonstrate a relationship between memory function and intrinsic connectivity within the ventral salience network.

As activation within the salience network has in previous studies been associated with memory only for arousing or otherwise evocative material (Canli *et al.*, 2000; Kensinger and Schacter, 2006; Sergerie *et al.*, 2006), and meta-analyses have not pointed to salience network activity during encoding as a factor predicting successful memory (Kim, 2011), it seems unlikely that the relationship observed here is due to direct participation of the salience network during memory processing. Thus the negative affect induction appears to have had a more potent effect in individuals with greater salience network connectivity, leading to a larger enhancement of memory in these individuals. Consistent with this view, multiple regression analyses showed significant interactions between vAI–pgACC connectivity and affect induction, such that salience node connectivity was predictive of memory only under negative induction.

In contrast, the more inclusive 'major targets' measure of ventral salience connectivity did not interact with the mood induction factor. Instead, this measure of connectivity approached significance in predicting memory performance irrespective of mood induction. This suggests that average ventral salience connectivity may have influenced memory performance even under neutral induction. Although subjects were induced into a neutral mood state in this condition, it should be noted that all the stimuli used were novel. As we conceptualize novelty itself as inherently affective to some degree (Weierich *et al.*, 2010), it is possible that individual differences in salience network connectivity influenced memory through its effect on the novelty response. Thus, this finding suggests that the salience network may also modulate the encoding of novel neutral experiences to some degree.

Similarly, the stimuli making up the paired associates in this experiment were all relatively neutral. Although some studies have found that arousal during encoding leads to enhanced memory for neutral stimuli (Erk *et al.*, 2003; Anderson *et al.*, 2006; Steidl *et al.*, 2006; Greene *et al.*, 2010), others have found that arousal only enhances memory for stimuli that are themselves affectively charged (Buchanan and Lovallo, 2001; Cahill *et al.*, 2003; Abercrombie *et al.*, 2006). In this study, negative affect induction prior to encoding enhanced memory for neutral material. Additionally, the intrinsic connectivity of the salience network predicted memory following negative induction, demonstrating that the salience network can influence memory for neutral material when encoding occurs in an aroused state.

A possible interpretation of the relationship between ventral salience network connectivity and memory is that individuals with greater salience network connectivity also have greater connectivity within other networks, such as the DMN, that are more directly involved in encoding. However, multiple regression analysis showed that salience network connectivity predicted memory performance independently of DMN connectivity. Thus, the contribution of ventral salience network connectivity to memory is not due to any obvious association between the connectivity of these two networks. Rather, it seems that the salience network influences memory in contexts associated with arousal in addition to the previously established relationship between the DMN and memory. Multiple regression also showed that the interaction between salience and default mode connectivity did not relate to memory, indicating that default mode connectivity does not influence the extent to which greater salience connectivity relates to superior affective memory.

Evidence that the salience and DMNs influence memory independently and without interaction may have clinical implications. If the connectivity of the DMN has no effect on the relationship between salience connectivity and memory, then individuals with impaired memory performance due to low levels of default network connectivity should still exhibit enhanced memory for arousing material, provided the salience network is intact. Consistent with this view, multiple studies of the elderly, whose DMN connectivity is reduced but whose salience network function is relatively preserved, show affective memory enhancement (Kensinger *et al.*, 2002; Denburg *et al.*, 2003; Leal and Yassa, 2014).

These findings also imply that individuals with particularly high levels of salience network connectivity should exhibit particularly strong memory for material encoded under negative affective conditions, due to an increased response to negative affect. Multiple studies suggest that individuals suffering from post-traumatic stress disorder, which is characterized by pathologically intrusive memory for negative experiences, show both greater connectivity of the insula to other salience nodes and greater stress responses than do controls (Rabinak *et al.*, 2011; Sripada *et al.*, 2012), Similarly, increased connectivity between salience network nodes including amygdala and putamen has been observed in individuals suffering from depression, who exhibit a pronounced memory bias for negative events (Palmer *et al.*, 2014).

One potential limitation of this study is the fact that the order of induction was not counter-balanced, with negative mood induction always occurring during the first session. This was done intentionally, in the interest of maximizing the

affective contrast between sessions. As novelty is inherently affective (Weierich *et al.*, 2010), presenting the negative session first allowed the arousal associated with novelty to be added to that arising from affect induction, resulting in a larger affective difference. Similarly, to the extent that participants habituated to the novelty of the procedure, this would result in a reduced affective response during the neutral session, again heightening the affective difference. It remains possible, nonetheless, that practice effects from the first session to the next may have influenced recognition performance. In this case, performance during the neutral session would have been facilitated, causing these results to underestimate the effects of affect induction on memory.

Additionally, the relatively short retention interval in this design leaves open the possibility that mood induction may have influenced retrieval in addition to encoding processes. Future studies are needed to more clearly distinguish the influence of ventral salience connectivity on encoding and retrieval. Another potential limitation is that physiological responses were not measured during induction or encoding, preventing a direct test of the interpretation that an increased arousal response mediated association between salience network connectivity and memory. Future studies should examine the relationship between salience connectivity, arousal responses and memory in a single experiment, in order to confirm that salience network connectivity influences memory through increased arousal responses in those with high connectivity.

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