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Ongoing monitoring of mindwandering in avoidant grief through cortico-basal-ganglia interactions

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Abstract

An avoidant grief style is marked by repeated and often unsuccessful attempts to prevent thinking about loss. Prior work shows avoidant grief involves monitoring the external environment in order to avoid reminders of the loss. Here we sought to determine whether avoidant grievers also monitor the internal environment in attempts to minimize conscious awareness of loss-related thoughts. Individuals bereaved of a first-degree relative, spouse or partner within the last 14 months participated in a functional magnetic resonance imaging (fMRI) study ($N = 29$). We first applied machine learning to train neural patterns for attentional control and representation of the deceased ($N = 23$). The attentional pattern was trained using fMRI data from a modified Stroop task assessing selective attention to reminders of the deceased. The representational pattern was trained using fMRI data from a task presenting pictures and stories of the deceased. We observed spontaneous fluctuations in these processes occurring during a neutral mindwandering fMRI task ($N = 27$). At higher levels of avoidant grieving, activation of attentional control disrupted the relationship between the representational process and thoughts of loss. These findings show that avoidant grief involves attentional control to reduce the likelihood that deceased-related representations reach full conscious awareness.

Key words: MVPA; grieving; mindwandering; basal ganglia; frontotemporoparietal

Introduction

Avoidant grieving describes a grief style aimed at preventing thoughts of loss from occurring and suppressing them out of consciousness when they do (Shear, 2010; Stroebe and Schut, 2010). Avoidant grievers show more difficult grieving and, para-doxically, more frequent thoughts of loss (Bonanno *et al.*, 2005; Eisma *et al.*, 2013; Eisma *et al.*, 2014; Eisma *et al.*, 2015a). By contrast, those who have less frequent thoughts of loss without exerting effort to do so have better outcomes (Bonanno *et al.*, 2002). The ongoing effort and failure to prevent thoughts of loss therefore comprise a central dynamic in avoidant grieving.

To prevent thinking of the loss, avoidant grievers are hypervigilant in monitoring the environment for potential reminders of the loss. Monitoring of the external environment has been shown through a faster tendency to push and saccade away from reminders of the deceased (Eisma *et al.*, 2014; Eisma *et al.*, 2015a). Such monitoring underlies an effort to minimize encounter with external reminders of the deceased. However, when mental processing decouples from the environment (i.e. mindwandering), self-generated thoughts arise from the internal environment (Schooler *et al.*, 2011; Smallwood and Schooler, 2015). Avoidant grief may therefore involve monitoring the contents of mindwandering in an attempt to prevent self-generated thoughts of loss. Mindwandering occupies nearly 50% of mental activity (Killingsworth and Gilbert, 2010) and is inherently unpredictable. As a result, continuous monitoring of the contents of mindwandering may occupy a significant amount of the cognitive reserve available to avoidant grievers.

While the external environment contains physical reminders of the loss, the internal environment contains mental representations that may precipitate a thought of loss. Deceased-related mental representations (d-MRs) describe the network of information symbolizing the deceased. Thoughts of loss arising during mindwandering can be predicted by activation of a neural d-MR network. Moreover, avoidant grievers experience more intense activation of these representations and subsequently more frequent thoughts of loss (Schneck *et al.*, 2017). These findings suggest that mental representations contribute to thoughts of loss and that avoidant grievers attempt to suppress these representations, ironically increasing their salience and frequency. These results accord with general research about the salience increasing effect of attempted suppression (Wegner, 1994). Hence, mental representations of the deceased likely comprise the target for which avoidant grievers scan their internal environment. Once identified, avoidant grievers can attempt to block such representations from reaching consciousness.

This type of attempted control over the mind relies on what has been termed an ironic process, which searches the mental state for undesired or inconsistent content, which the person can then attempt to suppress from reaching consciousness (Wegner, 1994). In grieving, deceased-related selective attention (d-SA) has been shown to identify reminders of the deceased presented externally (Schneck *et al.*, 2018b) and may identify such reminders arising internally. This attention can serve several functions depending on grief style and context. In general grieving, this attention increases immediate engagement with explicitly presented reminders of the deceased (Schneck *et al.*, 2018b) and can be activated independently of conscious loss processing during mindwandering (Schneck *et al.*, 2018a). However, in avoidant grieving during mindwandering, selective attention can serve as the ironic process that searches the internal mental space for potential reminders of the deceased to suppress from consciousness (Dehaene and Naccache, 2001). Similar processes of vigilant avoidance, in which people scan the environment for reminders of a threat and then suppress reactions to those reminders, have been identified in repressive coping (Derakshan *et al.*, 2007). We aimed to demonstrate that avoidant grievers employ selective attention (i.e. d-SA) during mindwandering to block arising mental representations (i.e. d-MR) from reaching consciousness.

