

## Self-generated Unconscious Processing of Loss Linked to Less Severe Grieving

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### ABSTRACT

**BACKGROUND:** The intense loss processing that characterizes grieving may help people to adapt to the loss. However, empirical studies show that more conscious loss-related thinking and greater reactivity to reminders of the deceased correspond to poorer adaptation. These findings raise the possibility that loss processing that is unconscious rather than conscious and is self-generated rather than reactive may facilitate adaptation. Here, we used machine learning to detect a functional magnetic resonance imaging (fMRI) signature of self-generated unconscious loss processing that we hypothesized to correlate with lower grief severity.

**METHODS:** A total of 29 subjects bereaved within the past 14 months participated. Participants performed a modified Stroop fMRI task using deceased-related words. A machine-learning regression, trained on Stroop fMRI data, learned a neural pattern for deceased-related selective attention (d-SA), the allocation of attention to the deceased. Expression of this pattern was tracked during a subsequent sustained attention fMRI task interspersed with deceased-related thought probes (SART-PROBES). d-SA pattern expression during SART-PROBES blocks without reported thoughts of loss indicated self-generated unconscious loss processing. Grief severity was measured with the Inventory for Complicated Grief.

**RESULTS:** d-SA expression during SART-PROBES blocks without conscious deceased-related thinking correlated negatively with Inventory for Complicated Grief score ( $r_{25} = -.711, p < .001$ , 95% confidence interval =  $-0.89$  to  $-0.42$ ), accounting for 50% of variance. This relationship remained significant independent of demographic correlates of Inventory for Complicated Grief ( $B_{25} = -30, t = -2.64, p = .02$ , 95% confidence interval =  $-56.2$  to  $-4.6$ ). Unconscious d-SA pattern expression also correlated with activity in dorsolateral prefrontal cortex and temporal parietal junction during the SART-PROBES (voxel:  $p < .001$ , cluster:  $p < .05$ ).

**CONCLUSIONS:** Self-generated unconscious loss processing correlated with reduced grief severity. This activity, supported by a cognitive social neural architecture, may advance adaptation to the loss.

**Keywords:** Dorsolateral prefrontal cortex, Grieving, Machine learning, Mind wandering, Temporal parietal junction, Unconscious

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Early grieving is generally marked by increased mental engagement with the loss (1). This loss processing may help bereaved individuals to reconstruct meaning, reformulate their relationship with the deceased, and cope with the event of the death (2–6). Contrasting this view, empirical studies relate more loss processing with severe and unremitting grief (7–16). However, these studies identify loss processing through reactivity to reminders of the deceased or rumination. When loss processing manifests as reactivity or rumination, it is perceptually guided or conscious. Both of these attributes may account for the detrimental relationship with grieving observed in prior work.

When loss processing is perceptually guided, it occurs in reaction to explicitly presented reminders of the deceased (17–20). Such reactivity has been identified through attentional bias (12,15,21), neural responses (11), saccades (16), and approach–avoidance (22) and has been related to a poorer

outcome. The content and timing of perceptually guided loss processing depend on the external stimuli and might not reflect the elements of grieving that are relevant to the bereaved. Mental processing occurring independent of external stimulation can be described as self-generated rather than perceptually guided (17–20). Self-generated processing of the loss arises idiosyncratically and naturalistically and is therefore more likely to advance adaptation to the loss.

When loss processing gains conscious access, it is reportable, subjectively experienced, durable (23), and noticed as a thought or image related to the loss. Processing of the loss that is not subjectively experienced lacks conscious access and is therefore unconscious. Questionnaire studies relate more pronounced conscious loss processing with worse grief outcomes (7–10). Excessive thinking about the loss may represent rumination (8,10,16,24,25), which can detract from engagement in current life demands and future orientation (26).

Unconscious processing may allow the bereaved to integrate the reality of the loss in parallel with engaging with current demands and without lapsing into ruminative cycles.

In summary, prior work has investigated manifestations of loss processing whose content and context may block or reverse its potential beneficial effects. When the content of loss processing is perceptually guided, it is dependent on external stimulation and may fail to incorporate the specific needs of the bereaved individual. When the context of loss processing is conscious, it may lead to elaborative ruminative cycles that detract from engagement in ongoing demands.

We therefore sought to identify loss processing as it occurred independent of ongoing stimulation (i.e., self-generated) and without conscious access (i.e., unconscious). To do this, we tracked self-generated unconscious processing of the loss in a sample grieving a recent death using a machine-learning based neural-decoding method. Neural decoding employs multivariate pattern analysis (MVPA) on a first set of functional magnetic resonance imaging (fMRI) data to learn a pattern of brain activity associated with a target mental process. This pattern serves as a decoder for a second set of data to track the occurrence of that mental process.

