Does rumination cause “inhibitory” deficits?

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Running head:

Rumination and inhibition

Abstract

Inhibitory processes have been implicated in depressive rumination. Inhibitory deficits may cause difficulties in disengaging from ruminative content (e.g., Joormann, 2005), or rumination may constitute a working memory load, causing deficits in inhibitory control (e.g., Hertel, 2004). These hypotheses have different implications for the treatment of depression. We conducted a systematic review of existing evidence, and conclude that most studies do not unambiguously measure inhibition. The majority of published evidence is correlational, and thus supports neither causal direction. No published experimental studies have investigated the inhibitory deficit → rumination causal direction, and only six have investigated the rumination → inhibitory deficit hypothesis. In two of these studies the dependent variable has low construct validity. One study reported no effect of rumination on interference, and three did not control for mood effects. There is need for carefully designed experimental research that has the potential to investigate these proposed causal mechanisms.

Keywords:

Rumination; depression; interference; working memory; inhibition

Does rumination cause inhibitory deficits?

Depressive rumination is defined as "repetitively focusing on the fact that one is depressed; on one's symptoms of depression; and on the causes, meaning and consequences of depressive symptoms" (Nolen-Hoeksema, 1991, p. 569). There is extensive evidence that rumination maintains and exacerbates depressive symptoms (Morrow & Nolen-Hoeksema, 1990; Nolen-Hoeksema, 2000; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Watkins, 2008), that rumination is a vulnerability factor for the onset of depression (Nolen-Hoeksema, 1991) and that, in contrast to strategies that help regulation and recovery from negative mood (Rusting & DeHart, 2000), rumination perpetuates low mood. Understanding the cognitive causes and consequences of persistent rumination is of value in improving recovery from dysphoric moods and reducing vulnerability to depression.

Recent investigations have examined how the cognitive deficits and biases observed in depressed individuals are associated with the tendency to ruminate in response to sadness (e.g., Gotlib & Joormann, 2010; Joormann, Yoon, & Zetsche, 2007). In a review of cognitive inhibition and depression, Joormann et al. (2007) highlighted evidence that trait rumination was associated with poor performance on tasks thought to index cognitive control. The key aspect of cognitive control, in so far as it relates to rumination, was considered by Joormann et al. (2007) to be the ability to apply cognitive inhibition to control the contents of working memory. They argued that inhibitory processes constitute a central function of working memory and proposed that "malfunctioning inhibitory processes may have severe cognitive and emotional consequences, and rumination may be one of them" (p. 129). However, as noted by Joormann and colleagues (Joormann et al., 2007; Joormann & Gotlib, 2010), the construct validity of a number of the paradigms in which researchers have invoked inhibition has been questioned (e.g., MacLeod, Dodd, Sheard, Wilson & Bibi, 2003; MacLeod, 2007, Mayr & Bucher, 2007). More generally, a problematic issue is that researchers often invoke

the term “inhibition” both as explananda and explanandum – both as a description of a phenomenon to be explained, and as a hypothesized mental process to explain that phenomenon. In the current review, although we retain the terminology adopted by each theorist when initially reviewing their model, we later re-conceptualize all these models as concerning the application of control processes to reduce interference from task-irrelevant material in order to avoid this problem. Interference is the empirical result whereby the presence of task-irrelevant stimuli impairs accuracy and/or speed on task-relevant stimuli. When reviewing data, we consider it with respect to both the empirical observation of interference, and to the construct of inhibitory control; we adopt this approach in order to avoid making the assumption that inhibition is the most compelling explanation for a given observation of interference.

Whitmer and Gotlib (2013), in their recent review of the data correlating trait rumination with cognitive processes that influence information processing, highlight the considerable expansion of work in this field in recent years and present a novel model that proposes trait rumination is associated with a narrowed attentional focus, which is characterised by reduced cognitive flexibility and enhanced maintenance of a focal goal. Both Joormann et al. (2007) and Whitmer and Gotlib (2013) indicate the need for a systematic examination of the causal nature of the established association between rumination and cognitive control processes. Previous reviews in this area have generated a number of key questions and hypotheses but have tended to focus primarily on correlational data, which does little to clarify the question of causality. There has yet to be a systematic review evaluating the experimental evidence for the hypothesised causal mechanisms relating depressive rumination and “inhibitory” (interference-control) deficits.

In the current article, we critically review the extant literature on rumination and cognitive control processes; for the first time, this literature is reviewed to examine which of

the main competing causal accounts best accommodate the available data. We begin by defining and operationalizing rumination, inhibition, and interference control. We consider the main classes of theory about the relationship between rumination and cognitive control, and systematically review existing evidence relevant to determining the causal relationship between ruminative response tendencies and the ability to apply cognitive control to reduce interference from task-irrelevant information. We focus specifically on studies that are of direct relevance to this question, with a particular emphasis on experimental studies. A number of theorists have emphasised the role of stimulus valence in the relationship between rumination and interference control. In some cases, studies have used non-emotional stimuli, whereas others have examined interference control deficits in processing emotional material. We therefore additionally review this evidence with respect to the potential role of emotional material in the relationship between rumination and interference control deficits. The characterisation of biases in the allocation of attentional resources in depression that are less clearly attributable to failures of cognitive control is beyond the scope of this review (see Koster, De Lissnyder, Derakshan, & De Raedt, 2011 for a recent review of this literature).

Conceptualizing and Measuring Rumination

Response Styles Theory (RST; Nolen-Hoeksema, 1991) conceptualises depressive rumination as a stable, trait-like style of responding to depressed mood involving persistent focus on one's negative emotional state. Rumination is typically assessed on the Ruminative Responses Scale of the Response Styles Questionnaire (RSQ; Nolen-Hoeksema & Morrow, 1991), which is the measure adopted by the majority of research examining rumination and interference control. The RRS is a 22-item scale that asks participants to report the frequency with which they ruminate in response to sad or depressed moods (e.g., participants are asked to rate how frequently they "analyse recent events to try and understand why you are depressed", when feeling down, sad, or depressed). Treynor, Gonzalez and Nolen-Hoeksema

(2003) identified two distinct components within the RRS – *brooding* and *reflection*. Brooding is conceptualised as negative and evaluative focus on the self, and is proposed to be maladaptive; reflection is conceptualised as a purposeful focus on problem solving aimed at alleviating symptoms of depression and is argued to be adaptive. According to RST (Nolen-Hoeksema, 1991) ruminative responses are habitual and automatic, typically developing during childhood.

Although the majority of research examining the relationship between rumination and interference control has adopted Nolen-Hoeksema's (1991) formulation of rumination, a number of other important models of rumination have also been proposed. Goal-oriented theories of rumination (e.g., Carver & Scheier, 1982; Martin & Tesser, 1996; Pyszczynski & Greenberg, 1987; Watkins, 2008, 2010) propose that detection of a discrepancy between one's current status and anticipated progress towards a goal instigates ruminative thoughts, which continue until either the discrepancy is resolved (by resuming one's anticipated rate of goal progress) or the individual disengages from the goal (Martin & Tesser, 1996).

Conceptualizing and Measuring Inhibition and Interference

MacLeod (2007) proposed that the construct of inhibition is best conceptualized as "the stopping or overriding of a mental process, in whole or in part, with or without intention" (p.5). In a number of tasks that are regarded as classic demonstrations of inhibitory processes, alternative accounts are also possible (e.g., Neill & Mathis, 1998; MacLeod et al., 2003; MacLeod, 2007). For example, negative priming is a form of interference revealed by the slowing of response to a stimulus that has recently been ignored. It has been argued by some that negative priming reflects the time taken to overcome inhibition of previously ignored material that has subsequently become relevant (e.g., Houghton & Tipper, 1984). However, there are alternative accounts of negative priming that do not implicate inhibition, and it is a matter of debate whether negative priming is best described as an inhibitory

phenomenon (see e.g. May, Kane, & Hasher, 1995; Tipper, 2001, Mayr & Buchner, 2007). In our review of the empirical data regarding rumination and cognitive control, we use the more theoretically neutral terminology of *interference* in cases where there is not reasonable consensus that inhibitory processes underlie the observed result of interference. For example, the magnitude of negative priming in an individual is less controversially described as the extent to which interference from no longer relevant material impairs efficient task performance, than as an index of their ability to *inhibit* previously relevant information (although even the former description is debatable; a point to which we return to later).