To test this possibility, we observed ongoing interactions between deceased-related representational (d-MR) and attentional systems (d-SA) during mindwandering. As displayed in Figure 1, our model suggests that during a period of mindwandering, avoidant grievers (darker yellow) employ d-SA (red)
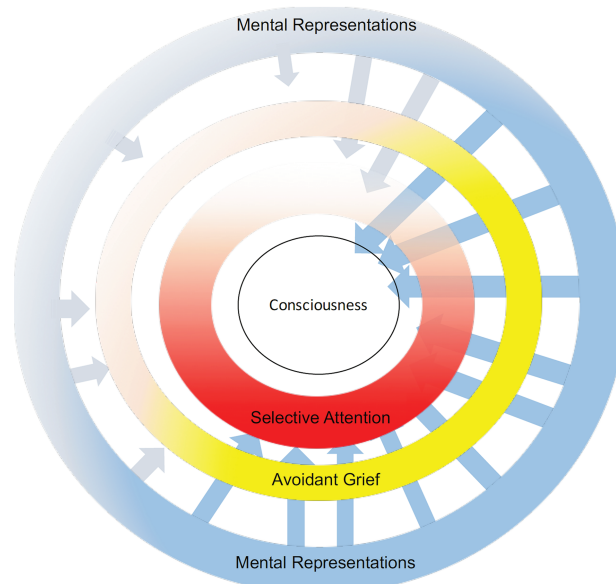

Fig. 1. Mental processes underlying self-generated thoughts of loss during mindwandering. This figure displays a model by which individuals with a more avoidant grief style (i.e. darker yellow) experience more frequent and intense activation of mental representations of the deceased (i.e. darker blue arrows). In the context of this activation, the engagement of selective attention (i.e. darker red) blocks representations from reaching conscious awareness. When avoidant people fail to engage selective attention (i.e. lighter red), the activated mental representations do reach conscious awareness (i.e. arrows entering consciousness).

to block d-MR (blue) from entering consciousness. Because of the salience-increasing effect of maintained vigilance (Wegner, 1994), avoidant grievers experience more frequent and more intense d-MR (darker blue), paradoxically creating more stress and pressure as d-SA plays a greater role (darker red) in blocking these from reaching consciousness.

To do this, we tracked ongoing neural signatures of d-SA and d-MR during an extended non-emotional sustained attention task designed to promote mindwandering (Smallwood *et al.*, 2004; McVay and Kane, 2013). Tracking of ongoing fluctuations in mental states can be achieved with neural pattern decoding. Neural decoding employs multivariate pattern analysis (MVPA) on a first set of functional magnetic resonance imaging (fMRI) data to detect a pattern of brain activity associated with a target mental process (i.e. pattern training). This pattern is then applied to a second set of data to predict the occurrence of that mental process (i.e. pattern expression).

Training of the neural pattern for d-SA was implemented using a modified Stroop task. In this task, words reminiscent of the deceased are presented in different colors and subjects report the color of the word as fast as possible. Delays in reporting the color therefore indicate the diversion of selective attention away from word color and towards the meaning of the word (Williams *et al.*, 1996; Holle *et al.*, 1997; Whalen *et al.*, 1998; Algom *et al.*, 2004). While d-SA manifests as longer reaction time in the Stroop task, this task is optimized to identify response time (RT) delays linked to initial automatic orientation to reminders of the deceased. Following this initial orientation, d-SA can be used to identify and then suppress reminders from further conscious elaboration.

d-MR comprises the abstract symbol for the deceased that exists independently of a specific perceptual or cognitive modality (Schneck *et al.*, 2017). We sought to delineate a neural model

Pattern Training Tasks
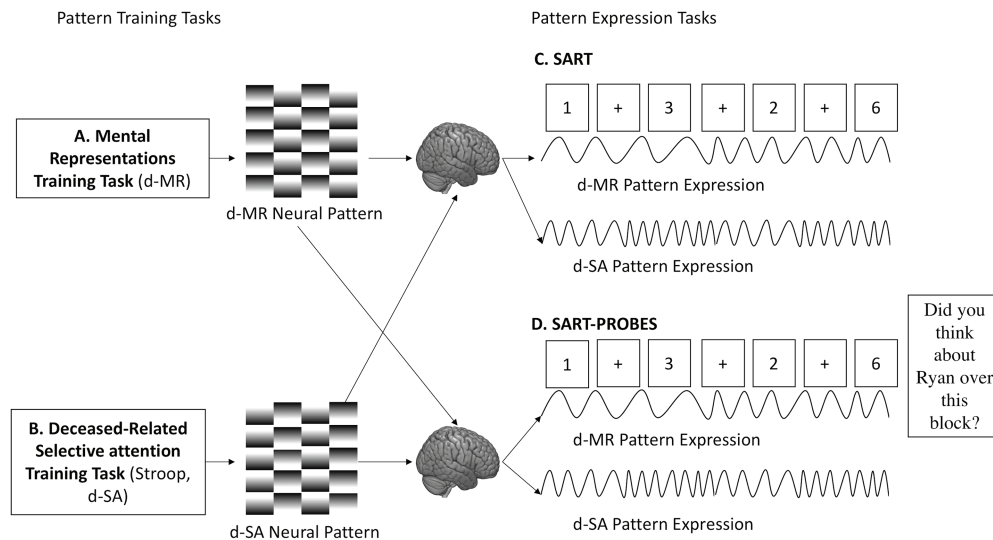
Pattern Expression Tasks

Fig. 2. Continuous pattern expression. Neural patterns for d-SA and d-MR were respectively derived from the Stroop and Mental Representations tasks using MVPA. Neural decoding was then applied by tracking the expressions of these patterns during both SART tasks. These expressions served as a proxy for the fluctuations of d-SA and d-MR as they unfolded during the neutral SART tasks.

for d-MR incorporating across visual, memory and relational representations of the deceased. We further aimed to ensure that the neural pattern represented the deceased specifically, rather than attachment figures in general, emotional states or demographic features of the deceased. We therefore constructed a task employing pictures, memories and an instruction to imagine being together with a person. These were presented in respect to the deceased, a living-attachment and a fictional but demographically comparable avatar while assessing ongoing shifts in emotional state. This training task allowed the delineation of a d-MR neural network that incorporated across multiple representational modalities and was independent of general attachment, demographic and emotional processing.

