Spontaneous thought gets stuck with rumination

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Title: Spontaneous thought gets stuck with rumination

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Abstract

Although there has been extensive interest in rumination as a trait-level contributor to psychopathology, research on the neural correlates of ongoing rumination is relatively recent. In this chapter, we examine rumination as a unique mode of thought capable of arising in both normative and pathological contexts. Viewed through the lens of spontaneous thought, we consider rumination as a spontaneously occurring form of thought that becomes "stuck" in a repetitive, highly constrained context. In considering the implications of this viewpoint, we explore the contexts in which rumination has been identified as well as its relationship to other forms of spontaneous thought such as mind-wandering.

Keywords: Rumination, Mind-wandering, fMRI, Default Network, Depression

Spontaneous thoughts form currents in our stream of consciousness. These thoughts can be defined as effortlessly arising, non-instrumental cognition, moving the stream of consciousness in ways unbidden by the thinker (Klinger, 2009). Although these currents generally flow forward, they can also loop and circle back as an eddy. Thoughts that form such mental eddies are marked by their perseverative and repetitive nature and are commonly referred to as ruminations (Watkins, 2008). Rumination is a form of repetitive thinking that is often self-referential in nature (Segerstrom, Stanton, Alden, & Shortridge), and it has been recognized both as a trait-level contributor to psychopathology (Nolen-Hoeksema, 2000) and as a more state-like mode of thought (LeMoult, Arditte, D'Avanzato, Joormann, 2013).

In this chapter, we review the research literature on rumination through the lens of spontaneous thought. Although rumination is a stereotyped thought process, its spontaneous emergence can provide important insight into its neural correlates and behavioral outcome. In this chapter, we therefore consider rumination as a spontaneously occurring form of thought whose progression is highly constrained and repetitive (see Christoff et al., in press for a review of spontaneous thought). We begin by defining trait and state rumination and examine how they are operationalized and measured in research and clinical settings. We examine the factors that precipitate ruminative thoughts, the contexts in which they persist, and the impact of ruminative thinking on other domains of cognitive and affective function. We then review the cognitive neuroscience of rumination, characterizing the brain regions involved. Finally, we contrast rumination with another commonly studied form of spontaneous thought – mind-wandering. This comparison will serve to challenge commonly held conceptions of rumination and

suggests the possibility of ruminative thought as a protracted, or "sticky", form of spontaneous mind-wandering. We conclude the chapter by describing potential research and clinical implications and how rumination may provide a unique vantage point from which to investigate the role of affect in spontaneous thought.

I. Rumination: Definition and measurement

Rumination is defined primarily by its perseverative nature, with a specific focus on the self and self-relevant concerns. The theoretical conceptualization of rumination remains an area of debate (see Smith & Alloy, 2009). For example, the Goal-Progress model (Martin, Tesser, & McIntosh, 1993) considers rumination to be a general self-regulation strategy; in contrast, the Response Styles Theory (Nolen-Hoeksema, 1991) regards rumination as a specific form of cognitive dysfunction, associated with a heightened vulnerability to depression. These differing perspectives have shaped much of the research into rumination. In particular, the Response Styles Theory has been the most influential model in cognitive neuroscience investigations of rumination, which have emphasized rumination's role as a precipitating factor in psychopathology. Response Styles Theory defines rumination as a passive, repetitive, and self-relevant thought process occurring in reaction to or in concert with negative affect (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). This definition considers rumination to be a stable, trait-like response that is triggered in reaction to negative events such as the death of a loved one (Nolen-Hoeksema & Davis, 1999).

Response Styles Theory studies of rumination typically measure rumination using the Ruminative Reponses Scale (RRS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003), a

22-item questionnaire that assesses tendency to experience thoughts such as "Why do I always react this way?" As the RRS measures the degree to which individuals generally engage in ruminative thoughts, it provides a marker of trait rumination. Trait rumination can be conceived of as an individual difference in cognitive bias towards ruminative thoughts. As we discuss in greater depth below, trait rumination has been associated with functional brain organization, consistent with the idea that the tendency to ruminate may arise from stable individual differences (Ray et al., 2005).