A number of researchers have argued that inhibitory control is not a unitary ability but that instead it fractionates into multiple components (e.g., Friedman & Miyake, 2004; Hasher & Zacks, 1988; Nigg, 2000), these components being: (a) resistance to distraction (including the blocking of irrelevant information from access to working memory, WM); (b) resistance to proactive interference (i.e., the ability to resist interference from information that was previously relevant to the task but has since become irrelevant); and (c) inhibiting prepotent responses. A number of researchers (e.g., Aron, 2007; Bissett, Nee, & Jonides, 2009) have argued that whilst there is evidence to suggest that inhibitory control is implicated in withholding prepotent behavioural responses, it is not clear that inhibition plays a role in other types of interference, such as resistance to proactive interference.

Theoretical accounts relating rumination and interference

There are four possible accounts of the relationship between rumination and deficits in the ability to apply cognitive control to resolve interference. First, impaired interference (I) control causes increased rumination (R) (I→R). Second, on-going rumination causes impaired interference control (R→I). Third, there is a bi-directional relationship between rumination and interference control (R↔ I). Fourth, the association between rumination and interference control deficits is secondary to a third factor, such as depression, which causes

both increased rumination and impaired interference control. These contrasting accounts of rumination and interference control processes have distinct implications for clinical understanding of, and interventions for, depression. In the sections that follow, we categorize extant theories as belonging to one of these four classes of account.

The theoretical models that have been proposed in support of these causal hypotheses have operationalized the ability to resolve interference in different ways. Linville (1996) and Joormann (2006) both invoke the construct of inhibition. Joormann specifically considers the application of inhibitory processes to distinct aspects of the ability to control the contents of working memory (e.g., Joormann et al., 2007). Other authors have adopted the terminology of cognitive control and have favoured a more procedural approach to conceptualising the relationship between rumination and complex cognition (e.g., Hertel, 2004). The models converge in proposing that there is a causal relationship between rumination and constructs implicating the application of higher level cognitive control to resist interference from task-irrelevant content.

It is of note that a number of the theorists primarily emphasise one causal direction but also acknowledge the possibility of a bi-directional account (e.g., Joormann, 2005 is primarily concerned with the I→R hypothesis but additionally recognises a bi-directional hypothesis). There is therefore some overlap between the different theoretical accounts of rumination and interference control, and much of the theoretical work in this field cannot be neatly classified as solely considering on one of the four causal hypotheses. Where a theorist has proposed one causal hypothesis but additionally noted other possible accounts, we weight our review of their model to reflect that emphasis.

Interference-control deficits as a cause of rumination (I→R)

The most elaborated accounts of inhibitory deficits as a cause of rumination have been developed by Linville (1996) and Joormann (2005). Koster and colleagues have recently

introduced a related account (Koster, De Lissnyder, Derakshan, & De Raedt, 2011). Linville (1996) proposed two possibilities: (1) that ruminative thoughts access consciousness because they are goal-related (i.e., in the absence of inhibitory deficits), and (2) that stress and depression might deplete inhibitory capabilities, resulting in rumination (see also Hasher & Zacks, 1979). It is the second possibility we consider here.

Linville proposed a number of mechanisms by which weakened inhibitory attentional processes might cause intrusive ruminative thoughts to occur. Firstly, difficulties in preventing ruminative thoughts accessing working memory as a consequence of poor inhibitory control might result in concurrent and inefficient processing of both one's current task and the focus of ruminative thinking. Second, inefficient inhibitory control might result in proactive interference of thoughts pertaining to a concern that has subsequently become irrelevant due to a change in goals. Third, depleted inhibitory control could allow proactive interference from rejected interpretations and unsuccessful attempts at goal-pursuit.

Joormann's (Gotlib & Joormann, 2010; Joormann, 2005; Joormann et al., 2007; Joormann, 2010; Joormann & D'Avanzato, 2010) model of cognitive control mechanisms in depression proposes that deficits in the ability to control the contents of working memory, and specifically in the application of inhibitory processes in service of this, causes depressed individuals to experience difficulties blocking or removing irrelevant negative content from working memory. This, in turn, fosters rumination. Joormann (2005) proposes that all three of the inhibitory process subtypes (Friedman & Miyake, 2004) are implicated in rumination. First, Joormann proposes that depressed individuals have a specific deficit in preventing irrelevant negative material from accessing working memory (i.e., resistance to distraction), which once activated is not easily discarded from working memory (i.e., resistance to proactive interference), resulting in rumination and persistent negative mood. Second, Joormann proposes that poor inhibition causes depressed individuals to experience

difficulties overcoming a depression-related prepotent tendency to ruminate and argues that inhibition of such responses (prepotent response inhibition) is required in order to redirect attention to the current task.

Koster and colleagues (Koster et al., 2011) propose a reciprocal relationship between depression, attentional control, and rumination, whereby depression is characterised by impaired attentional control in the presence of negative information. Koster et al. define attentional control as "the ability to selectively attend to task-relevant information and to inhibit distraction by task-irrelevant material" (p. 139), and argue that this implicates inhibition, set-shifting, and the monitoring and updating of working memory contents. Impaired attentional disengagement from negative material is in turn proposed to contribute to the vulnerability to persistent and repetitive rumination. Finally, persistent rumination is hypothesised to exacerbate negative mood, thereby further narrowing attentional focus and exacerbating biases in the allocation of attentional resources such that mood congruent emotional material is preferentially processed and depletes available attentional resources.

Interference-control deficits as a consequence of rumination (R→I)

A number of theoretical accounts (Andrews & Thomson, 2009; Beevers, 2005; Ellis & Ashbrook, 1988; Hertel, 1997, 2004; von Hecker & Sedak, 1999) share the hypothesis that ruminative thoughts occupy attentional resources, thereby reducing available working memory capacity or executive control capabilities and impairing performance on concurrent tasks that require effortful processing. Thus, an alternative model of the relationship between rumination and interference-control processes is that on-going rumination results in greater cognitive interference and thus causally impairs concurrent task performance. The different theoretical accounts that share this hypothesis make a series of related but distinct predictions regarding the relationship between state rumination and cognitive control.

The cognitive exhaustion model of depression (Kofta & Sedak, 1998; von Hecker & Sedak, 1999) proposes "uncontrollability, and in particular ruminating thoughts about uncontrollable conditions, lead to a depletion of those cognitive resources that support generative and flexible, constructive thinking" (von Hecker & Sedak, 1999, p. 835). The model thus predicts that rumination-related impairments will be evident on tasks that require flexible shifting between different task goals.

Beevers's (2005) dual process model of cognitive vulnerability to depression, and resource allocation models of depression (Ellis & Ashbrook, 1988; Hartlage et al., 1993), propose that cognitive capacity is occupied by mood-congruent and ruminative thinking in depression, and as a consequence, cognitive capacity available for processing information relevant to concurrent effortful tasks is reduced. Beevers's (2005) dual process model, and the resource allocation models (Hartlage et al., 1993), share the prediction that ruminative thoughts result in impairments that are specific to cognitive tasks that are attentionally demanding, and the degree of impairment is predicted to be determined by the effortfulness of the task.

Interference-control deficits as both cause and consequence of rumination

A number of theorists (e.g., De Raedt & Koster, 2010; Hartlage et al., 1993; Hertel, 2004; Joormann et al., 2007) note the possibility that impaired interference control is both a cause and a consequence of rumination. Depleted interference-control resources may interfere with the capacity to override ruminative response tendencies. Once initiated, rumination may result in a cognitive load, further depleting inhibitory resources available for other tasks.