d-SA and d-MR neural pattern expressions were tracked during two neutral sustained-attention-to-response tasks (SARTs). One of these was 10 min long and contained experience sampling about deceased-related thinking (SART-PROBES); another was 8 min long without thought probes (SART). The SART tasks provide relatively non-stimulating environments optimized to promote mindwandering during which we could observe ongoing expression of the d-SA and d-MR patterns (Smallwood *et al.*, 2004; McVay and Kane, 2013). These pattern expressions provided a proxy for d-SA and d-MR as they transpired during mindwandering (Figure 2). Experience sampling during the SART-PROBES allowed us to determine how avoidant grievers engage d-SA to monitor the contents of mindwandering to prevent d-MR from evolving into self-generated thoughts of loss. Using the SART, we were able to explore these processes absent deceased-related cueing.

Methods

Subjects and recruitment

Twenty-nine people bereaved of a first-degree relative or partner within 14 months participated. Twenty were bereaved by suicide and had been recruited as part of a suicide-bereavement study. Subjects were 18–65 years old, had normal color vision and spoke English as a first language. Recruitment was done through postings on social media web sites. All subjects were

medically healthy as determined by medical history, examination and standard blood and urine tests. Exclusion criteria were current: bipolar disorder (i.e. manic episode within the past year), substance use disorder (i.e. met criteria within past 6 months), obsessive–compulsive disorder and lifetime schizophrenia or schizoaffective disorder assessed with the Structured Clinical Interview for DSM-IV Axis I (First *et al.*, 1995). Subjects taking psychiatric medications were required to be on a stable dose for 2 weeks prior to scanning. The New York State Psychiatric Institute IRB approved this study, and all subjects gave written informed consent.

Procedure

Between 3 and 14 months post-loss, subjects underwent a prescan interview, an MRI and then a post-scan interview. Interviews occurred within 1 week of MRI. Grief severity was measured with the Inventory for Complicated Grief (ICG; Prigerson *et al.*, 1997), and avoidance was measured with the avoidance subscale of the Impact of Events Scale (IES; Zilberg *et al.*, 1982; Baumert *et al.*, 2004). During the pre-scan interview, subjects provided words, pictures and stories relating to the deceased and a relationship matched living control. During the postscan interview, subjects completed structured interviews and questionnaires.

MRI

MRI acquisition and pre-processing are the same as described in prior work and explained in supplemental information (Schneck *et al.*, 2017; Schneck *et al.*, 2018a; Schneck *et al.*, 2018b).

Tasks

d-SA Task. During the scan, subjects completed four runs of a cognitive and emotional Stroop task. Each run consisted of four blocks of words: deceased, living, congruent and incongruent. The design for the Stroop task is presented in Figure 3A. Subjects
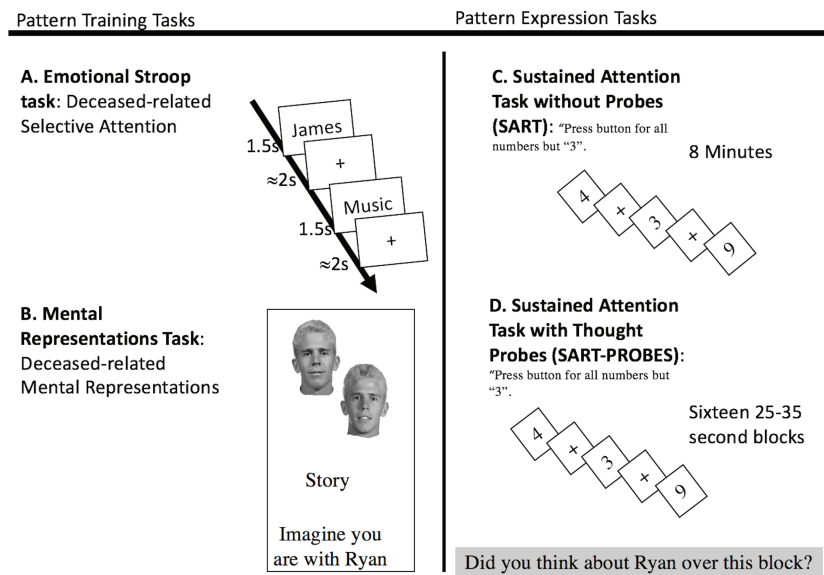
Fig. 3. Pattern training and expression fMRI tasks. An emotional Stroop and mental representation task were used to identify neural patterns for d-SA and d-MR. Words were presented in the Stroop task in red, green or blue and are written here in black for display only. The expression of these patterns was then tracked during a 10 min neutral sustained attention task and a second identical task with interspersed thought probes.

were presented with words and instructed to identify the color of the word font as fast as possible using a right-hand held button box. Training was conducted until subjects reached 100% accuracy and speed of color-button pressing dropped under 1 s for 10 consecutive practice trials. All 15 words were presented for 1.5 s and followed by a randomly jittered fixation cross averaging 2 s. In total, subjects completed 60 trials per condition. A 10 s fixation cross was presented in between each block. Word presentation and color pairings were randomized within a block, and a block order was permuted across runs.

d-MR task. We used a multi-modal person-processing task to define a neural pattern for d-MR. This task employed three person conditions (i.e. deceased, living and demographic control). The living control accounted for attachment-related representations, while the demographic control accounted for activity associated with processing demographic features of the deceased. Each person block lasted for 46.5 s and comprised three modalities: picture, story and think. In the picture modality, two pictures corresponding to the person condition were displayed for 7.5 s each. In the story modality, one of the three stories was presented in successive phrases of three lines with each line being presented for 5 s. The stories were alternated across blocks. In the think modality, subjects were instructed to imagine being with the person for 15 s. Each modality was separated by a 500 ms fixation, and each person-condition block was followed by valence (1 = Very Sad, 2 = Sad, 3 = Neutral, 4 = Happy, 5 = Very Happy) and arousal (1 = Very Relaxed, 2 = Relaxed, 3 = Neutral, 4 = Aroused, 5 = Very Aroused) probes. Stimulus collection, pre-processing and presentation order are described fully in (Schneck *et al.*, 2017).