We first used MVPA to delineate a neural pattern weighting matrix (i.e.,  $W$ ) representing deceased-related selective attention (d-SA) (i.e., the allocation of attention to the deceased) using a modified Stroop task (13,27). In this task, words reminiscent of the deceased are presented in different colors, and subjects report the color of each word as fast as possible. Attention to the meaning rather than the color of the word comprises a parallel process that slows down reaction time (RT) to report the color (27,28). When the words presented are reminders of the deceased, slower RT indicates greater allocation of attention to the deceased. While other processes may also influence RT to deceased-related words such as sustained attention, semantic processing, arousal, and motor processing, we controlled for these processes using task regressors and alternate Stroop conditions.

Hence, the model learned a pattern of fMRI activity predictive of longer RTs to deceased-related words (Figure 1A). This selective attention to the deceased occurs in parallel with the main task, which is to name the color of each word (27). While d-SA occurring during the Stroop task is not necessarily unconscious or self-generated, this type of parallelized allocation of attention to off-task deceased-related information likely occurs during self-generated unconscious processing of loss as well, where some degree of attention to the loss is siphoned away from ongoing conscious activities to allow for unconscious loss processing. For this reason, d-SA, as identified through a Stroop task, can serve to track loss processing occurring during a second task.

We next used the d-SA pattern to decode neural activity during 10-minute neutral sustained attention to response task probes (SART-PROBES) (29), in which interspersed probes queried deceased-related thinking (Figure 1B). The SART provides a relatively nonstimulating environment that is optimized to promote mind wandering while maintaining low-level on-task focus (29,30). While the thought probes presented during the SART may cue deceased-related processing, we

collected brain data occurring after the probe was presented, and thus deceased-related processing during this time period is self-generated rather than perceptually guided (17). As a result, engagement of d-SA during blocks of SART-PROBES in which no thoughts of loss were reported implies processing of the loss that is both unconscious and self-generated (Figure 1C), which we hypothesized to be correlated with less grief severity.

Data from both the Stroop task and SART have been used previously. Data from the Stroop task alone were used for a study investigating attentional bias to the deceased (13). Data from the SART were used to test the ability of a separate neural decoder to predict conscious thoughts (31). The current study did not investigate attentional bias or conscious thought prediction. Rather, we report a Stroop-based neural decoder to interpret brain activity occurring during the SART in the absence of conscious thoughts as a measure of self-generated unconscious processing of the loss.

## METHODS AND MATERIALS

### Subjects and Recruitment

A total of 29 people bereaved of a first-degree relative or partner within the past 14 months were enrolled. Of these, 20 people were bereaved by suicide and had been recruited as part of a suicide bereavement study. Subjects were 18 to 65 years old, had normal color vision, and were native English speakers. Recruitment was done through postings on social media websites. Subjects were medically healthy as determined by medical history, examination, and standard blood/urine tests. Exclusion criteria were current bipolar disorder (i.e., manic episode within the past year), current substance use disorder (i.e., met criteria within past 6 months), current obsessive-compulsive disorder, and lifetime schizophrenia or schizoaffective disorder assessed with the Structured Clinical Interview for DSM-IV Axis I (32). Subjects taking psychiatric medications were required to be on a stable dose for 2 weeks prior to scanning. Subjects taking benzodiazepines or sleep medications refrained from using these medications for 72 hours prior to scanning. The New York State Psychiatric Institute Institutional Review Board approved this study, and all subjects gave written informed consent.

### Procedure

Between 3 and 14 month postloss, subjects underwent a prescan interview, an MRI scan, and then a postscan interview. Both interviews occurred within 1 week of the scan. Grief severity was measured with the Inventory for Complicated Grief (ICG) (33). During the prescan interview, subjects provided words describing the deceased and a relationship-matched living control for use in the Stroop task. During the postscan interview, subjects completed all structured interviews and questionnaires.

### Magnetic Resonance Imaging

Full details of MRI imaging and preprocessing are provided in the Supplement.

**Tasks**

**Deceased-Related Selective Attention Task.** A Stroop task was used to define the neural pattern corresponding to d-SA. Across four runs, each run consisted of four blocks of words: deceased, living, congruent, and incongruent. In deceased and living blocks, the words provided by the subject describing the deceased and living attachments were presented in red, green, or blue. In congruent blocks, the words “red,” “green,” and “blue” were presented in the corresponding colors. In incongruent blocks, the color words were presented in a different color. Subjects were instructed to indicate the color of the word font as quickly as possible. Task training and presentation is described in full in our prior work (13).