Hertel (2004) proposes that depressed individuals have habits of ruminating and argues that "Deficient cognitive control sets the stage for habits to emerge. At the same time, thoughts that habitually occupy attention leave little mental room for thoughts about anything

else" (p. 195). Hertel's (2004) model thus conceptualises the relationship between rumination and cognitive control as reciprocal. Such a proposal implies that the relationship between rumination and interference resolution may be bi-directional and have a synergistic effect on cognitive capacity.

Hertel (Hertel & Rude, 1991; Hertel, 1997, 2004) further proposes that constrained situations (for example, memory tasks that require participants to verbally rehearse the test material during the learning phase) eliminate the opportunity to ruminate, and that deficient attentional control, habits of attending to ruminative thoughts, and difficulties initiating task-focused cognitive strategies are responsible for depressed individuals' impaired performance on unconstrained tasks. Hertel (1997) posits that depressive impairments are greatest on unconstrained tasks that permit task-irrelevant ruminative thought, thus task performance is predicted to be improved under more structured (e.g., Hertel & Rude, 1991) or attentionally demanding (e.g., Krames & MacDonald, 1985) conditions.

Whitmer and Gotlib (2013) hypothesise that trait ruminators are characterised by a narrowed attentional scope, whereby cognitive processing is limited to a restricted set of information. Narrowing attentional scope is proposed to increase the likelihood of rumination, and lowered mood is proposed to result in a narrowing of attentional scope. The model thus argues that attentional scope is a mechanism underpinning the association between depressed mood and increased rumination. A narrowed attentional scope is hypothesised to have different consequences for cognitive control, depending on whether optimal task performance requires cognitive flexibility, or the ability to maintain a single task goal in the absence of external reinforcement. Specifically, Whitmer and Gotlib argue that narrowed attentional scope causes both benefits (reduced susceptibility to distraction) and deficits (increased cognitive inflexibility) to aspects of interference control. Whitmer and Gotlib further propose that for high trait ruminators both reduced cognitive flexibility and

greater resistance to distraction play a causal role in increased rumination. This hypothesis is broadly consistent with I→R models of rumination. Whitmer and Gotlib conceptualise their narrowed attentional scope hypothesis as complementary to resource depletion models, which they characterise in terms of an R→I causal account. Their model is thus consistent with a bi-directional account whereby the cognitive concomitants of a narrowed attentional scope cause increased rumination, which in turn reduces available cognitive resources.

Interference-control deficits and rumination as consequences of depression

A number of theorists note that depressive symptoms such as negative affect or loss of motivation, may cause both rumination and interference-control deficits (e.g., Frings, Wentura, & Holtz, 2007; Hartlage et al., 1993; Jones et al., 2010; Joormann, 2010; Whitmer & Gotlib, 2013). Thus, it is possible that rumination and interference-control deficits are not causally related, and that both are a consequence of depression.

Literature Search

A computerised search using keyword terms was conducted to identify relevant publications. The search (using wild cards such as ruminat* for rumination, ruminative, ruminate, ruminator) included the following keyword terms intended to identify studies examining rumination: *rumination, depression, dysphoria, self-focus, repetitive thought, perseverative, worry*, which were combined with each of the following keyword terms to identify studies examining interference control: *inhibition, inhibitory, interference, prepotent, cognition, cognitive, executive, attention, working memory, memory*, entered into ISI Web of Knowledge and PsycINFO from the beginning of the database through to August 2013. In addition, the reference lists of the identified publications, as well as key review articles and chapters (e.g., Joormann, 2005; Hertel, 2004; Whitmer & Gotlib, 2013) were reviewed for relevant literature. Only English language papers that examined rumination and interference

control processes in adult samples were included. Studies that did not include a behavioural measure of interference were not included (for example, studies reporting a correlation between trait rumination and self-report measures of off-task thinking, or studies reporting the patterns of deployment of neural resources associated with rumination). Finally, studies for which it was not possible to obtain the necessary information either from published sources or the relevant authors (i.e., no manuscript was available) were not included. A table summarising the studies identified and reporting their design, the cognitive task used, the valence of the task stimuli, and the main findings is presented in the Appendix.

To our knowledge, this is the first review reporting a systematic literature search to examine this field in depth with respect to the proposed causal relationship(s) between rumination and interference. Whitmer and Gotlib's (2013) systematic review considers an overlapping body of work, but their focus is different in four ways. First, they consider correlational evidence in depth, while the current review covers this only briefly, focussing instead on experimental work, which – unlike correlational studies – can inform the issue of causal direction central to this review. Second, Whitmer and Gotlib's review omits twelve relevant studies considered in the current review (Cheun et al., 2012; Curci Lanciano, Soleti, & Rime, 2013; De Lissnyder, Koster, Everaert, Schacht, Van den Abeele, & De Raedt, 2012; Joorman & Gotlib, 2010; Lee Pe, Vandekerckhove, & Kuppens, 2013; Lee Pe et al., 2013; Levens et al. 2009; Owens & Derakshan, 2013; Stoute & Rokke, 2010; Vanderhasselt et al., 2011; von Hippel et al., 2008; Wong & Moulds, 2008). Third, Whitmer and Gotlib (2013) generally take the construct validity of interference-control measures at face value, while the current review critically examines that construct validity, employing what is known from the often-extensive non-clinical literature on these measures. Fourth, Whitmer and Gotlib's review is primarily a vehicle for the introduction of a new model (the attention scope model). The attentional scope theory has potential to guide and inform future research, but the focus

in the current article is on the evaluation of more established – and hence more widely tested - accounts.

In our systematic review, we identified three main types of studies: (a) correlational studies relating individual differences in trait rumination to interference, (b) prospective studies that related individual differences in trait rumination to interference longitudinally, and (c) experimental studies that manipulated state rumination and measured subsequent interference control. In the sections that follow, we briefly summarize the correlational and prospective studies and consider the predominant patterns of findings emerging from such data. However, such data cannot discriminate between the four potential accounts of the relationship between interference and rumination discussed above. Thus, we only consider in detail those studies which have the potential to discriminate between the four accounts. Establishing the construct validity of the paradigms that have been adopted by these experimental studies is critical to developing a clear synthesis of the evidence relating rumination and interference. The experimental studies are thus organized by experimental paradigm, and each paradigm is reviewed and critically evaluated in terms of whether, on conservative criteria, it can be considered to index inhibitory control or interference.

Evidence of an association between rumination and interference control processes

Over 20 studies report a correlation between trait rumination and interference (Altamirano, Miyake, & Whitmer, 2010; Berman et al., 2011; Bernblum & Mor, 2010; Daches, Mor, Winquist, & Gilboa-Schechtman, 2010; Davis & Nolen-Hoeksema, 2000; De Lissnyder, Koster, & De Raedt, 2012; De Lissnyder, Koster, Everaert et al., 2012; Hertel & Gerstle, 2003; Joormann, 2006; Joormann & Gotlib, 2008; Joormann & Gotlib, 2010; Joormann, Levens, & Gotlib, 2011; Joormann, Nee, Berman, Jonides, & Gotlib, 2010; Joormann & Tran, 2009; Lau, Christensen, Hawley, Gemar, & Segal, 2007; Lee Pe, Raes et al., 2013; Lee Pe, Vandekerckhove et al., 2013; Levens, Muhtadie, & Gotlib, 2009; Meiran,

Diamond, Toder, & Nemets, 2011; Owens & Derakshan, 2013; Smallwood et al., 2002; Stout & Rokke, 2010; Vanderhasselt, Kuhn, & De Raedt, 2011; von Hippel, Vasey, Gonda, & Stern, 2008; Whitmer & Banich, 2007; Whitmer & Banich, 2010; Whitmer & Banich, 2012; Zetsche, D'Avanzato & Joormann, 2012). Four studies found no evidence of an association between trait rumination and behavioural measures of interference (Cheun Yee Lo, Lau, Cheung, & Allen, 2012; Goeleven et al., 2006; Krompinger & Simons, 2011; Ray et al., 2005). Three prospective studies report a longitudinal relationship between trait rumination and interference (Demeyer, De Lissnyder, Koster, & De Raedt, 2012; De Lissnyder, Koster, Goubert, Onreadt, Vanderhasselt, & De Raedt, 2012; Zetsche & Joormann, 2011). There is thus convergent evidence from a number of measures of interference control that individual differences in trait rumination are related to the capacity to resist interference from material that is not currently relevant.