A cognitive bias towards rumination, however, is distinct from engaging in a ruminative episode. Active, or state, rumination is a mode of thought that has been associated with specific affective states and cognitive abilities. State rumination following a stressor negatively predicts emotional recovery, even after controlling for trait rumination levels (LeMoult et al., 2013). State rumination has also been associated with cognitive functions such as increased abstract-verbal processing, reduced concrete imagery (Goldwin & Behar, 2011), and poor task switching ability (Whitmer & Gotlib, 2012b).

Obtaining reliable measures of rumination has proven challenging. This is particularly the case for assessments of trait rumination where measures can have markedly different stability estimates. Trait rumination, as measured by RRS scores, exhibits low reliability over time. In individuals who recover from depression over a six-month period, a significant relationship between change in RRS scores and change in depressive symptoms was found ($r = 0.41$, $p < 0.01$; Kasch, Klein, & Lara, 2001). This suggests that rumination as measured by the RSS is closely related to clinical status rather than measuring a non-pathological individual difference. Others have argued that this low

stability across diagnostic categories derives from the inclusion of symptom-focused items of the RRS, which can be expected to change with improved clinical status (Bagby, Rector, Bacchiochi, & McBride, 2004). They thus propose that RRS items with a symptom-focus may reflect a current depressive episode, while items that assess individual differences in ruminative tendency may be more self-focused and therefore better predict future occurrence of depressive episodes.

This parcellation of the RRS into symptom- and self-focused items has been further refined into three RRS subscales: reflection, brooding, and depression-related (Treynor et al., 2003). The depression-related RRS subscale has been criticized for its overlap with the Beck Depression Inventory (Beck, Rush, Shaw, & Emery, 1979) and is not widely used in assessing the unique determinants of non-depressive rumination. RRS-Reflection (RRS-R) items are considered to reflect an intentional, internal evaluation of negative affect as a means of cognitive problem solving; RRS-Brooding (RRS-B) items reflect a passive, persistent comparison of one's response style with an unachieved ideal (Treynor et al., 2003). Both RRS-R and RRS-B subscales share negative outcomes including current major depressive episode severity and memory biases towards negative information (Nolen-Hoeksema et al., 2008). Nonetheless, these subscales have been differentially implicated in depressive episode duration, leading to the suggestion that RRS-R reflects an adaptive form of rumination in contrast with the more maladaptive RRS-B (Treynor et al., 2003). This is in agreement with individual subjective experience, where participants with high RRS-R scores are more likely to self-report that their ruminations enable productive problem solving (Watkins & Moulds, 2005).

The close association between rumination and psychopathology in the Response Styles Theory model has led to suggestions that a normative range of rumination cannot exist within a Response Styles Theory framework. Instead, the RRS-R, rather than reflecting a subtype of rumination, would represent a distinct form of repetitive thought known as reflection (Watkins, 2008). This is an important, if unresolved, distinction, and it has been largely unexplored in investigations of state rumination. Repetitive thought has been linked to positive behaviors, including improved problem solving (Watkins & Baracaia, 2002), suggesting that state rumination can yield constructive outcomes (Baars, 2010). In considering rumination as a form of spontaneous thought, exploration of such normative, reflective forms of rumination will be an important avenue for future research.

II. Rumination: Causes and contexts

Rumination has been identified both in healthy (Piguet et al., 2014) and in clinical populations, such as those with depression, anxiety, obsessive-compulsive disorder (OCD), and post-traumatic stress-disorder (PTSD; Nolen-Hoeksema et al., 2008). Exploring rumination in these populations provides insight into the factors that affect the emergence and maintenance of ruminative thought.

Rumination in Healthy Populations

In healthy individuals, several factors affect the emergence and persistence of rumination. Perhaps the most robust of these is gender. A meta-analysis by Johnson & Whisman (2013) found that women are significantly more likely to report higher levels of trait rumination, regardless of diagnostic status (Cohen's $d = 0.24$). This is consistent with the increased prevalence of depression in women (Kessler et al., 2015). Indeed,

Response Styles Theory was developed in part to explain the higher incidence of depression in women (Nolen-Hoeksema et al., 2008). The cognitive and neural mechanisms associated with sex differences in rumination have yet to be investigated (but see Belleau, Taubitz, & Larson, 2014).