**Sustained Attention to Response Task Probes.** In the SART-PROBES, subjects pressed a button every time a number came onscreen except for the number 3. Numbers were presented for 1.5 seconds, with an intertrial jitter averaging 2 seconds. The number 3 was presented 11% of the time to ensure subject engagement. Trials were presented in blocks ranging from 25 to 35 seconds. Following each block, binary thought probes assessed thoughts about the deceased, the living control, and the self occurring in the past block. Subjects completed 16 blocks. This task provides low-level attentional engagement in the context of which processing of loss can be self-generated unconsciously (29,34) and is described fully in our prior work (31).

**Analyses**

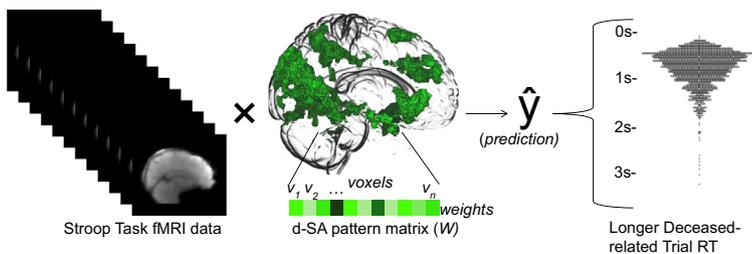
This study involved three broad goals, namely to 1) identify a neural pattern for d-SA based on MVPA analyses of the Stroop fMRI tasks, 2) track the continuous expression of d-SA during the SART-PROBES, and 3) relate d-SA expression during blocks of the SART-PROBES without loss-related thoughts (i.e., self-generated unconscious processing of loss) to grief severity.

**Identifying a Neural Pattern for d-SA**

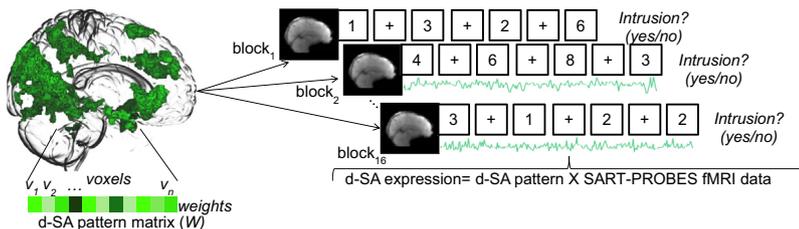
Prior to learning a multivariate d-SA neural pattern, we first used a univariate analysis to identify a mask of voxels involved in d-SA. In the Stroop task, longer RTs to deceased-related words serve as a proxy for attention to the deceased. To identify voxels associated with d-SA, we therefore correlated voxelwise blood oxygen level-dependent (BOLD) signal with longer RTs to deceased-related words [deceased-related (BOLD × RT)].

This feature selection allowed us to control for button pressing, sustained attention, and motor processing subtracted voxels correlation with RT to congruent words [deceased-related (BOLD × RT) – congruent (BOLD × RT)]. To ensure that neural response to RT reflected attentional processing rather than neural reaction to the substantial semantic differences between deceased-related and color-congruent words, a trial level on/off regressor was included. We have previously shown that the process of d-SA likely comprises a

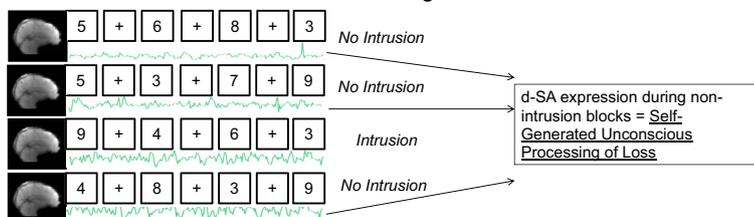
**A Pattern Learning Task: Modified Stroop**



**B Pattern Expression Task: SART-PROBES**



**C Self-Generated Unconscious Processing of Loss**



**Figure 1.** Identifying self-generated unconscious processing of loss. **(A)** A modified Stroop functional magnetic resonance imaging (fMRI) task was used to learn a neural pattern corresponding to deceased-related selective attention (d-SA). To do this, a machine-learning regression delineated a voxelwise d-SA weighting matrix (green) that optimized the prediction of longer reaction times (RTs) to deceased-related words from trial-level Stroop fMRI data. **(B)** Subjects completed 16 blocks of an extended neutral sustained attention task (SART-PROBES). During this task, they were instructed to push a button every time they saw a number except for the number 3, and intermittent probes assessed the occurrence of a thought about the deceased (i.e., an intrusion). The d-SA weighting matrix identified in the prior step was applied to fMRI data produced during the SART-PROBES. Expression of the d-SA neural pattern indicated the similarity between SART-PROBES neural data at each time point and the neural pattern associated with slower Stroop trials (green oscillations). This served as an ongoing measure of d-SA transpiring during the SART-PROBES. **(C)** Expression of the d-SA neural pattern during SART-PROBES blocks without reported thoughts of loss was taken as a measure of self-generated unconscious processing of the loss.

subset within a broader process of attachment-related attention (13,35). As a result, the contrast of deceased-related versus congruent words, rather than deceased-related versus living words, was used. For this analysis, we employed a threshold of voxel  $p < .01$  and cluster-corrected  $p < .05$ . This lenient threshold was used for this preparatory analysis in order to incorporate more information into the subsequent MVPA.