A substantial number of the paradigms employed are ambiguous with respect to the specific processes that they are indexing. For example, Davis and Nolen-Hoeksema (2000) assessed cognitive control using the Wisconsin Card Sorting Task (WCST; Grant & Berg, 1948) which is understood to implicate attention, set-shifting, inhibition, and working memory (e.g., Greve, Williams, Haas, Littell, & Reioso, 1996; Miyake, Friedman et al., 2000). Thus, Davis and Nolen-Hoeksema's study supports the proposal that rumination is associated with impaired performance on cognitive tasks, but it is not possible to infer whether this relationship is specific to interference on the basis of their data. However, several studies report an association between trait rumination and interference using paradigms with better construct validity (for example, a number of studies report an association between trait rumination and interference on Oberauer's (2001) modified Sternberg task, which is regarded as a relatively valid index of interference; Joormann &

Gotlib, 2008; Joormann, Levens & Gotlib, 2011; Joormann, Nee, Berman, Jonides, & Gotlib, 2010).

Interestingly, several of the other correlational studies in this area report evidence consistent with the idea that trait rumination is associated with *more efficient* performance on tasks implicating inhibitory control or interference, although the authors of those studies seldom interpret their results in this manner. For example, a number of studies have demonstrated an association between trait rumination and reduced backward inhibition, which is interpreted by the authors of those studies as demonstrating impaired inhibitory control in high trait ruminators (De Lissnyder et al., 2010; Whitmer & Banich, 2007; Whitmer & Gotlib, 2012). Backward inhibition is an empirical phenomenon related to task switching, and is indexed as the additional time taken to switch to a recently employed task set (e.g., switching back to task A in task sequence A-B-**A**) relative to the time taken to switch to a less recently employed task set (e.g., switching to the task C task sequence A-B-**C**). Thus, the reduced backward inhibition observed in high trait ruminators, relative to controls, indicates *greater* efficiency in returning to recently performed task sets, and thus suggests more efficient cognitive control in high trait ruminators than in controls. De Lissnyder et al. (2010) report that trait brooders exhibited reduced backward inhibition specifically for angry faces using an affective shift task, suggesting that their observation of enhanced efficiency may be attributable to facilitated processing of negative material. However, Whitmer and Banich (2007) and Whitmer and Gotlib (2012) employed neutral stimuli, indicating that emotional valence is not sufficient to account for the association between trait rumination and reduced backward inhibition in at least two of these three studies. Similar patterns of findings are reported in studies examining negative affective priming (e.g., Joormann, 2006; Joormann & Gotlib, 2010), performance on the modified Stroop task (Altamirano et al., 2010), retrieval induced forgetting (Whitmer & Banich, 2010),

and suppression-induced forgetting (Hertel & Gerstle, 2003). Of these studies, six involved emotional material (Hertel and Gerstle (2003) and Joormann (2006) report enhanced performance for positive and negative stimuli; Joormann and Tran (2009) report enhanced performance for positive stimuli; Zetsche and Joormann (2011) and Joormann and Gotlib (2010) report enhanced performance for negative stimuli; Pe, Vandekerckhove et al. (2013) report enhanced performance for positive, negative and neutral stimuli) and a further two involved neutral stimuli (Altamirano et al., 2010; Whitmer & Banich, 2010). Thus, the role of emotional stimulus valence may contribute to some but not all observations of rumination-related performance benefits. Whilst Altamirano et al. (2010) would recognise this characterisation of their findings, in all other cases our interpretation is at odds with the interpretation of the authors. We discuss this contentious issue in further depth towards the end of this review.

In summary, fifteen studies are consistent with high trait rumination being associated with deficits in interference control (Bernblum & Mor, 2010; Berman et al., 2011; Daches et al., 2010; Davis & Nolen-Hoeksema, 2000; Demeyer et al., 2012; De Lissnyder Koster, & De Raedt, 2012; De Lissnyder, Koster, Everaert et al., 2012; De Lissnyder, Koster, Goubert et al., 2012; Lau et al., 2007; Levens et al., 2009; Joormann & Gotlib, 2008; Joormann et al., 2011; Owens & Derakshan, 2013; Stout & Rokke, 2010; Zetsche et al., 2012), four are indicative of trait rumination being associated with both benefits and deficits to interference control processes (Altamirano et al., 2010; De Lissnyder et al., 2010; Whitmer & Banich, 2007; Zetsche & Joormann, 2011), and seven are consistent with trait rumination being associated with the utilization of a level of interference control that is more appropriate to the demands of the task and thus results in benefit to performance (Hertel & Gerstle, 2003; Lee Pe, Vandekerckhove et al., 2013; Joormann, 2006; Joormann & Gotlib, 2010; Joormann & Tran, 2009; Whitmer & Banich, 2010; Whitmer & Gotlib, 2012).

However, this sort of data does little to further understanding about the causal nature of the relationship between rumination and interference control. Sleeping with the light on during infancy is correlated with myopia in later life (Quinn et al., 1999) but the relationship is unlikely to be causal (e.g., Gwiazda et al., 2000). In the case of rumination and interference control, the association may be mediated by confounding variables such as depression or low mood. Hence, the remainder of this review focuses on experimental evidence that in principle has the potential to provide evidence for or against the two leading causal accounts. Specifically, we consider experimental evidence in which the hypothesised cause has been manipulated and changes in the effect of interest have been examined. The proposed causal impact of poor interference control on rumination would be examined by manipulating the effectiveness of interference control processes and measuring the effect that this has on the susceptibility to rumination. The proposed causal impact of rumination on interference control would be examined by manipulating rumination and measuring the effect that this has on interference control capabilities.

Impaired Interference Control as a Cause of Rumination: The Evidence

Despite many commentators implicitly or explicitly postulating impaired interference control as a cause of rumination (e.g., Hertel, 2004; Joormann, 2006; Joormann & Gotlib, 2008; Levens et al., 2009; Whitmer & Banich, 2007; 2010), there are no published experimental studies that have examined this possibility. There are some prospective studies (e.g., Zetsche & Joormann, 2011), but prospective studies cannot establish causality (as the example of childhood myopia, cited earlier, illustrates). There are also no experimental studies examining Whitmer and Gotlib's (2013) recent proposal that a narrowed attentional scope (defined as impaired cognitive flexibility and reduced susceptibility to distraction) causes rumination. Future work to provide a more detailed specification of how attentional

scope might be operationalized and measured will be an important step in examining the hypotheses generated by this account of trait rumination and cognitive control.

Rumination as a Cause of Impaired Interference Control: The Evidence

There are six experimental studies (Curci et al., 2013; Hertel, 1998; Philippot & Brutoux, 2008; Watkins & Brown, 2002; Whitmer & Gotlib, 2012; Wong & Moulds, 2008) that have examined the effects of experimentally manipulating rumination on subsequent performance on cognitive tasks. Although experimentation is a necessary condition for establishing causality, it is not a sufficient one; at a minimum, the independent and dependent variables must have acceptable construct validity, and there must be adequate control for confounding variables. In the sections that follow, we critique the construct validity of the experimental procedures in the extant experimental literature.

Random Number Generation

Watkins and Brown (2002) compared the performance of depressed and non-depressed individuals on a random number generation task following rumination and distraction inductions. In the random number generation task, participants are instructed to say the numbers 1 to 9 in a random order 100 times at a rate of one per second, which is paced using a metronome. An alternative version of the task involves pressing keys corresponding to each number in a random order. Watkins and Brown (2002) found that depressed patients were impaired on generation of random numbers relative to non-depressed patients in the rumination condition but not in the distraction condition, in which the groups did not differ. Thus, their results are consistent with the proposal that depression-related impairments in cognitive control are maintained by ongoing rumination, and are ameliorated by distraction, which temporarily eliminates rumination.