Age is also an important moderator of rumination, with decreasing prevalence across the lifespan. Although rumination has been relatively underexplored in children, the significant gender difference noted in adults has been reported in adolescents as young as 12 years of age (Jose & Brown, 2007). At the other end of the lifespan, rumination is seen to markedly decrease from its adolescent peak, reaching its lowest levels in individuals over 60 years of age (Sütterlin, Paap, Babic, Kübler, & Vögele, 2012). As with sex disparities, the mechanisms underlying these age-related differences in rumination have yet to be fully investigated. Recent interest in the impact of aging on spontaneous cognition (Maillet & Schacter, 2016; see also O'Callaghan & Irish, this volume), however, promises future developments.

Rumination in Psychopathology

Unlike studies of healthy adults, substantially more work has characterized the prevalence, presentation, and determinants of rumination in psychopathology. In Major Depressive Disorder, rumination is characterized as an uncontrollable, intrusive focus on the causes and consequences of depressed mood (Morrow & Nolen-Hoeksema, 1990). Initial work with Response Styles Theory focused largely on rumination as a risk factor in the development and maintenance of depression (Nolen-Hoeksema, 1991). In a longitudinal study of bereaved adults, rumination was found to be associated with higher depression levels at six months post-loss, independent of other factors such as social

supports, negative cognitive outlook, baseline depression, and co-occurring environmental stressors (Nolen-Hoeksema, Parker, & Larson, 1994).

The association between rumination and depression has been argued to be an artifact of its definition within the Response Styles Theory model. For example, work investigating the stability of trait rumination in longitudinal samples has observed low test-retest reliability, with RRS total scores strongly influenced by depression status (Kasch et al., 2001). Nonetheless, the association between rumination and depression has been reliably observed in studies that have adopted alternative theoretical frameworks. The Self-Regulatory Executive Function model advanced by Matthew & Wells (2004) also suggests that rumination may play a role in the onset of depression as well as other mood disorders.

In recent years the Response Styles Theory conceptualization of rumination has been investigated as a thought-pattern associated with other psychiatric disorders, including non-suicidal self-injury, anxiety, substance abuse, and eating disorders (Nolen-Hoeksema et al., 2008). Initial work focused largely on the expression of rumination in these disorders when comorbid with depression, such as mixed anxiety/depressive disorders (Nolen-Hoeksema, 2000). Although depression has a high co-morbidity with other psychopathology, particularly anxiety (Kessler et al., 1996), rumination has been demonstrated to occur in these illnesses independent of depression. Rumination is a dominant feature of generalized anxiety disorder (GAD), OCD, and PTSD.

Generalized anxiety disorder. Rumination scores on the RRS correlate strongly with anxiety symptoms (Brozovich et al., 2015), although this is not the most common form of repetitive thought in GAD. The core cognitive feature of generalized anxiety

disorder is a predominance of worry—an intrusive apprehension of future events (American Psychiatric Association [APA], 2013). There are several similarities between worry and rumination, such as their shared description as unproductive, repetitive thought patterns; their abstract-verbal nature; and their close associations with psychopathology (Fresco, Frankel, Mennin, Turk, & Heimberg, 2002). Both worry and rumination correlate significantly with anxiety and depressive symptoms (Segerstrom, Tsao, Alden, & Craske, 2000) and are associated with neuroticism (Perkins, Arnone, Smallwood, & Mobbs, 2015).

Nonetheless, worry and rumination have distinguishing characteristics. For instance, a factor analysis of worry and rumination items reveals that they load upon separate factors (Fresco et al., 2002). Rumination and worry differentially mediate the relationship between neuroticism and psychopathology, with worry contributing more to anxiety disorders and rumination contributing more to depression (Muris, Roelofs, Rassin, Franken, & Mayer, 2005). Importantly, worry and rumination also have different time orientations, with worry focused on future events or outcomes and rumination concentrating on past experience (Nolen-Hoeksema et al., 2008). Accordingly, worry has been hypothesized as a form of emotional coping via cognitive distancing from threatening internal experiences (Behar, DiMarco, Hekler, Mohlman, & Staples, 2009), while rumination involves fixation on the source and symptoms of distress (Curci, Lanciano, Soleti, & Rimé, 2013).