SART. Two SARTs were administered: one without thought probes (SART, Figure 3C) and one with thought probes (SART-PROBES, Figure 3D). In the SART, subjects were instructed to press a button every time a number came on screen except for '3'. Numbers were presented on screen for 1.5 s with an inter-trial jitter averaging 2 s. The number 3 was presented 11% of

the time to ensure subjects remained engaged in the task. The SART presented trials continuously for 8 min. Following this task, retrospective questions were presented about deceased-related thinking occurring during the SART. The SART-PROBES presented trials in blocks of 25–35 s. Following each block, thought probes were presented as follows: (i) Did you think about name of deceased during the past block (Yes/No)? (ii) Did you think about name of living control during the past block (Yes/No)? (iii) Did you think about yourself during the past block (Yes/No)? Subjects completed 16 blocks. The SARTs were incorporated after the start of the study, and therefore two subjects did not perform them.

Analyses

This study involved three goals: (i) Identify neural patterns for d-SA and d-MR based on MVPA analyses of Stroop and Mental Representations fMRI tasks. (ii) Track the continuous expression of d-SA and d-MR patterns during the SARTs. (iii) Determine the relationship between avoidant grief style and engagement of d-SA to reduce the relationship between d-MRs and thoughts of loss.

Identifying neural patterns for d-SA and d-MR

Feature selection overview. Prior to learning a multivariate pattern for d-SA and d-MR, we used univariate analyses to identify voxels linked to each psychological process. These analyses were performed to limit the voxel input for MVPA and reduce the risk of overfitting and to increase the likeliness that the voxels used for MVPA corresponded to the psychological processes of interest (i.e. d-SA or d-MR). Further explanation is presented in Supplementary Materials.

Feature selection for d-MR. Stories and pictures of the deceased from the d-MR task were used to identify a set of voxels-involved d-MR. This was done through separate univariate *t*-tests identifying (i) voxels associated with pictures of the deceased *vs*

pictures of both the living- and demographic control attachment and (ii) voxels associated with stories of the deceased *vs* stories of both controls. Both *t*-tests controlled for self-reported valence and arousal. No significant activation was related to the think instruction and so this was left out of subsequent analyses. To identify a multi-modal set of voxels activated for both pictures and stories, a conjunction analysis was employed on the results of the separate picture and story *t*-tests (Nichols *et al.*, 2005). The conjunction analysis was thresholded at voxel–*P* < 0.001, cluster–*P* < 0.1. The lenient cluster threshold was used due to the stringency of conjunction analyses and the fact that this analysis was used only for feature selection.

Feature selection for d-SA. Response time to deceased-related words on the Stroop task was used to identify voxels involved in d-SA. To control for potential confounds of button pressing, sustained attention and motor processing, we contrasted with voxels associated with reaction time to congruent words [deceased-related (BOLD × RT)-congruent (BOLD × RT)]. To ensure that neural activity 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 subset within a broader process of attachment-related attention (Schneck *et al.*, 2018b). As a result, the contrast of deceased-related *vs* congruent, rather than deceased-related *vs* living words, was used.

A standard hierarchical mixed effects model was employed in FSL (FMRIB Software Library V6.0; Jenkinson *et al.*, 2012) to identify voxels whose correlation with reaction time was greater for deceased *vs* congruent words [deceased-related (BOLD × RT)-congruent (BOLD × RT)]. This approach rather than a *t*-test was used to better account for subject level variability in RT to each trial. For this analysis, we employed a threshold of voxel–*P* < 0.01 and cluster corrected *P* < 0.05. This threshold was used because d-SA is conceptualized as a relatively broad process that overlaps with attachment-related attention, and therefore, we sought to an inclusive mask of voxels for the sake of incorporating more information into the subsequent MVPA.

Pattern training. MVPA was applied to the d-MR and d-SA task neural data. In each case, MVPA predicted the occurrence of the target psychological process (i.e. d-MR or d-SA) based on neural activity within the feature mask. The neural pattern comprises the relationships between voxels within the feature mask that optimally predict the target process using the labels provided by the tasks (i.e. response time to deceased-related Stroop words for d-SA; pictures and stories of the deceased for d-MR). Across multiple iterations of the prediction, a weighting matrix (*W*) is applied to the neural data to optimize prediction. Full details of the model training are included in the supplemental information.

Tracking of d-SA and d-MR pattern expression during SARTs

The weighting matrices (*W*) identified in the pattern training steps were applied to the SART datasets. In addition to standard pre-processing, 4D time series of SART and SART-PROBES data were registered to standard space, and motion effects were regressed out using standard FSL six-degree motion regressors. Each SART time series was also standardized by its own mean and standard deviation (s.d.).