### Pattern Learning

To develop the d-SA neural pattern, MVPA predicted RT to deceased-related words based on Stroop fMRI activity within the prespecified mask. A spatial filter, represented by a weighting vector  $W$ , was developed to optimally predict d-SA by exploiting the relations between voxels within the pattern. This spatial filter  $W$  is optimized across multiple iterations of the prediction of RT. The  $W$  that best predicts RT is then selected as the pattern decoder. Full details of the MVPA are provided in the [Supplement](#).

### Tracking of d-SA Pattern Expression During the SART-PROBES

The decoder identified in the pattern-learning step was next applied to the SART-PROBES dataset. Four-dimensional time series of SART-PROBES data were registered to standard space, and motion effects were regressed out using 6° motion regressors. Each time series was standardized by its own mean and standard deviation. Blocks of SART-PROBES with errors (i.e., omissions or commissions) were excluded from subsequent analyses because of the potential effects of errors on metacognitive processes occurring during this task.

Pattern expression was estimated by applying the d-SA pattern decoder (i.e.,  $W$ ) to the SART-PROBES fMRI data. Model application entails voxelwise multiplication of the  $W$  in the preselected feature masks with the values for the new BOLD data, followed by a linear summation across voxels. This produces repetition time (TR)-by-TR d-SA pattern expression. Greater d-SA pattern expression at a given time point indicates higher neural similarity to slower Stroop trials and therefore higher likelihood that d-SA is occurring.

### Unconscious Pattern Expression

We next calculated blockwise averages of d-SA pattern expression for each of the 16 SART-PROBES blocks. Each block was labeled as an intrusion or nonintrusion block based on whether the subject reported thinking about the deceased over the course of that block. Subject-level averages of d-SA output were calculated for intrusion blocks (i.e., conscious processing of loss) and nonintrusion blocks (i.e., unconscious processing of loss) separately. To account for the hemodynamic response delay, we applied the model starting at the fourth TR following each probes period and into the second TR into the next probes period. Average d-SA expression taken from nonintrusion blocks was correlated with ICG score, a measure of grieving severity.

We refer to d-SA expression occurring during blocks of SART-PROBES with no reported thoughts of loss as unconscious. This delineation of unconscious is entirely based on the lack of conscious access that is identified by subjective report

(23) and is not rooted in the training or application of the d-SA pattern itself. While the d-SA pattern was trained during a conscious time period (i.e., the Stroop), its occurrence in the absence of subjectively experienced thoughts of loss denotes an unconscious processing of the loss.

Because the neural pattern was derived during the Stroop task, which is conscious, it is possible that the derived pattern corresponds to conscious processing of the loss, which may be inherently related to ICG. To preclude this possibility, we also calculated conscious d-SA expression from d-SA output during SART-PROBES blocks with reported thoughts of loss. A control analysis was conducted estimating the relationship between conscious d-SA and ICG. If d-SA were biased to be related to ICG, then this analysis would yield a significant correlation as well.

### Functional Neuroanatomy of Self-generated Unconscious Processing of Loss

Finally, we sought to identify the functional neuroanatomy of self-generated unconscious processing of loss. We computed individual general linear models for each subject's SART-PROBES fMRI data on residualized data that removed the effect of responding to SART trials and errors. Each model included a regressor for d-SA pattern expression and block label (i.e., intrusion/nonintrusion) and the interaction between the two (i.e., d-SA  $\times$  intrusion/nonintrusion). A fixed-effects analysis calculated average voxel activity associated with the interaction of d-SA and intrusion/nonintrusion label (voxel:  $p = .001$ ; cluster:  $p < .05$ ).

## RESULTS

**Table 1** describes the sample demographics. The ICG mean score of 26.14 (SD = 12.84) indicates generally severe grief, although scores had a wide range (1–50). Axis I disorders included major depressive disorder and the following anxiety disorders: generalized anxiety disorder, posttraumatic stress disorder, and specific phobia. Ten subjects met criteria for complicated grief on the basis of an ICG score of 30 or above and 6 months elapsed since loss (1). ICG score correlated with time since loss, income, a current diagnosis of major depressive disorder, number of previous depressive episodes, length of lifetime depression diagnosis, current psychiatric medication use, and as-needed benzodiazepine/sleep medication use (not used for 72 hours before scan) (**Table 1**).