Obsessive-compulsive disorder. There is a substantial comorbidity between OCD and depression, with approximately 17% of individuals meeting criteria for both disorders in an epidemiological sample (Andrews, Slade, & Issakidis, 2002). Individuals

suffering from non-comorbid OCD, however, also report high scores on the RRS (Dar & Iqbal, 2015). This may be due in part to the similarities between rumination and compulsive thoughts. The characterization of rumination as a failure to disengage from repetitive, internal thought is remarkably similar to obsessive-compulsive disorder, a condition characterized by the occurrence of persistent, repetitive thoughts (obsessions) and the completion of rituals (compulsions) in response to those thoughts (Bokor & Anderson, 2014).

Similar behavioral deficits have been documented in both OCD and rumination, including reduced task-switching ability (Meiran, Diamond, Toder, & Nemets, 2010). Unlike rumination, however, obsessions can be both visual and verbal and are not necessarily self-focused, instead involving general concerns such as fear of harm or contamination (Franklin & Foa, 2011). These concerns arouse feelings of anxiety and distress, thereby driving subsequent compulsions. Rumination, on the other hand, reduces the likelihood that individuals will enact solutions to perceived problems (Ward, Lyubomirsky, Sousa, & Nolen-Hoeksema, 2003).

Post-traumatic stress disorder. Rumination is a common symptom of PTSD, with 94% of assault survivors in one study reporting ruminating on their experience of the assault (Michael, Halligan, Clark, & Ehlers, 2007). Interestingly, high levels of rumination have been suggested to play a causal role in the course of PTSD, particularly in the development and maintenance of intrusive memories (Ball & Brewin, 2012). Such memories, a central feature of PTSD, are a spontaneous re-experiencing of previous negative events and cause substantial subjective distress (APA, 2013).

Although both intrusive memories and rumination focus on past experiences, there are important differences. Chief among them is the ability of rumination to extend beyond a specific event (e.g., thinking "Why do I always react this way?"). There is also a strong difference in their subjective experience with intrusive memories experienced as primarily visual (Ehlers et al., 2002) whereas ruminations are largely abstract in nature and verbally-mediated.

Rumination is also reported as a feature in pathological aging. Although rumination has been shown to decrease with advancing age (Sütterlin et al., 2012), high trait rumination has been suggested to play a role in Alzheimer's disease (Marchant & Howard, 2015). Further explorations of the prevalence of rumination in aging and neurodegenerative disease will be helpful in characterizing the neural basis of ruminative thought.

III. Impact of rumination on cognitive and emotional functioning

In the previous section we considered the causes of ruminative thought in health and psychopathology. Here we examine associations between rumination and specific areas of cognitive and affective functioning.

Rumination and memory

Memory plays a critical role in rumination. Rumination involves a fixation on past experiences and their subsequent effects (Nolen-Hoeksema et al., 2008), a process that depends in large part on memory for these previous experiences. Memory in rumination, however, has been suggested to exhibit specific cognitive biases. These include negative memory bias, such that individuals recall negatively valenced events

more easily than those of neutral or positive valence (Lyubomirsky, Caldwell, & Nolen-Hoeksema, 1998). Rumination has also been associated with over-general memory, or reduced specificity of recalled events (Watkins & Teasdale, 2001; Raes, Hermans, Williams, Geypen, & Eelen, 2006).

There has been debate as to whether negative memory bias and over-general memories are specific to rumination or are simply associated with rumination due to their more general occurrence in depression (Elliott, Rubinsztein, Sahakian, & Dolan, 2002; Park, Goodyer, & Teasdale, 2004). Perhaps the strongest evidence for their dissociation comes from neuroimaging work. In treatment-naïve depressed patients, high levels of trait rumination were associated with increased resting-state functional connectivity (RSFC) of medial prefrontal cortex and anterior cingulate cortex to the broader Default Network (DN; Zhu et al., 2012), including the posterior cingulate cortex, medial prefrontal cortex, medial temporal lobe, and inferior parietal lobule (Bucker, Andrews-Hanna & Schacter, 2008; Raichle et al., 2001). In the same patients, increased RSFC of the posterior cingulate cortex to the DN correlated with more over-general memory (Zhu et al., 2012). This anterior-posterior dissociation suggests that, at least in depressed individuals, distinct neural mechanisms may support cognitive biases towards trait rumination as compared to over-general memory. However, a recent investigation suggests that the brooding subtype of rumination is specifically associated with an over-general memory bias (Romero, Vazquez, & Sanchez, 2014), opening future lines of inquiry into the mechanism for this association.