Random number generation is generally considered to involve working memory and is frequently interpreted as an index of cognitive control processes (e.g., Baddeley, Emslie,

Kolodny & Duncan, 1998; Brown, Soliveri, & Jahanshahi, 1998), including the ability to inhibit prepotent counting responses, the ability to generate possible responses, the ability to maintain the complete set of response options in mind continually, and to recall those that have recently been used (Towse & Valentine, 1997). Thus, Watkins and Brown's (2002) finding suggests that state rumination impairs cognitive control processes, but does not establish that this effect is specific to interference control.

Operation word memory span test (OSPAN; Turner & Engle, 1989)

Curci et al. (2013) examined the impact of negative and neutral mood inductions on self-reported rumination and available working memory resources in individuals high and low in working memory capacity. Current working memory capacity (as assessed by the OSPAN), and positive and negative emotions (assessed by the Differential Emotion Scale; DES; Izard, Dougherty, Bloxom, & Kotsch, 1974) were assessed before and after participants were randomised to read written passages of either negative or neutral emotional valence. Self-reported rumination and intrusive thoughts were assessed immediately after the second OSPAN test, and 24 hours later. Following the mood induction, self-reported rumination mediated the association between negative emotional state and working memory performance on the OSPAN; negative emotion on the DES was found to cause increased rumination, which in turn reduced working memory capacity. A number of cognitive control processes including strategy selection, monitoring, resource allocation, and other non-executive processes have been implicated in OSPAN performance (e.g., Unsworth & Engle, 2005). Thus, Curci et al.'s data is consistent with the hypothesis that ruminative thoughts about negative emotional states occupy working memory capacity, but does not establish that this specifically impacts on interference control.

Directed forgetting

Wong and Moulds (2008) used a directed forgetting paradigm to examine cognitive control amongst dysphoric and non-dysphoric individuals following either rumination or distraction. Directed forgetting tasks (Anderson & Spellman, 1995; Anderson & Green, 2001; Nee & Jonides, 2008) require participants to forget a subset of previously studied material. Subsequent recall of both the material that they were instructed to remember, and that which they were told to forget is measured: proactive interference from the to-be-forgotten material is indexed by increased recall of this material and decreased recall of the material to be remembered. MacLeod (1998) reviewed the evidence regarding theoretical accounts of directed forgetting, and concluded that when participants are instructed which material is to be forgotten using a list procedure (as opposed to being cued whether to remember or forget each item before the next item is presented), the paradigm can be regarded as a relatively clear measure of resistance to proactive interference.

Wong and Moulds reported that dysphoric participants in the rumination and distraction conditions did not differ in directed forgetting for positive, negative, or neutral words; all dysphoric participants exhibited standard directed forgetting effects. However, Wong and Moulds found that their rumination and distraction inductions differentially influenced change in self-reported self-focus (using the standard VAS scales that have been used in studies with these manipulations – e.g., Watkins, 2004), but not in happiness or sadness. The majority of studies that have used the rumination and distraction inductions have found a reliable differential effect on changes in self-reported mood (e.g., Lavender & Watkins, 2004; Lyubomirsky, Caldwell & Nolen-Hoeksema, 1998; Lyubomirsky, Kasri, & Zehm, 2003; Lyubomirsky & Nolen-Hoeksema, 1995; Nolen-Hoeksema & Morrow, 1993; Watkins & Teasdale, 2001), which is used as a manipulation check for the successful induction of rumination versus distraction. Thus, it is not clear that the rumination manipulations operated in the usual way in this study. One could infer from this that it is not

clear that rumination had been reliably induced since rumination is understood to exacerbate dysphoric mood states. Alternatively, one could argue that this study represents a potentially valuable case where self-focus changes independent of mood, and interestingly the study finds no evidence to indicate that rumination in the absence of mood change impairs interference control.

Controlled retrieval (process dissociation procedure)

Hertel (1998) compared the performance of dysphoric and non-dysphoric students on the fragment completion test of memory for studied word pairs, using Jacoby's (1991, 1996, 1998) procedure to dissociate controlled and automatic retrieval. Jacoby's (1996) stem-completion task presents participants with a series of neutral word pairs, which they are instructed to remember for a later memory test (learning phase). In the test phase, participants are given word stems to complete. In trials where the instruction "use old" is presented, participants must use the stem as a cue to recall a word from the learning phase and complete the stem with this word. For trials in which the instruction "use new" is presented, participants must also use the stem to cue recall of a word from the learning phase, but must not use the recalled words to complete the stem and instead produce a novel completion. Jacoby (1991, 1998) developed a process dissociation procedure whereby the relative contributions of controlled and automatic processes to the task are estimated. Completions using an old word can be achieved via both controlled retrieval, with a probability of R, and automatic processes (i.e., the word came to mind automatically), with a probability of A. When participants are asked to retrieve a new word, production of an old word reflects the success of automatic processes and failure of controlled processes (Jacoby, 1991, 1998). The estimate of controlled retrieval is thus the proportion of targets correctly used on "use old" trials minus the proportion used erroneously on "use new" trials.

Between the encoding phase and the stem-completion phase, Hertel (1998) manipulated rumination by allocating participants to one of three conditions: a rumination induction, an unconstrained interval (in which it was hypothesised that dysphoric individuals would be likely to engage in rumination), and a distraction induction. Dysphoria-related impairments in controlled retrieval, relative to the non-dysphoric group, were observed following a rumination induction, or a period of unconstrained thought, but not following a distraction induction. Thus, consistent with the hypothesis that rumination causes interference-control deficits, eliminating the opportunity to ruminate eliminated cognitive control impairments. Hertel's measure of interference control appears to have adequate construct validity. However, there was no manipulation check of the rumination induction, which limits the extent to which the findings can be reliably attributed to rumination.

Stroop interference

Philippot and Brutoux (2008) used a modified Stroop task to examine interference control processes for neutral stimuli in dysphoric and non-dysphoric female undergraduates following a rumination or distraction induction. The study included conditions designed to examine Stroop interference (participants were asked to name the ink colour of printed congruent and incongruent colour words) and flexibility (participants were presented with colour words printed in different ink colours, some of which were framed; they were asked to read the framed words and to say the ink colour of the unframed words). Dysphoric participants in the rumination condition made significantly more interference errors than any other participant group, and dysphoric participants across both conditions made more flexibility errors than the control group.

The Stroop paradigm is one of the most frequently used cognitive tests and is designed to index interference control (MacLeod, 2005). One way of conceiving Stroop interference is as a measure of prepotent response inhibition, with the prepotent response

being naming the word (e.g., Friedman & Miyake, 2004; May & Hasher, 1998). Another possibility is that Stroop interference is a consequence of competition from the task level (i.e., the reading task set), rather purely the response level (Monsell, Taylor & Murphy, 2001); an account that does not necessarily implicate inhibition. In the light of multiple plausible accounts of Stroop interference, it seems safest to conclude that Stroop interference provides an index of interference, but not necessarily of inhibition. Philippot and Brutoux's (2008) study thus demonstrates a causal influence of rumination on the efficiency of interference resolution.

Task switching and backward inhibition

Whitmer and Gotlib (2012) examined the effect of a rumination induction on the backward inhibition procedure (described in an earlier section), and reported that depressed ruminators exhibited significantly greater switch costs than both depressed individuals in the distraction condition and non-depressed ruminators. In contrast to the correlational data we discussed earlier (Whitmer & Banich, 2007, Whitmer & Gotlib, 2012), there were no effects of depression or rumination on backward inhibition in this experimental manipulation. It is of note that the manipulation checks following the rumination and distraction inductions examined mood, but not self-focus. The absence of a self-focus manipulation check casts some doubt as to whether rumination was effectively induced in this study.