### d-SA Feature Selection and Pattern Learning

In the Stroop task, BOLD activation in lateral occipital cortex, temporal fusiform gyrus, subgenual cingulate, orbital frontal cortex, and anterior insula, among other regions, correlated with slower deceased-related trial RT. Engagement of these regions in slower responses to deceased-related trials indicates involvement in d-SA. Subsequently, the d-SA pattern-learning algorithm predicted RT from the neural data within this mask ( $p = 10^{-3}$ ). This  $p$  value may be artificially decreased owing to the preselection provided by the univariate analysis. We present this  $p$  value only to demonstrate that the MVPA was successful and therefore the derived  $W$  matrix can be relied on. This analysis provided a spatially distributed neural pattern (i.e.,  $W$ ) ([Supplemental Figure S1](#)

## Self-generated Unconscious Processing of Loss

**Table 1. Sample Description (N = 29)**

	Mean	SD	Correlation With ICG
Age, Years	44	13	-.26
Months Since Loss	8.06	3.79	.64 <sup>b</sup>
Education, Years	16.44	1.90	.05
	<i>n</i>	%	
Household Income			-.39 <sup>a</sup>
>\$70,000	18	62.1	
\$60,000–\$69,000	6	20.7	
\$50,000–\$59,000	1	3.4	
\$40,000–\$49,000	0	0	
<\$39,000	4	13.8	
Marital Status Single	11	37.9	.19
Male Subjects	6	20.7	-.25
Current Major Depressive Disorder	10	34.5	.63 <sup>b</sup>
Years since first diagnosis, range	1–36		.49 <sup>a</sup>
Prior depressive episodes			.45 <sup>a</sup>
0 Episodes	14	48.3	
1 Episode	7	24.1	
2 Episodes	4	13.8	
3 Episodes	2	6.9	
5 Episodes	2	6.9	
Current Anxiety Disorder	5	17	.17
Current Psychiatric Medication Use	10	34.5	.51 <sup>b</sup>
SSRI	6	20	.14
Atypical antipsychotic	2	6	n/a
Bupropion	1	3	n/a
Anticonvulsant	1	3	n/a
SSNRI	1	3	n/a
PRN Use of Benzodiazepines or Sleep Medications <sup>c</sup>	7	24	.51 <sup>b</sup>

Household income was coded with five interval levels of >\$70,000, \$60,000–\$69,000, \$50,000–\$59,000, \$40,000–\$49,000, and \$30,000–\$39,000. Psychiatric medication use was coded as a binary variable corresponding to whether or not a subject was currently using a psychiatric medication.

ICG, Inventory for Complicated Grief; n/a, not applicable; PRN, as-needed; SSNRI, selective serotonin norepinephrine reuptake inhibitor; SSRI, selective serotonin reuptake inhibitor.

<sup>a</sup> $p < .05$ .

<sup>b</sup> $p < .01$ .

<sup>c</sup>Subjects with a PRN prescription of benzodiazepines or sleep medications refrained from using these medications for 72 hours prior to scanning.

and Supplemental Table S1) to be used for decoding the SART-PROBES data.

### Sustained Attention to Response Task Probes

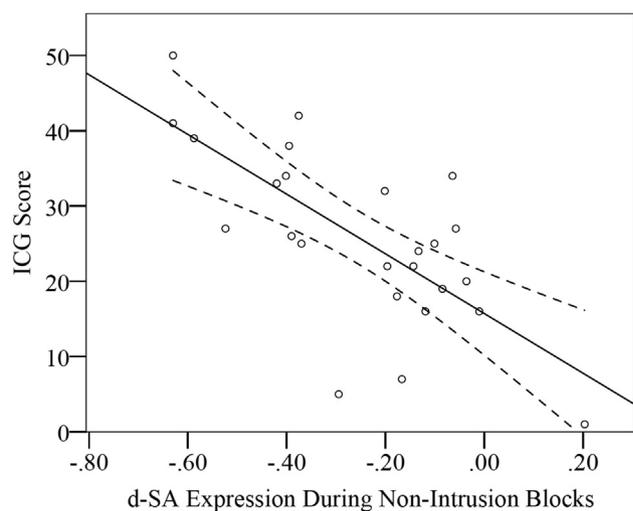
Two subjects did not complete the SART-PROBES due to time limit in the scanner. Of the 27 subjects who completed the SART-PROBES, 25 produced at least one block with no intrusions or errors (mean = 7.6, SD = 3.39, range = 1–13). One outlier value for d-SA fell outside of the interquartile range and was censored down to the next closest value. As previously reported, there was no significant relationship between intrusions and errors (31).