Pattern expression was estimated by applying the d-SA and d-MR neural patterns (i.e. *W*'s) to the SART and SART-PROBES fMRI data. Model application entails voxel-wise multiplication of the *W*'s in the pre-selected feature masks with the values for the new BOLD data, followed by a linear summation across voxels. This produces a TR-by-repetition time (TR) model output of the d-SA and d-MR pattern expressions.

After generating the TR-by-TR pattern expression for both d-MR and d-SA as manifested during the SART-PROBES, we calculated blockwise averages of d-SA and d-MR pattern output for each of the 16 blocks. 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. For the SART, the average was calculated for the whole task, starting four TRs after the beginning of the task and continuing two TRs past its conclusion.

Predicting thoughts of the deceased during SART-PROBES

The prior step provided continuous neural proxies of d-SA and d-MR occurring during the SART and SART PROBES. We now aimed to test the relationship between avoidant grief style and the interactive competitive relationship between d-SA and d-MR in relationship to thoughts of loss.

A mixed-effects logistic regression was implemented in R 2.15.13 (Team 2012) to predict self-reported deceased-related thinking during the SART-PROBES from a full factorial model of d-SA, d-MR and avoidance. This is a longitudinal model identifying predictors of deceased-related thoughts based on d-SA and d-MR expression occurring in the block immediately prior to that self-report across all 16 blocks per subject. Subject level averages were modeled out as a random intercept. The model included all possible two-way interactions as well. Blocks of SART-PROBES trials with errors (i.e. commissions or omissions) were excluded from this analysis because of the potential effects of errors on self-awareness during a task that asks people to retrospect on their thinking.

Predicting post-task reports of thoughts of the deceased following SART

We next sought to determine the roles of avoidance and d-SA and d-MR pattern expression during the SART in predicting post-SART reports of thoughts of the deceased occurring during that time. It was not possible to test interactive relationships between these variables on this dataset because each subject produces only one report of deceased-related thinking summarizing the whole SART time period, as compared to 16 responses per subject for the SART-PROBES. As a result, we conducted a multiple linear regression investigating subject level avoidance and subject level averages for pattern expression of d-SA and d-MR during the SART as predictors of post-task reports of thoughts of the deceased.

Results

Table 1 describes demographic and clinical characteristics of the sample. ICG mean score of 26.14 (s.d. = 12.84) indicates generally severe grief, although scores had a wide range (1–50). Thoughts of loss occurring on the SART-PROBES correlated with

Table 1. Clinical and demographic characteristics

Demographic and clinical variables	M (s.d.)	Correlation with thoughts of loss on SART-PROBES
Age	44.06 (13.65)	−0.43**
Months since loss	8.06 (4.79)	0.51**
CES-D	1.63 (0.43)	0.59**
IES-A	1.71 (0.59)	0.47*
Education years	16.43 (1.9)	−0.35
Medication use	N = 10 (34%)	0.25
Errors on SART-PROBES	7.52 (5.35)	0.12
Thoughts of loss on SART[a]	1.67 (0.75)	0.44*
Thoughts of loss on SART-PROBES[b]	0.31 (0.34)	1
Males	N = 6	

*Correlation significant at $P < 0.05$.

**Correlation significant at $P < 0.01$.

[a]Calculated as average response to probes about thoughts of loss occurring during beginning, middle and end of SART. Responses scored on a scale of 1 ('Did not think about deceased') to 4 ('Thought about deceased consistently').

[b]Calculated as percentage of correct blocks during SART-PROBES in which thoughts of loss were reported.

ICG = Inventory for Complicated Grief; CES-D = Center for Epidemiological Studies-Depression; IES-A = Impact of Event Scale–Avoidance.

time elapsed since loss, younger age, current depression severity and higher avoidance (Table 1).

Feature selection

For both training tasks, univariate feature selections identified voxel maps associated respectively with d-SA and d-MR. In the Stroop task, BOLD activation in a frontotemporoparietal network correlated with slower responses to deceased-related trials (Figure 4, Supplementary Table S1, Supplementary Figure S1). This analysis controlled for semantic word processing and attention to color-congruent words. Engagement of these regions in slower *vs* faster responses to deceased-related trials therefore indicates their involvement in attention to the deceased (i.e. d-SA). We have previously presented the results for the d-MR feature mask and here display it only to identify the anatomical relationship with the d-SA feature mask (Schneck *et al.*, 2017). Voxels in the bilateral basal ganglia, left orbital frontal cortex and insula were associated with deceased-related blocks as compared to control blocks (Figure 4).

Pattern training

For both d-SA and d-MR, pattern-training algorithms were conducted within pre-selected feature masks generated by the univariate analyses (Figure 4). As previously reported for d-MR (Schneck *et al.* 2017), the multivariate logistic regression model achieved significant cross-validated average out-of-sample classification accuracy of deceased-related pictures and stories ($P < 0.01$), and maximum accuracy achieved was AUC = 0.63. For d-SA, the MVPA regression model significantly predicted response time to deceased-related words ($P = 10^{-3}$). These values are likely inflated due to the pre-selection provided by the univariate analysis. We were not concerned about circularity in this case because the goal of the MVPA analyses was only to identify the corresponding weighting matrices to be used for
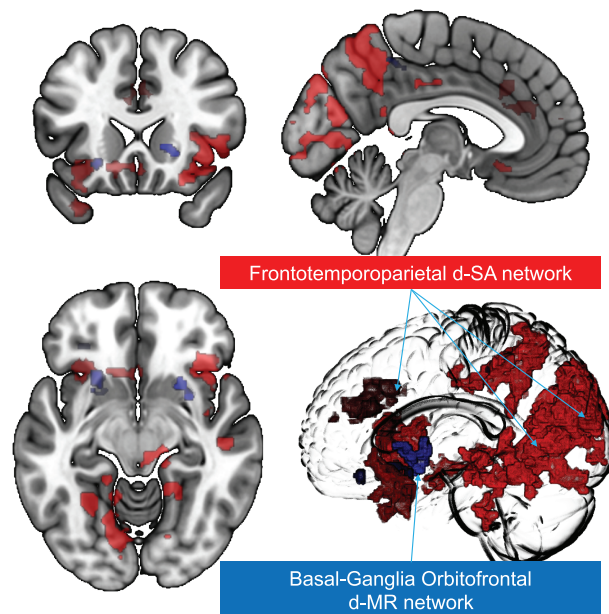