Convergent evidence from working memory load

The hypothesis that rumination causes impaired interference control typically assumes mediation of this relationship through rumination occupying working memory capacity, and thus impairing performance on tasks that are sensitive to working memory load (Hester & Garavan, 2005). Consistent with this account, Curci et al (2013) report state rumination mediated the association between negative mood and working memory capacity, and many of the tasks used to assess interference resolution in the studies reviewed above are known to be

sensitive to the imposition of concurrent working memory load, or to systematically vary according to working memory span. For example, the Stroop task is sensitive to individual differences in working memory span such that individuals low in working memory capacity make more errors and exhibit larger response latency interference effects (Kane & Engle, 2003). Working memory load reduces R (controlled retrieval) whilst leaving A (automatic generation of the word without recollection) relatively unimpaired on inclusion-exclusion memory tasks such as that used by Hertel (1998) (Jacoby, 1998). Working memory load also impairs random number generation (Towse & Valentine, 1997), and task switching (see Vandierendonck, Liefooghe, & Verbruggen, 2010 for recent discussion). Indeed, there is no firm evidence to discount working memory span being critical to any of the interference control paradigms that have been related to rumination.

Summary

There is preliminary evidence that is consistent with the proposal that state rumination interferes with concurrent cognitive control resulting in decrements to task performance. Three studies provide evidence that induced rumination impairs performance on tasks that can be regarded as relatively clear measures of interference (Hertel, 1998; Philippot & Brutoux, 2008; Whitmer & Gotlib, 2012); one study reports a null finding (Wong & Moulds, 2008). In all three positive cases, describing the studies as measuring inhibitory control is going beyond the data. If researchers wish to investigate inhibitory control specifically, future experimental work may wish to consider using tasks which basic research supports as indices of inhibition. Examples include the stop-signal task and the response signal procedure (Logan, Cowan, & Davis, 1984; Ratcliff, 2006).

Confounding variables

Mood state

Rumination and distraction inductions differ in emotionality (Philippot & Brutoux, 2008). Distraction temporarily improves low mood in depressed individuals (Lyubomirsky, Kasri, & Zehm, 2003, Whitmer & Gotlib, 2012), whilst rumination exacerbates negative mood (Lyubomirsky et al., 2003, Whitmer & Gotlib, 2012), but has little emotional impact on people in a neutral mood. Negative mood is itself associated with poor performance on executive tasks (e.g., Channon, 1996; Snyder, 2013), reduced attentional flexibility (Ellenbogen, Schwartzman, Stewart, & Walker, 2002), mood-congruent biases in attention and memory (Koster, De Raedt, Leyman, & De Lissnyder, 2010), and more frequent attentional lapses when completing tasks requiring sustained attention (Smallwood, Fitzgerald, Miles, & Phillips, 2009). Moreover, negative mood is hypothesised to narrow attentional focus at the expense of flexible and creative thinking (e.g., Clore & Gasper, 2000; Koster et al., 2011). It is thus possible that it is the change in mood induced by rumination or the improvement in mood induced by distraction that mediates the differential effects of rumination and distraction on interference, rather than these effects being a direct consequence of rumination per se.

Of the three studies that provide evidence for the hypothesis that rumination causes impaired interference control, Philippot and Brutoux (2008) and Hertel (1998) did not assess the affective consequences of their rumination and distraction manipulations, and so mediation via mood state cannot be ruled out. Whitmer and Gotlib (2012) found that the rumination induction worsened mood more for depressed than non-depressed individuals, as would be predicted by a mood-based account. Future work including a non-ruminative mood induction as a control condition is needed in order differentiate the consequences of rumination for cognitive control from the consequences of exacerbating or alleviating depressed mood. Watkins and colleagues have examined the effects of two variants of the standard rumination induction which are equivalent in emotional valence and effect of

negative mood (e.g., Watkins & Teasdale; 2004; Watkins & Moulds, 2005). Only one of these is consistent with the phenomenology of depressive rumination by focusing on abstract thinking about "why". The effect of rumination on interference control can be distinguished from the effect of low mood and could therefore potentially be examined through the use of such inductions.

Motivation

Once activated, ruminative thoughts might be prioritised at the expense of optimal task performance because such thoughts pertain to personally important concerns. Thus, as noted by Linville (1996), a full account of the relationship between rumination and interference needs to address both cognitive and motivational components of rumination.

Future challenges

Testing the I →R hypothesis

No studies have yet examined the hypothesis that manipulating inhibitory control influences subsequent rumination. An important methodological issue for this line of investigation is what constitutes a valid index of state rumination. Previous work has tended to focus on the consequences of state rumination, inferring rumination from self-report measures of state mood and self-focus (e.g., Nolen-Hoeksema, 2000). A direct measure of state rumination is essential in order to experimentally test hypotheses regarding putative causes of rumination, including the predictions derived from I→R models. Recent research examining the causal impact of goal discrepancies on state levels of rumination indicates that thought probe methodologies offer a promising approach to directly assess state rumination about idiographic personal concerns (Roberts, Watkins, & Wills, 2013).

Future work manipulating inhibitory control and indexing levels of state rumination with such direct measures before and after manipulations will be an important avenue for directly testing the hypothesis that impaired inhibitory control causes rumination. A particular

challenge with respect to this question is that a robust and valid manipulation of inhibitory control has not yet been established, although there are a number of possibilities that merit investigation. First, a manipulation that temporarily depletes interference control resources (e.g., with alcohol consumption, Easdon & Vogel-Sprott, 2000) could be employed. Alcohol consumption has been demonstrated to influence the cognitive control resources that are deployed in inhibitory processing (e.g., Easdon & Vogel-Sprott, 2000; Fillmore, Vogel-Sprott, & Gavrilescu, 1999; Finnigan, Schulze, & Smallwood, 2007). Second, methods designed to improve interference control (e.g., a working memory training programmes, Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) could be adopted to manipulate interference control. Such programmes have been demonstrated to improve performance of measures of working memory capacity, and thus would be predicted to reduce the tendency to ruminate in response to low mood. However, it is of note that the extent to which such training benefits transfer to novel tasks is the subject of debate (see Shipstead, Redick & Engle, 2012 for recent review).

More is not always better

The pattern of correlational data regarding trait rumination suggests another intriguing avenue for future research. There is correlational evidence suggesting that in some circumstances trait rumination may be positively associated with better task performance on tasks that index interference control processes (specifically, the modified Stroop task, Altamirano et al., 2010; negative affective priming, Joormann, 2006; Joormann & Gotlib, 2010; retrieval induced forgetting, Whitmer & Banich, 2010; suppression-induced forgetting, Hertel & Gerstle, 2003; and directed forgetting, Joormann & Tran, 2009).

All these procedures use poorer performance (slower or less accurate) on a task as an index of stronger interference control. As a laboratory procedure to study interference control, such a technique is clearly valid. However, the authors of the studies examining the

association between trait rumination and performance on these tasks have equated stronger interference control with better interference control, and this may not always be a valid assumption. An alternative interpretation is that it is possible to have overly strong interference control at a cost to efficient task performance. For example, in the directed forgetting paradigm employed by Joormann and Tran (2009), high trait ruminators are just as good as low trait ruminators in suppressing a response when asked to do so, but they are better at recalling that suppressed response later on when asked to recall it. The fact that this superior performance is observed in several studies for which the materials are neutral (Altamirano et al., 2010; Whitmer & Banich, 2007; Whitmer & Banich, 2010; Whitmer & Gotlib, 2012) rules out alternative accounts in terms of processing biases (see Koster et al., 2011). The hypotheses that rumination sometimes leads to better interference control, and/or that better interference control sometimes leads to greater rumination (e.g., Whitmer & Gotlib, 2013) are striking and currently based solely on correlational data. Experimental investigation of these hypotheses may be important topics for future research.