The role of rumination in memory biases continues to be explored (e.g., Hach, Tippett, & Addis, 2014), but this work is complicated by the co-occurrence of depression.

It is likely that part of the difficulty in disentangling the effects of rumination and depression on memory is due to the assessment of trait rather than state measures of rumination. Trait rumination has been seen to fluctuate with depression (Kasch et al., 2001), making it difficult to parse their relative impact on memory biases.

Rumination and executive control

Executive control appears to be closely associated with ruminative thought. Both state (Watkins & Brown, 2002) and trait (Joormann, Levens, & Gotlib, 2011) rumination have been associated with a failure of executive control. Behavioral studies demonstrating associations between executive control and rumination have operationalized executive control in myriad ways, including stereotyped responding (Watkins & Brown, 2002) and working memory manipulation (Joormann et al., 2011). Studies investigating the impact of trait rumination on executive control at the level of the brain, using a working memory paradigm, have reported increased activation of DN regions (Bartova et al., 2015) and decreased activation of visual areas (Piguet et al., 2014).

Task switching paradigms have also been used to examine the effect of rumination on executive function. Indeed, rumination has been likened to a difficulty in switching between internal and external attention (Northoff & Sibille, 2014), suggesting that rumination should yield significant impairments in task switching. In line with this hypothesis, trait rumination has been impaired filtering of currently irrelevant tasks (Owens & Derakshan, 2013). State rumination, in contrast, has been demonstrated to yield the opposite pattern of results, with slower task switching but no impairment in

filtering of irrelevant tasks (Whitmer & Gotlib, 2012b). However, this association was only observed in depressed participants (Whitmer & Gotlib, 2012b).

The Attentional Scope Model of Rumination proposed by Whitmer & Gotlib (2013) addresses this discrepancy by arguing that individual differences in executive control are associated with susceptibility to rumination. The authors suggest that trait rumination as a cognitive bias may be more likely to impact automatic inhibition processes such as inhibiting irrelevant tasks; state rumination as an ongoing mode of thought would instead impact inhibition that relies on executive control (Whitmer & Gotlib, 2013). This is in contrast to the suggestion that rumination depletes cognitive resources, yielding impaired executive control (Curci et al., 2013).

Rumination and negative affect

Rumination has been closely associated with negative affect. Indeed, within the framework of Response Styles Theory rumination is defined to occur in reaction to or in concert with negative affect (Nolen-Hoeksema et al., 2008). Experimental results have confirmed this relationship, and negative affect has been reliably associated both with experimentally-induced state rumination as well as with high levels of trait rumination (Thomsen, 2006).

Negative affect is also a defining feature of major depression (APA, 2013). The association between depression and rumination, particularly trait rumination (Kasch et al., 2001), therefore provides a potential complication in assessing the unique effects of rumination on affect. By examining state rather than trait rumination, however, these processes have been reliably dissociated. Studies that have induced rumination in depressed individuals have seen an increase in negative affect beyond baseline (Nolen-

Hoeksema & Morrow, 1993). Similarly, inducing rumination in healthy individuals increases negative affect (Huffziger et al., 2013), an effect that is distinct from depressive symptoms (Pasyugina, Koval, De Leersnyder, Mesquita, & Kuppens, 2015). These studies suggest there is a clear positive relationship between state rumination and negative affect. However, the direction of this relationship is complicated by evidence that individuals who engage in rumination have a bias towards negative stimuli (Ray et al., 2005). That is, ongoing rumination may directly feed forward into negative affect, or preferentially interpreting negative stimuli may create a feedback loop that then yields increased rumination. Future work using a state assessment of rumination will continue to provide a clearer picture of the relationship between rumination and affect.