### Self-generated Unconscious Processing of Loss and Grief Severity

Higher average d-SA output during nonintrusion blocks (i.e., self-generated unconscious processing of loss) correlated with lower ICG score, accounting for 50% of variance ( $r_{25} = -.711$ ,  $p < .001$ , 95% confidence interval [CI] =  $-0.89$  to  $-0.42$ ) (Figure 2). By contrast, d-SA output during conscious intrusion blocks did not correlate with ICG scores ( $r_{19} = -.195$ ,  $p = .43$ , 95% CI =  $-0.61$  to  $0.34$ ).

d-SA output during nonintrusion blocks accounted for 30% of the variance in ICG score when controlling for current diagnosis of major depressive disorder, number of previous depressive episodes, length of lifetime depression diagnosis, time since loss, psychiatric medication use, and household income ( $B_{25} = -27$ ,  $t = -2.44$ ,  $p = .02$ , 95% CI =  $-50$  to  $-3$ ) (Supplemental Table S2). To investigate potential effects of medication type, we computed this regression while controlling for selective serotonin norepinephrine reuptake inhibitor use as well as as-needed use of benzodiazepines or sleep medications (although subjects in this latter category had not used these medications for 72 hours), d-SA accounted for 55% of variability in ICG when controlling for these factors ( $B_{25} = -37$ ,  $t = -4.56$ ,  $p < .001$ , 95% CI =  $-55$  to  $-20$ ).

Within the suicide-bereaved sample alone, d-SA expression during nonintrusion blocks accounted for 53% of variance in ICG score ( $r_{18} = -.73$ ,  $p < .001$ , 95% CI =  $-0.91$  to  $-0.41$ ) (Supplemental Figure S2). Nevertheless, the findings in the whole sample were not entirely driven by suicide bereavement given that d-SA expression accounted for 44% of variance in ICG score when controlling for loss type ( $B_{25} = -29.68$ ,  $t = -4.29$ ,  $p < .001$ , 95% CI =  $-44.02$  to  $-15.34$ ) (Supplemental Table S3). These findings also remained when employing only the original 23 subjects whose data contributed to the training models (Supplemental Figure S3).



**Figure 2.** Grief severity and self-generated unconscious processing of loss. Deceased-related selective attention (d-SA) expression during non-intrusion blocks of the sustained attention to response task probes (i.e., self-generated unconscious processing of loss) correlated inversely with grief severity as measured by the Inventory for Complicated Grief (ICG). Dotted lines display 95% confidence intervals.

### Control Analyses

It is possible that the relationship between unconscious d-SA expression and ICG score was a function of directed versus nondirected thinking rather than deceased-related processing. Control analyses accounted for directed thinking in the pattern training and expression steps, respectively.

Directed thinking in the pattern-training step was identified by general selective attention (g-SA). In the Stroop task, g-SA is the difference in RT to incongruent versus congruent color words (36). Responding to incongruent words involves more directed thinking and focus than responding to congruent words, and therefore this pattern can delineate mental processing relating to effort and directed thinking. Hence, an identical analysis was performed replacing deceased-related words for color-incongruent words in the pattern-learning step. The derived g-SA pattern was next applied to SART-PROBES data, and the resulting output from nonintrusion SART-PROBES blocks was calculated. g-SA pattern expression during nonintrusion blocks of the SART-PROBES did not correlate significantly with ICG score ( $r_{25} = .26$ ,  $p = .20$ , 95% CI =  $-0.16$  to  $0.61$ ).

To control for directed thinking in the pattern expression step, we extracted d-SA output during the SART-PROBES based on whether subjects had reported a self-related thought during a given block. Thoughts of the self comprise a form of directed thinking occurring during the SART-PROBES aside from deceased-related thinking. d-SA output from SART-PROBES blocks with no reported self-related thoughts did not significantly correlate with ICG ( $r_{25} = -.28$ ,  $p = .17$ , 95% CI =  $-0.60$  to  $0.11$ ).