The role of valence of task stimuli

The role of stimulus valence in rumination-related interference control difficulties is complex. Although some studies suggest that the correlation between trait rumination and interference control deficits is specific to emotional or negatively valenced material (Bernblum & Mor, 2010; Demeyer et al., 2012; De Lissnyder et al., 2011; De Lissnyder, Koster, & De Raedt, 2012; Berman et al., 2011; Joormann & Gotlib, 2008; Joormann et al., 2011; Lau et al., 2007), a substantial number of studies demonstrate that trait rumination is associated with impaired interference control when processing neutral material or irrespective of the emotionality of the material (Altamirano et al., Daches et al., 2010; Davis & Nolen-Hoeksema, 2000; De Lissnyder et al., 2010; Levens et al., 2009; Stout & Rokke, 2010; Whitmer & Banich, 2007; von Hippel et al., 2008). Further studies are needed to

systematically examine the relationship between rumination, and interference resolution when processing positive, negative, and neutral stimuli.

Rumination involves prolonged and repetitive focus upon and processing of negative material, and high trait ruminators preferentially process negative material and demonstrate difficulties resolving interference from negative distractors (Koster et al., 2011). Repeated and sustained processing of negative self-relevant material and difficulties disengaging from this is likely to exacerbate and prolong negative moods and dysphoric states, increasing vulnerability to depression (Nolen-Hoeksema, 1991). Studies that directly contrast the potential presence of interference control deficits amongst depressed individuals in measures that implicate the same inhibitory subtype but contrast neutral and emotionally valenced materials will be a potentially useful step in clarifying the potential role of emotional material in the relationship between depression and interference control deficits.

To date, the data regarding the effects of induced rumination on interference control is limited to neutral stimuli. An R→I account would predict that rumination-related impairments would be evident across neutral and emotional stimuli and attributable to reduced cognitive capacity. Additionally, the impact of induced rumination might be predicted to be strongest in the context of negative material, as depressive-related biases towards the processing of negative content would cause a greater pull on resource allocation.

The predictions regarding an I→R hypothesis are less clear with regard to the role of stimulus valence but theorists have tended to focus on the processing of emotional material (e.g., Joormann, 2005). According to control theories of rumination, goal pursuit plays an important role in rumination (e.g., Martin & Tesser, 1996). If the hypothesised causal role of interference control in state rumination is specific to negative material then impaired interference control would be predicted to increase susceptibility to negative rumination (about lack of expected goal progress) but not positive rumination (about greater than

expected goal progress). In contrast, if impaired interference control for all emotional material plays a causal role in rumination, then increased rumination about both positive and negative goal discrepancies would be predicted when interference control capabilities are depleted or impaired. Future work systematically examining these predictions will be a valuable step in clarifying the role of stimulus valence in the I→R model.

Taxonomies

Different operationalizations of interference control have been implicated in theories of rumination and inhibition. A number of studies have adopted paradigms that implicate the resistance to interference subtype (e.g., De Lissnyder et al., 2010; Hertel, 1998; Hertel & Gerstle, 2003; Joormann & Gotlib, 2008; Joormann & Tran, 2009; Joormann et al., 2010; Whitmer & Banich, 2007; Whitmer & Banich, 2010). This is consistent with theoretical accounts of this relationship (Linville, 1996; Joormann et al., 2007), to which the resistance to proactive interference operationalization of interference control is most relevant (e.g., Friedman & Miyake, 2004; Linville, 1996). A substantial number of additional studies provide further convergent evidence that rumination is related to interference control processes. Thus, on the basis of existing evidence, rumination appears to be most clearly related to the resistance to interference subtype.

However, the evidence regarding rumination and the prepotent response inhibition subtype is relatively weak, with few studies having examined this operationalization with respect to rumination. Thus, it is not clear if the relationship between rumination and interference control is specific to one or more of the subtypes of interference control. There is a need for studies adopting multiple measures in order to address the distinct operationalizations of inhibition proposed by the taxonomies (e.g., Friedman & Miyake, 2004).

Clinical Implications

The different proposed accounts of the relationship between rumination and interference control processes have distinct implications for clinical understanding of, and interventions for, rumination and depression. The three accounts specifying a causal relationship each predict distinct approaches to reducing cognitive interference and rumination in depression.

The R→I account would suggest that the extent of cognitive impairments reported across episodes of depression, and also during recovery, may be related to the extent and severity of pathological rumination. Moreover, it implies that rumination does not occur as a consequence of underlying interference control deficits, suggesting that other models (a habitual response style, Nolen-Hoeksema, 1991; control theory, Watkins, 2008) may account for rumination. Clinically, this would suggest that targeting interference control processes would not be an efficacious way to reduce rumination. Moreover, it suggests that specifically targeting pathological rumination through extant treatments focusing on processing style (Watkins et al., 2007, 2011) should be beneficial in reducing the cognitive impairments that are reported in depression.

In contrast, the I→R account would imply that underlying interference control deficits would need to be a key target for the assessment and treatment of rumination. This account would predict that for interventions to have a long-term benefit in reducing rumination, they would need to address deficits in interference control, perhaps through cognitive training programmes designed to increase working memory capacity (see Shipstead et al., 2012 for recent review and critique of WM training approaches) or enhance inhibitory control (e.g., Muraven, 2010). Moreover, this account predicts that experimental assessment of interference control may be a good index of potential susceptibility to pathological rumination, to be used to identify individuals at high risk and to assess the impact of interventions. Moreover, this account would indicate the potential value of neurobiological

interventions to improve interference control, whether through psychopharmacological intervention or through identifying relevant neural substrates through functional MRI and then manipulating their activity through repeated transcranial magnetic stimulation (for detailed discussion of the use of TMS in depression see Loo & Mitchell, 2005). A bi-directional relationship would indicate the potential value of both of these approaches.

Conclusions

The relationship between rumination and interference control is an important research topic with clear clinical and theoretical importance in advancing our understanding of depression. Research should, as a matter of urgency, move beyond correlational studies, to carefully designed experimental studies that have the potential to investigate the proposed causal mechanisms. With over twenty correlational studies but just six experimental studies to date, and with the experimental studies having significant limitations in terms of construct validity and confounding variables, there is a clear need for further experimental research in this area. Such limited experimental research as there is tentatively suggests that rumination may cause deficits in interference control; describing them as deficits of inhibitory control goes beyond the data. The idea that interference-control deficits cause rumination has not yet been the subject of experimental research.

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APPENDIX: *Studies examining the relationship between rumination and interference control processes*

✓ = relatively clear index of interference control processes ? = a number of possible interpretations of the task