IV. Neural basis of ruminative thought

Spontaneous thought has been consistently linked with a core set of brain regions including the medial prefrontal cortex, medial temporal lobe, posterior cingulate cortex, and inferior parietal lobule (Bucker et al., 2008; Andrews-Hanna, 2012; Andrews-Hanna, Smallwood & Spreng, 2014). These regions constitute the DN, a large-scale neural network implicated in self-relevant thoughts such as memory, prospection, and theory-of-mind (Buckner & Carroll, 2007; Spreng Mar & Kim, 2009). Recent meta-analytic work has suggested that non-DN regions are equally important in spontaneous thought, including the lingual gyrus, dorsal anterior cingulate cortex, temporopolar cortex, insula, and rostrolateral prefrontal cortex (Fox, Spreng, Ellamil, Andrews-Hanna, & Christoff, 2015). In examining rumination as a form of spontaneously occurring thought, it is

valuable to see how its associated functional neuroanatomy—both in trait and state assessments—align with other forms of spontaneous thought.

Trait Rumination

Resting-state functional connectivity (RSFC) MRI is a widely used tool to investigate the intrinsic functional architecture of the human brain. Patterns of RSFC reveal important relationships with individual differences in cognition and behavior (Stevens & Spreng, 2014). Among groups assumed to exhibit different levels of trait rumination—such as healthy individuals vs. those with psychopathology—early investigations attributed differences in RSFC profiles to differing ruminative tendencies (Grecius et al., 2007). In depressed individuals, increased RSFC between the subgenual prefrontal cortex and DN structures was associated with higher RRS scores, particularly on the brooding subscale (Berman et al., 2011; Hamilton, Farmer, Fogelman, & Gotlib, 2015). High RRS scores in remitted depression have also been associated with reduced middle frontal gyrus connectivity with the DN and the subgenual anterior cingulate cortex of the salience network (SN) (Jacobs et al., 2014). The SN, including the dorsal anterior cingulate and fronto-insular cortex, has been suggested to play a crucial role in attending to biologically relevant stimuli (Seeley et al., 2007). That both the SN and DN exhibit altered connectivity at high levels of trait rumination aligns with the triple-network model of psychopathology (Menon, 2011). According to this view, psychopathology emerges from impairment in the DN, SN, a central executive network, or their interactions. The central executive network, including the posterior parietal cortex and dorsolateral prefrontal cortex, is thought to be responsible for the control of attention and planning (Menon, 2011). Indeed, all three networks have been implicated in

depression (Hamilton, Chen, & Gotlib, 2013; Nejad, Fossati, & Lemonge, 2013; Sheline et al., 2009).

Both functional and structural neural correlates of trait rumination have been explored in healthy populations. Gray matter volume in the inferior frontal gyrus, anterior cingulate cortex, and mid-cingulate cortex is associated with higher RRS scores (Kuhn et al., 2012). In the same study, reduced amplitude of intrinsic, low-frequency fluctuations in functional connectivity among these regions is also associated with greater trait levels of rumination. Increased entorhinal cortex and reduced middle occipital gyrus activation during resting intervals has also been associated with higher RRS scores (Piguet et al., 2014). During a negative cognitive reappraisal task investigated with fMRI, higher RRS scores have been associated with greater amygdala activity (Ray et al., 2005).

The identification of regions outside of the DN in studies of trait rumination is perhaps surprising given the clinical focus on the DN as the neural substrate of ruminative thought (Hamilton et al., 2013; Marchetti, Koster, Sonuga-Barke, & De Raedt, 2012). However, this association of the DN and rumination may be an artifact of *a priori* selection of the DN as regions of interest in previous research. Hamilton and colleagues (2011) specifically isolated activation from the DN to compare with activations outside the DN. The authors reported that depressed individuals with more consistent DN activations, or "DN-dominance," reported higher RRS-Depression Related scores. They hypothesized that this over-activation might reflect a failure of the right fronto-insular cortex to attenuate DN activity. Another study used posterior cingulate seed-based connectivity to define the DN in depressed and healthy individuals (Berman et al., 2011). Berman and colleagues found that greater RSFC between the DN and

subgenual anterior cingulate cortex correlated with higher RRS scores (2011). A more recent study assessed the dynamic RSFC—or fluctuation of RSFC across a scanning session—of a medial prefrontal cortex seed region to investigate differential DN trajectories in depression (Kaiser et al., 2015). Here, increased medial prefrontal cortex and insula dynamic connectivity was linked to higher levels of self-reported rumination within the past two weeks (Kaiser et al., 2015). Despite their explicit focus on the DN, each of these studies implicates non-DN regions in trait rumination, particularly in the presence of depressive symptomatology.