Fig. 4. Basal ganglia–orbitofrontal and frontotemporoparietal feature masks. Feature masks produced by univariate analyses for d-MR (blue) and d-SA (red) were used as input to respective MVPA analyses. For the d-MR feature mask, activation is seen in basal ganglia, orbital frontal cortex and insula (voxel–$P < 0.001$). For the d-SA mask, activation is seen in a broad frontotemporoparietal network (voxel–$P < 0.01$, cluster–$P < 0.05$).

neural decoding and not to estimate effect sizes or P-values for the training tasks.

Pattern expression during SART-PROBES

Two subjects did not complete the SART-PROBES due to timing limitations. On the SART-PROBES, there were a total of 275 error-free blocks, out of which 85 (30%) contained reports of thoughts of loss. There was no significant relationship between errors and thoughts of the deceased (Table 1).

Neural patterns for d-SA and d-MR were applied to the SART and SART-PROBES fMRI data to produce ongoing proxies of d-SA and d-MR during these time periods (Figure 2C and D). Pattern expression outputs for the d-MR and d-SA neural patterns were inspected for outliers falling outside the interquartile range. Five outlier values were identified for d-MR and one for d-SA; these were winsorized (i.e. censored down to the nearest value within the interquartile range). d-MR pattern expression was not significantly related to d-SA expression or errors during either the SART ($F_{350} = 0.55$, $P = 0.45$, $F_{329} = 0.97$, $P = 0.32$) or the SART PROBES ($F_{265} = 0.26$, $P = 0.61$, $F_{402} = 0.33$, $P = 0.56$).

Predicting thoughts of the deceased during SART-PROBES

The three-way interaction of d-SA, d-MR and avoidance significantly predicted thoughts of loss. Specifically, the multiplicative term combining all three variables predicted the odds of a thought of loss as one-tenth that of the odds predicted by the lower-level two-way interactions [odds ratio (OR; for one s.d. change in predictor) = 0.09; Table 2]. Meaning that for high-avoidant subjects, as d-SA increased, the prediction of thoughts of loss from d-MR was less than one-tenth the odds as predicted

Table 2. Predicting thoughts of loss from D-MR, D-SA and avoidance

	B[a]	OR[b]	95% CI	P
Three-way interaction				
d-MR	0.33 (0.66)	1.45	0.73–2.68	0.39
d-SA	0.72 (1.17)	2.06	1.17–4.09	0.27
Avoidant grief style (IES-A)	1.0 (0.54)	2.73	0.94–7.94	0.07
d-MR × d-SA	2.21 (0.84)	9.11	1.92–43.18	0.93
d-MR × IES-A	−0.25 (0.71)	0.77	0.21–2.90	0.43
d-SA × IES-A	1.11 (0.73)	3.06	0.73–12.88	0.37
d-SA × d-MR × IES-A	−2.37 (0.82)	0.09	0.02–0.47	**0.004**
Two-way interaction—high-avoidant grief style				
d-MR	−0.13 (0.31)	0.88	0.48–1.60	0.66
d-SA	0.68 (0.29)	1.96	1.1–3.5	**0.02**
d-MR × d-SA	−1.04 (0.38)	0.35	0.17–0.75	**0.006**
Two-way interaction—low-avoidant grief style				
d-MR	0.3 (0.28)	1.36	0.78–2.38	0.26
d-SA	0.11 (0.34)	1.12	0.58–2.2	0.73
d-MR × d-SA	0.76 (0.31)	2.14	1.15–3.99	**0.01**

[a]Logistic regression coefficients are reported for one s.d. increase in the predictor.
[b]OR = odds ratio for one s.d. change in predictor.
Results from mixed effect logistic regressions predicting thoughts of loss during the SART-PROBES from ongoing interactions between d-SA and d-MR as a function of avoidant grief style. Results are presented as a three-way interaction for the entire sample, spanning levels of avoidant grief style, as well as a two-way interaction between d-MR and d-SA at high and low levels of avoidant grief style.

by any of the two-way interaction combinations. The combination of avoidance, d-SA and d-MR therefore served as an accurate predictor of the lack of thinking about the loss as compared to other models. This effect was maintained when controlling for age, loss type, time since loss and depression severity ($B = −21.41$, $P = 0.003$, OR = 0.08, 95% CI: 0.02–0.38).

To parse this interaction, a median split was used to create high ($n = 17$) and low ($n = 10$) avoidance groups. For subjects in the high-avoidance group, the relationship between d-MR and thoughts of loss was moderated by d-SA. Meaning, on blocks with high d-SA expression, increasing d-MR expression was less likely to result in a thought of loss (Figure 5B, blue line). On blocks with lower d-SA expression, as d-MR expression increased, the odds of a thought of loss increased as well (Figure 5B, red line). Specifically, as d-SA increased, the odds of a thought of loss predicted by d-MR was approximately one-third the odds that of a thought of loss predicted by d-SA and d-MR alone (OR = 0.35; Table 2). Meaning that as d-SA increased the relationship between d-MR, a thought of loss decreased in the high-avoidance group. In the low-avoidance group, the opposite was found. As d-SA expression increased the odds that d-MR would predict, a thought of loss also increased (OR = 2.14; Figure 5A; Table 2).