### Validation of d-SA Expression

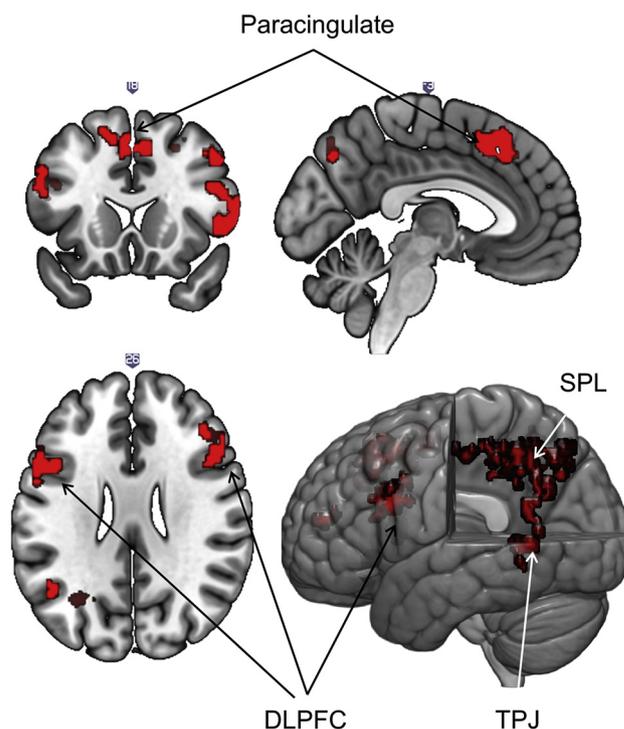
To validate d-SA pattern expression during the SART-PROBES as a measure of deceased-related processing, we calculated a paired-samples  $t$  test comparing d-SA expression during blocks with and without conscious thoughts of loss. While a significant amount of processing may occur unconsciously, it remains likely that, as a measure of deceased-related thinking, d-SA would be higher during blocks with conscious thoughts of loss. As expected, d-SA expression was higher during blocks with conscious thoughts of loss (mean =  $-0.09$ , SD =  $0.21$ ) than during blocks without them (mean =  $-0.28$ , SD =  $0.21$ ), paired-samples  $t_{16} = -2.55$ ,  $p = .02$ , 95% CI =  $-0.32$  to  $-0.04$ .

### Functional Neuroanatomy of Self-generated Unconscious Processing of Loss

During the SART-PROBES, greater d-SA activation during nonintrusion blocks correlated with BOLD signal in superior frontal gyrus, dorsolateral prefrontal cortex, superior parietal lobe, and temporal parietal junction, among other regions (Figure 3 and Table 2).

### DISCUSSION

We identified self-generated unconscious loss processing by measuring ongoing fluctuations in a neural proxy of d-SA during a neutral task. Engagement of d-SA during this task, in the absence of a conscious thought of the deceased, correlated with less severe grieving. These findings shed light on



**Figure 3.** Clusters engaged by self-generated unconscious processing of loss. Voxel clusters whose blood oxygen level-dependent activity during nonintrusion blocks of the sustained attention to response task probes correlated with greater deceased-related selective attention pattern expression (i.e., self-generated unconscious processing; voxel:  $p < .001$ ; cluster:  $p < .05$ ). Multiaxial image centered on Montreal Neurological Institute (mm) coordinates:  $x = 16$ ,  $y = -3$ ,  $z = 26$ . DLPFC, dorsolateral prefrontal cortex; SPL, superior parietal lobe; TPJ, temporal parietal junction.

some of the unconscious and self-generated processes involved in grieving.

A central question in the bereavement field has been the role of grief work (i.e., the painful experiences of grief and engagement with reminders of the deceased) in adaptation to the loss (2,37). These experiences are thought to contribute to acceptance and adaptation to the reality of loss (2–6). At the same time, empirical work shows that greater reactivity to deceased-related stimuli and conscious thinking about the loss correspond with worse grief outcomes (7–12,15,21,22). Self-generated unconscious processing of the loss may allow bereaved individuals to adapt to the reality of the loss in a way that emphasizes their specific individual needs without becoming overwhelmed by loss-related thinking and rumination. This is the first study to date to assess this type of loss processing and, consequently, is one of the first studies to identify a relationship between loss processing and adaptation to the loss.

This interpretation posits self-generated unconscious loss processing as a dynamic element of the grief trajectory. This interpretation is made with the caveat that these findings are cross-sectional. Hence, self-generated unconscious processing might not influence the course of grieving at all but may simply be a trait of people with less severe grief. For example, prior episodes of depression that correlate to ICG score may

**Table 2. Clusters Associated With Self-generated Unconscious Processing of Loss**

	Cluster Center (MNI Coordinates), mm			Voxel Number	Average Z-Score
	x	y	z		
Angular Gyrus	44.13	36.18	55.88	272	3.48
Frontal Operculum	20.82	71.82	36.18	11	3.42
Frontal Orbital Cortex	20.67	78.25	29.19	64	3.48
Frontal Pole	49.90	85.59	43.75	108	3.38
Inferior Frontal Gyrus	36.21	71.55	44.48	368	3.45
Lateral Occipital Cortex	53.80	29.54	57.19	406	3.67
Middle Frontal Gyrus (DLPFC)	26.14	71.09	56.78	772	3.56
Middle Temporal Gyrus (TPJ)	75.55	35.60	38.77	110	3.47
Paracingulate Gyrus	44.84	73.77	58.56	261	3.52
Postcentral Gyrus	67.45	48.29	62.33	82	3.36
Precentral Gyrus	51.38	64.51	55.65	130	3.30
Precuneus	46.36	27.02	57.90	91	3.36
Superior Frontal Gyrus	44.47	74.50	61.35	273	3.54
Superior Parietal Lobule	62.63	37.52	60.96	245	3.73
Supramarginal Gyrus	53.96	41.35	59.19	214	3.49