State Rumination

State rumination, in contrast to the cognitive bias of trait rumination, reflects ongoing ruminative thought and is commonly examined via rumination induction. When compared to rest, rumination induction is associated with heightened functional connectivity between the right frontal pole and left lateral occipital cortex as well as between the right basolateral amygdala and left inferior frontal gyrus (Milazzo et al., 2014). Berman and colleagues (2014) found that the brain activation in depressed individuals during ongoing rumination significantly differed from that observed in a separate unconstrained resting-state run, with increased connectivity between the posterior cingulate cortex and regions including the inferior frontal gyrus and subgenual cingulate cortex. Such studies of rumination induction are rare, however, and significant work remains to be done examining task-evoked ruminative states.

Distraction has been suggested as an adaptive reaction to rumination (Nolen-Hoeksema, 1991). For this reason, task-based fMRI has examined state rumination relative to distraction. In a study by Cooney and colleagues (2010), induced rumination

("Think about why things turn out the way they do") was contrasted with concrete ("Think about a fan slowly rotating back and forth") and abstract ("Think about what contributes to team spirit") forms of other-focused distraction. The authors found that in healthy individuals, rumination relative to concrete distractions was associated with increased activation in inferior parietal lobule, precuneus, pre- and post-central gyrus, and superior parietal lobule. Rumination relative to more abstract distractions was associated with increased activation in the cuneus, precuneus, medial prefrontal cortex, and dorsolateral prefrontal cortex. The engagement of DN regions, such as the precuneus, inferior parietal lobule, and medial prefrontal cortex is consistent with the self-referential nature of rumination. The increased activation of non-DN regions such as the dorsolateral prefrontal cortex, however, suggests that other networks play an equally significant role in ongoing rumination. The involvement of multiple large-scale cortical networks in rumination suggests comparisons to another form of spontaneous thought, mind-wandering.

V. Rumination and mind-wandering as forms of spontaneous thought

Spontaneous thought occupies a large part of daily experience (Killingsworth & Gilbert, 2010; Singer & McCraven, 1961). However, as the work in this volume clearly demonstrates, defining the nature and the content of spontaneous cognition is an active area of research. Much of the research literature investigating spontaneous thought has focused on mind-wandering – also known as daydreaming or stimulus-independent thought. It is a form of internal cognition related to individual goals, concerns, and experiences (Smallwood & Schooler, 2015). While rumination is also internally-directed

and self-referential in nature, there has been little consideration of rumination as a form of spontaneously occurring cognition and no studies to date have directly contrasted mind-wandering and rumination as different forms of spontaneous thought. The lack of direct comparison may be due in part to the inability of most theoretical conceptions to distinguish between mindwandering and rumination, although more recent accounts have begun to address this issue (Christoff et al., 2016; Irving, 2016). In this final section we briefly compare mind-wandering and rumination with respect to their lifespan prevalence, functional impacts, and cognitive and neural correlates. We conclude the section by proposing a novel perspective on rumination as a form of protracted – or "sticky" – mind-wandering and spontaneous thought.

Rumination and mind-wandering both show decreasing prevalence in older adulthood (Jackson & Balota, 2012; Sütterlin et al., 2012), as older adults report less spontaneous cognition than young adults (Maillet & Schacter, 2016). Rumination and mind-wandering have also both been associated with negatively-valenced thought and negative affect (Wilson et al., 2014; but see Fox, Thompson, Andrews-Hanna, & Christoff, 2014; Poerio, Totterdell, & Miles, 2013). Mind-wandering, however, has also been associated with positive psychological outcomes, including future-planning and an enhanced sense of meaning (Smallwood & Schooler, 2015), whereas rumination has been associated with negative outcomes and the emergence of psychopathology (but see Andrews & Thomson, 2009). Nonetheless, as discussed earlier, there is evidence that the reflective subtype may be an adaptive form of rumination (Treynor et al., 2003).