Specificity of three-way interaction to d-SA and d-MR neural patterns

To test the extent to which this three-way interaction was specific to the neural pattern models identified for d-SA and d-MR in the training tasks, rather than being explained by arbitrary fluctuations in neural data occurring during the SART-PROBES, we extracted the average BOLD signal in both the d-SA and d-MR feature masks across the same time period during the SART-PROBES for which the neural patterns were applied (i.e. from four

TRs after each probe period until two TRs into the next probes period). This produced the output for each TR corresponding to average BOLD signal in the d-SA feature mask and one corresponding to the d-MR feature mask. We then used these outputs to calculate the three-way interaction now predicting thoughts of loss from average d-MR feature mask BOLD signal, average d-SA feature mask BOLD signal and subject level avoidance. As expected, this three-way interaction was not significantly predictive of thoughts of loss ($P = 0.17$).

Predicting post-task reports of thoughts of the deceased on the SART

On the SART, no thought probes were presented in-task but subjects did indicate deceased-related thinking at the end of the task. While controlling for both d-SA and avoidance, reduced d-MR during the SART predicted higher post-task reports of thoughts of loss occurring during the task, accounting independently for 31% of variance in post-task reported thoughts of loss [**d-MR**: $B(SE)_{26} = −71,46$ (24.44), $t = −2.92$, $P = 0.009$, 95%CI = −122.82 to −20.1; **d-SA**: B $(SE)_{26} = 2.40(2.29)$, $t = 1.04$, $P = 0.31$, 95%CI = −2.4 to 7.2; **IES-A**: $B(SE)_{26} = 0.33(0.25)$, $t = 1.30$, $P = 0.21$, 95%CI = −0.2 to 0.86].

Discussion

This is the first study to show that avoidant grievers monitor the contents of their mindwandering. This monitoring was linked to a reduced likeliness that mental representations of the deceased, arising during mindwandering, would lead to a conscious thought of loss. We build on prior research demonstrating avoidant monitoring of the external environment to avoid encounter with reminders of loss (Eisma *et al.*, 2014; Eisma *et al.*, 2015a). Ongoing monitoring over the contents of mindwandering in addition to the external environment may detract from
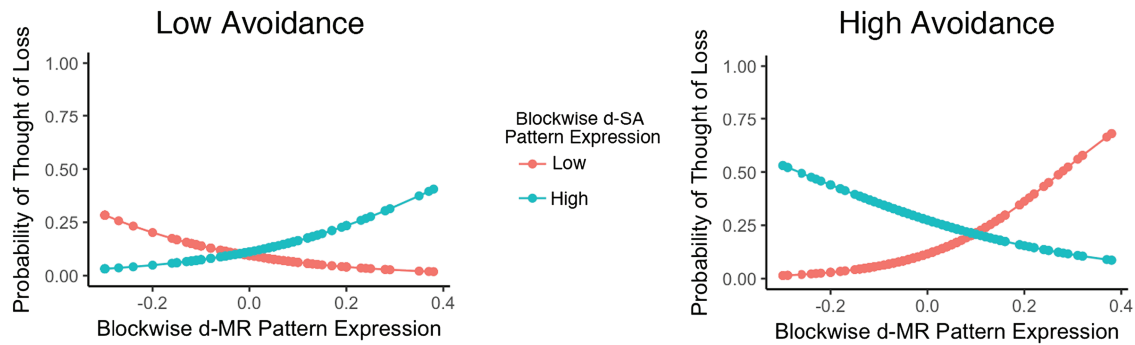
Fig. 5. Predicting thoughts of loss from blockwise pattern expression of d-SA and d-MR at high and low levels of avoidance. This figure displays the predicted probability of a thought of loss based on block-wise d-SA and d-MR output for subjects in the high- and low-avoidance groups separately. For subjects in the high avoidance group ($N = 17$), d-SA negatively moderated the relationship between d-MR and thoughts of loss ($P = 0.02$). Specifically, lower d-SA expression corresponded to a positive relationship between d-MR expression and the probability of a thought of loss occurring on that block (red line). Conversely, on blocks with higher d-SA expression, the relationship between d-MR expression and the probability of a thought of the deceased diminished (blue line). For subjects in the low-avoidance group ($N = 10$), d-SA increased the relationship between d-MR pattern expression on a given block and thoughts of loss ($P = 0.01$).

engagement in other life activities and contribute to the negative outcomes linked to this grief style.

Despite attempts to monitor mindwandering and avoid thoughts of loss, avoidant grievers still displayed more intrusive thoughts of loss overall on the task (Table 1). This finding accords with general research on avoidant grieving and research showing that attempted thought suppression ironically results in greater frequency of the target thought (Wegner, 1994; Eisma *et al.*, 2013; Eisma *et al.*, 2015b). Our findings suggest a mechanism by which this paradoxical effect occurs. During periods of mindwandering when mental representations of the deceased were low and d-SA is high, avoidant grievers were more likely to experience thoughts of loss (Figure 5B). Hence, the monitoring itself (i.e. d-SA) in the absence of a target to be suppressed (i.e. d-MR) may lead to thoughts of loss and contribute to the paradoxical effects of increased deceased-related thinking in avoidant grieving. Future longitudinal studies can also test whether this internal monitoring predicts worse grief outcomes.