Clusters whose blood oxygen level–dependent activity during nonintrusion blocks of the sustained attention to response task probes correlated with deceased-related selective attention (d-SA) pattern expression (voxel:  $p < .001$ ; cluster:  $p < .05$ ). This analysis controlled for the main effects of both d-SA expression and reported thoughts of loss. These results reflect the interaction of d-SA expression with reported thoughts of loss. Specifically, these clusters were engaged by higher d-SA expression when no thoughts of loss were reported.

DLPFC, dorsolateral prefrontal cortex; MNI, Montreal Neurological Institute; TPJ, temporal parietal junction.

also be a feature that plays a role in loss processing. Future longitudinal studies are needed to address the nature of self-generated unconscious loss processing as a trait or state characteristic.

The brain regions associated with self-generated unconscious processing of the loss are consistent with the roles of updating and modifying representations of the deceased. Regions involved in social processing and mental abstraction, such as temporal parietal junction, lateral occipital cortex, and superior parietal lobe, might modify and update the representation of the deceased (38–40), while dorsolateral prefrontal cortex might exclude this grief processing from consciousness (41). Nevertheless, these regions may simply reflect neural reaction to and regulation of representations of the deceased.

### Unconscious and Self-generated

During the SART-PROBES, thought probes occurred every 25 to 35 seconds. Hence, thoughts occurring early in the block may have been forgotten at a later time. As a result, pattern expression during a block labeled as a nonintrusion block may have occurred during a conscious intrusion. Nevertheless, the average of pattern expression was extracted for each block. Even if people forgot some of their conscious thoughts, it is

likely the case that, on average, nonintrusion blocks had fewer conscious thoughts than intrusion blocks. Pattern expression during nonintrusion blocks is thus more likely to be unconscious than pattern expression during intrusion blocks.

The SART combined with experience sampling, or thought probes, serves to assay self-generated processing (29,30,34). This type of processing occurs independent of the external environment (17). However, the label “self-generated” remains agnostic to the source of mental activity. While thought probes presented during the SART may have cued deceased-related thinking, d-SA occurring in parallel with the SART trials was decoupled from the current perceptual environment and therefore was self-generated.

### Limitations

This study was conducted with a relatively small sample and used a cross-sectional design, and findings require replication and validation with a larger longitudinal sample. Grieving is a dynamic process, and a postloss time range of 3 to 14 months may have introduced heterogeneity into our sample that could be eliminated with a more constrained sample. While we controlled for mental processes potentially contributing to RT by contrasting with color-congruent words in the univariate analysis and incorporating a semantic regressor, a better control would be a nonattachment control person condition. We did not include formal measures of rumination, which would have allowed the parsing of the relationship between unconscious processing and general and grief-related rumination.

### Future Studies

This study presents an initial demonstration of how the d-SA pattern can be used to identify unconscious loss processing in the absence of conscious thoughts of loss. Nevertheless, the relationship of this pattern to actual thoughts of loss remains unclear. Future studies should assess how well this pattern predicts thoughts of loss at the individual level in a real-time fMRI setting. This would further validate the d-SA pattern as a component of the conscious or unconscious processing of loss.

The univariate approach used for feature selection was chosen owing to the lack of a strong body of knowledge regarding neural correlates of deceased-related attention. Nevertheless, this approach raises concerns of circularity as the MVPA repeats the univariate analysis. This is a limitation of the current study. A more rigorous approach would be to adopt a leave-one-out training procedure for both the univariate and multivariate analyses. Given the small size of the sample and the lack of preexisting knowledge about deceased-related attentional processes, we adopted the current approach. Future studies with larger samples can use a more hypothesis-driven approach by adopting the weighting matrix presented here in a directed fashion or by employing leave-one-out procedures throughout all training steps.

### Conclusions

This study identified self-generated unconscious loss processing through expression of a neural pattern for deceased-related attention during a neutral task in the absence of

reported thoughts of loss. Greater self-generated unconscious processing of loss correlated with less grieving severity, and concurrent neural activity in temporal parietal junction and dorsolateral prefrontal cortex indicated a combination of social processing and conscious control. A longitudinal study can test whether such processing facilitates more successful adaptation to the loss.

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