Cognitively, mind-wandering is associated with flexible thinking and creative problem solving (Baird et al., 2012). In contrast, rumination is associated with cognitive

rigidity and reduced problem-solving capacity, especially in dynamically-changing contexts. However, this consideration of context may be the critical link between mind-wandering and rumination as forms of spontaneous thought. Both can occur automatically, disrupting ongoing thought processes and leading to off-task behaviors. While mind-wandering may facilitate mental flexibility and adaptive responding to a dynamically-shifting problem-space, rumination, particularly the reflective sub-type, may open the way to a more considered appreciation of long-standing, entrenched problems. Consistent with this view, rumination has recently been associated with an adaptive and intentional reprocessing of events (Fawcett et al., 2015).

This association between mind-wandering and rumination as forms of spontaneous thought may also be observed at a neural level. The mental flexibility linked to mind-wandering is associated with efficient coupling and decoupling of the default and frontoparietal control networks (Andrews-Hanna, Smallwood, & Spreng, 2014). In contrast, rumination, which has been linked with cognitive rigidity, has been associated with greater coupling of the default and salience networks (Carew, Miline, Tatham, MacQueen, & Hall, 2013). Critically, both the frontoparietal and salience networks are associated with shifting between internal and external foci of attention (Goulden et al., 2014; Spreng et al., 2013). This suggests that inefficient network coupling may lead to increased default network activity and the intrusion of off-task thoughts, whether brief wanderings or more protracted ruminations, into ongoing, goal-directed cognition.

These network interactions have recently been synthesized in a proposed model for spontaneous thought, put forward by Christoff and colleagues (in press). In it, the authors argue that mind-wandering arises as a result of differential variability and

constraint between sensorimotor areas as well as dorsal attention, frontoparietal, salience, and default networks. In particular, variability within the medial temporal lobe (MTL)-centered subsystem of the default network may generate spontaneous thought, which is then automatically constrained by the core component of default network and the salience networks to personally relevant concerns. When mind-wandering occurs, the frontoparietal control network can shift internal attention to impose deliberate constraints on the flow of spontaneous thought, thus ending the mind-wandering episode. We propose that rumination may emerge from the mechanisms outlined in this model but with an inefficient engagement of the frontoparietal control network to shift internal attention. Instead, the tight coupling of the salience and default networks yields a "sticky" pattern of highly self-relevant thought from which an individual is unable to shift internal attention.

Considering these similarities between rumination and mind-wandering as manifestations of spontaneously occurring thought – at the level of the brain and behavior – we therefore propose that rumination should be considered as a more protracted or 'sticky' form of mind-wandering and spontaneous thought. Seen through this lens, spontaneous off-task thoughts that occur more frequently in the context of a more dynamic problem-solving space, may, at times, become mired in more entrenched, and perhaps more affectively salient, problems. In this way, it is the content and context of spontaneous thought that delineate mind-wandering and rumination. If correct, this reconceptualization of rumination as a protracted form of mind-wandering and spontaneous cognition may open new paths for identifying novel diagnostic markers and intervention strategies to mitigate the negative functional impacts of ruminative thought.

IV. Future Directions

Future investigations of rumination, utilizing this framework of spontaneous thought, will be important in guiding the development of new interventions to attenuate ongoing depressive rumination. The role of mindfulness meditation in reducing depressive rumination has shown some promise (van Vugt, Hitchcock, Shahar, & Britton, 2012). There is also evidence that distraction-based interventions may be helpful (Hilt & Pollak, 2012), though the extent to which this is true may vary with the novelty of the distractor (Bar, 2009). Transcranial direct current stimulation has also been examined in decreasing both mind-wandering (Kajimura & Nomura, 2015) and rumination (Vanderhasselt et al., 2015), providing further support that these processes may share a common neural substrate.

In sum, rumination, long recognized as a cognitive bias in psychopathology, may also be a more protracted mode of spontaneous thought, perhaps reflecting altered interactivity between large-scale neural networks. Clear challenges lie ahead in the development of paradigms to more reliably probe aspects of rumination and its associated neural substrates. Doing so, however, will open the way for more effective treatments and provide a novel lens through which to study the cognitive, affective, and neural basis of spontaneous thought.

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