The present study characterizes several states of deceased-related processing in avoidant grief (Figure 6). (i) **Task focus**: this state is most common among non-avoidant grievers who, when engaged in an external task, evidence little effect of d-MRs on actual conscious thoughts of loss. (ii) **Suppression**: in this state, activated d-MRs are suppressed from consciousness by simultaneous d-SA. (iii) **Intrusion**: during intrusion, d-SA is low, and ongoing activated d-MRs correlate with spontaneous thoughts of loss. Avoidant people exhibit a high degree of intrusion and suppression, which may both contribute to the poor clinical outcomes associated with this coping style.

Sustained monitoring over mindwandering transpired through interactions between the d-MR basal-ganglia circuit and the d-SA frontotemporoparietal network. The basal ganglia encode motivational salience and habitual responding (Everitt and Robbins, 2005; Berridge, 2007) and receive inputs from across the associative cortex, which allow for the incorporation of new stimuli into the motivational salience framework (Ashby *et al.*, 2010). They interact with the cortical regions seen in the d-SA network such as anterior cingulate and dorsolateral prefrontal cortex, which incorporate higher-order motivations and broader goals into salience encoding (Everitt and Robbins, 2005; Grahn *et al.*, 2009). These d-SA regions also form part of the brain's ventral attention (i.e. attentional salience) and default networks (DNs) as identified through intrinsic functional
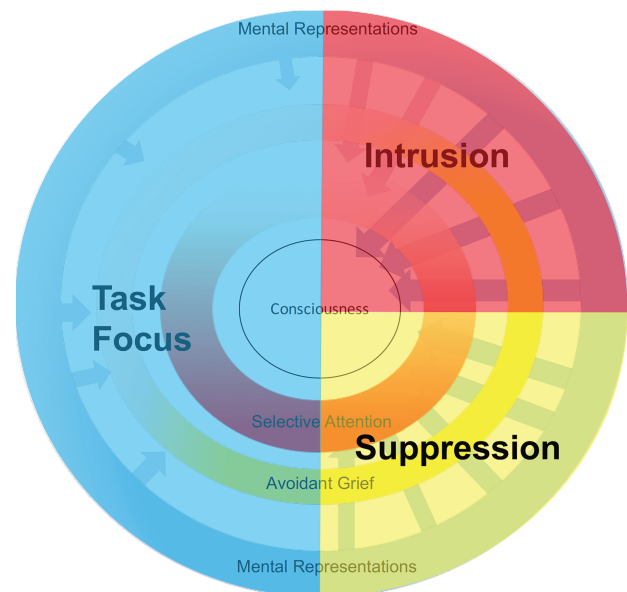

Fig. 6. Hypothetical model of deceased-related intrusive processing. Three states of deceased-related intrusive processing are defined. During task focus, d-MR is limited and not likely to lead to a thought of loss. During intrusion, d-MR is activated, and d-SA is not engaged, resulting in intrusive thoughts of loss. During suppression, d-MR and d-SA are engaged, leading to suppression of activated d-MRs from consciousness. Avoidant grievers evidence more frequent states of intrusion and suppression.

connectivity–based cortical parcellation (Yeo *et al.*, 2011). Hence, the interacting connectivity between motivational salience, attention and DNs in avoidant grieving may underlie the ongoing conflict over the degree of salience attributed to reminders of the loss and the role they play in capturing attention and altering the default state.

Our results indicate that employment of d-SA to monitor d-MR is context dependent. In the absence of thought probes, during the SART, less d-MR engagement, irrespective of avoidance style and d-SA, predicted higher post-task reports of thoughts of loss. These findings suggest that the role of d-SA in directing conscious processing towards or away from the loss may operate specifically in contexts that emphasize meta-cognition about deceased-related thinking. However, due to limited sample size,

this analysis was less powered than the SART-PROBES analysis, and therefore this conclusion is mentioned as a suggestion only.

Methodologically, this work builds on studies using neural decoding to track mental processes unfolding naturalistically. Prior work has used neural decoding to track negative mood and other emotional states as they transpired over time (Tusche *et al.*, 2014; Kragel *et al.*, 2016). We build on this work by tracking ongoing interactions between mental states as they occur spontaneously.

Limitations and future studies

This study grouped together grieving a loss by suicide and non-suicide. While we controlled for in analyses, it is possible that grouping of high- and low-avoidance subjects by loss type may have influenced findings. Future studies can recruit specifically across levels of avoidance in the same type of bereavement. Furthermore, incorporation of physiological monitoring during the SART may also provide more information about thought processes occurring during this time.

A central neural correlate of mindwandering is the connectivity in the DN (Andrews-Hanna *et al.*, 2014). A future study can assess the relationship between the mental processes of selective attention and mental representation investigated here and ongoing DN connectivity. It is likely that as vigilant monitoring over mental representations is engaged, DN connectivity would decrease as the mind becomes involved in the task of vigilance.

Conclusions

Avoidant grievers monitored mindwandering in a way that disrupted the potential occurrence of self-generated thoughts of loss. This monitoring manifested through the continuous application of an attentional network over a representational network during mindwandering, which was linked to a reduced relationship between the latter and self-generated thoughts of loss. The taxing effects of maintaining constant vigilance over ever-evolving contents of mindwandering may contribute to the poor outcomes linked to deliberate grief avoidance.

Supplementary data

Supplementary data are available at *SCAN* online.

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