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
			Experimental Studies			
Curci et al. (2013)	Manipulated rumination and then measured interference control	High and low working memory span	OSPAN	Neutral	?	Rumination following a negative mood induction mediated the association between negative mood and working memory capacity.
Hertel (1998)	Manipulated rumination and then measured interference control	BDI≥9 & BDI≤6	Fragment completion test of memory for studied word pairs, dissociating controlled and automatic retrieval.	Neutral words	✓	Impairments resisting proactive interference observed in both rumination conditions, but not in distraction condition.
Philippot & Brutoux (2008)	Manipulated rumination and then measured interference control	BDI≥18 & BDI≤10	Stroop task	Neutral words	✓	Impaired prepotent response inhibition observed for dysphoric participants in rumination condition, compared to those in distraction condition, and to non-dysphoric participants.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
			Experimental Studies			
Watkins & Brown (2002)	Manipulated rumination and then measured interference control	MDD & controls (not depressed in past 5 years)	Random Number Generation	Neutral	?	Depressed participants in rumination condition showed a greater tendency towards stereotyped counting responses than all others. Depressed participants in distraction condition did not differ from non-depressed controls.
Whitmer & Gotlib (2012)	Manipulated rumination and then measured interference control	MDD & controls	Task switching paradigm	Neutral	✓	Induced rumination caused greater switch costs relative to distraction for depressed participants but not for controls. No effects of depression status or rumination condition on preparation effect. High trait rumination was associated with reduced backward inhibition cost.
Wong & Moulds (2009)	Manipulated rumination and then measured interference control	BDI≥12 & BDI≤5	Directed forgetting paradigm	Positive, negative, and neutral words.	?	The rumination manipulations differentially effected self-reported self-focus, but not mood. Dysphoric participants in the rumination and distraction conditions did not differ in directed forgetting for positive, negative, or neutral words. All dysphoric participants exhibited standard directed forgetting effects.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
			Correlational Studies			
Altamirano, Miyake, & Whitmer (2010)	Correlational	Healthy students	Letter-naming task and modified Stroop paradigm	Letters and numbers (letter naming task) and neutral words (modified Stroop).	✓	Trait rumination was positively associated with postcue errors on the letter naming task (interpreted as a measure of goal flexibility), and was negatively associated with incongruent trial errors on the Stroop (interpreted as goal maintenance).
Berman et al (2011)	Correlational	MDD and healthy controls	Directed forgetting paradigm	Positive and negative words	✓	Individual differences in trait rumination were positively correlated with slower rejection of the negative words from the to-be-forgotten list.
Bernblum & Mor (2010)	Compared high and low trait brooders using quartile split	Healthy students	Memory refreshing task	Neutral and emotional words	?	Based on a quartile split high trait brooders demonstrated greater interference from emotional words.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Cheun Yee Lo, Lau, Cheung, & Allen (2012)	Used hierarchical linear modelling	Healthy students	Mental counting task	Neutral and emotional words (positive and negative)	✓	There was no relationship between switch costs and rumination, mood condition, or the interaction of the two
Daches, Mor, Winquist, & Gilboa-Schechtman (2010)	Correlational	Healthy students	Modified Garner task	Neutral words, and non-emotional self-referentially encoded words	?	Brooding was positively associated with Garner interference
Davis & Nolen-Hoeksema (2000)	Compared high and low trait ruminators using predetermined criteria on RSQ	RRS-SF≤1 item "often" or "always" & RRS-SF≥5 items "often" or "always"	Wisconsin Card Sorting Task (flexibility measure) and backward digit span (working memory measure) and Colours subtest (task switching measure)	Neutral	?	High RRS scorers made more perseverative errors than low RRS scorers. No group differences in WMC or task-switching.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
De Lissnyder, Derakshan, De Raedt, & Koster (2011)	Compared high and low trait ruminators using a median split	BDI-II-NL<14 & BDI-II-NL≥14	Mixed antisaccade task	Neutral	✓	No interaction of rumination with the anti-saccade benefit. High trait ruminators exhibited slower anti-saccade latencies than low ruminators overall, and the groups did not differ on pro-saccade latencies.
De Lissnyder, Koster, Derakshan & De Raedt (2010)	Correlational; compared high and low trait ruminators using a median split	BDI-II-NL<14 & BDI-II-NL≥14	Affective shift task (modified task switching paradigm)	Happy and angry faces	✓	High ruminators were impaired at resolving interference from irrelevant negative material. Depressive brooding was predictive of faster RTs on n-2 repetitions of negative material, BDI-II, RRS and reflective pondering were not. High ruminators had a greater shift-cost than low ruminators. Depressive brooding was predictive of set-shift costs, BDI-II, RRS and reflective pondering were not.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
De Lissnyder, Koster, Everaert et al. (2012)	Correlational	MDD & non depressed controls	Internal Shift Task (IST)	Neutral and angry faces	✓	Trait rumination correlated with switch costs on IST. No valence specific effects.
De Lissnyder, Koster & De Raedt (2012)	Compared high and low trait ruminators using a median split	BDI-II-NL<14 & BDI-II-NL≥14	Internal Shift Task (IST)	Neutral and angry faces	✓	High trait ruminators had larger switch costs when classifying faces according to emotionality relative to making gender classifications. High ruminators had larger switch costs to emotional faces than low trait ruminators
Goeleven, De Raedt, Baert, & Koster (2006)	Correlational	MDD, formerly MDD (2+ episodes) & controls	Negative Affective Priming Task	Happy and sad faces	?	Depression-related performance deficits for negative material were not related to trait rumination
Hertel & Gerstle (2003)	Correlational; compared high and low trait ruminators operationalized as the higher and lower scorer on the RSQ in each cell of their counterbalancing design	BDI≤6 & BDI≥9	Adapted think/no-think paradigm	Positive and negative words	✓	RRS was negatively correlated with intrusion effect size – participants higher in trait rumination recalled more suppressed targets. High RSS scorers forgot fewer suppressed targets than low RSS scorers.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Joormann (2006)	Correlational; compared high and low trait ruminators on the 21-item RSQ-R and RSQ-reflection operationalized using a median split	Healthy students	Negative Affective Priming task	Positive and negative words	?	High ruminators on both RSQ-R and on RSQ-reflection did not show negative priming effect for emotional words (both positive and negative). RSQ-R and RSQ-reflection were significantly negatively correlated with the negative bias score. A regression model identified CES-D (symptoms of depression) and RSQ-R as significant predictors of negative bias score.
Joormann & Gotlib (2008)	Correlational	MDD & controls (never disordered)	Modified Sternberg task	Positive and negative words	✓	Rumination was correlated with depression-related impairments resisting proactive interference from negative words.
Joormann & Gotlib (2010)	Correlational	MDD, RMD (1+ episode, currently remitted), & controls	Negative Affective Priming task	Positive, negative and neutral words	?	Depressed participants exhibited a reduced negative priming effect for negative material, and this was associated with greater trait rumination (RRS) and trait brooding. MDD participants exhibited an increased negative priming effect for positive material, and this was positively associated with trait reflection.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Joormann, Levens & Gotlib (2011)	Correlational	MDD and never depressed controls	Working memory manipulation task	Positive, negative, and neutral words	✓	MDD had bigger sorting costs (RT backwards trials – RT forwards trials) than controls. MDDs had bigger sorting costs for negative than positive or neutral trials. For MDDs only RRS scores significantly predicted sorting costs for negative words.
Joormann, Nee, Berman, Jonides, & Gotlib (2010)	Correlational	MDD & controls (no hx Axis I disorder)	Ignore/ Suppress task	Positive and negative words (study 1); letters (study 2)	✓	Expt 1: emotional words. MDD had greater interference effects (RT forget probes – RT control probes) for negative words than CTL. Rumination (RRS) was correlated with depression-related impairments resisting proactive interference from negative words. Expt 2: 4 or 8 letters (high and low WM load). No correlation between RRS and interference effects (RT forget probes – RT control probes).
Joormann & Tran (2009)	Compared high and low trait ruminators using median split	Healthy students	Directed forgetting task	Positive and negative words	?	No group differences in recall of negative words; high RRS group recalled more positive words. Low RRS group recalled fewer words under forget than remember instructions; high RRS group did not differ in recall of words under forget compared to remember instructions. Groups did not differ in frequency of positive intrusions (“recall” of words never presented); high RRS groups had more negative intrusions than low RRS group.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Krompinger & Simons (2011)	Correlated neural activity with trait rumination	Top & bottom 10% BDI scorers in student cohort	Stroop	Neutral words	✓	No significant behavioural effects. In the high BDI group N450 activity was more negative for incongruent than congruent trials, and this effect was correlated with trait rumination.
Lau, Christensen, Hawley, Gemar, & Segal (2007)	Correlational	MDD, anxious, and controls	Prose distraction task and stop signal task	Positive, negative and neutral words	?	RSQ-R correlated with negative interference index (RT negative distractors – RT neutral distractors in MDD group. No impairments observed on stop signal task.
Lee Pe, Raes et al (2013)	Correlational; experience sampling design	Students ranging in depressive scores	Affective interference resolution t ask	Positive, negative, and neutral words	✓	No significant association between positive or negative interference and rumination or reappraisal in everyday life. Negative interference scores moderated the association between negative affect and rumination in everyday life.
Lee Pe, Vandekerckhove et al. (2013)	Correlational	Unselected students	Emotional flanker	Positive, negative and neutral	?	No association between flanker interference as indexed by accuracy or RTs and rumination. Using diffusion model analysis, trait rumination associated with greater facilitation by negative and neutral distractors and reduced interference due to positive distractors
Levens, Muhtadie, & Gotlib (2009)	Correlational	MDD & controls (never disordered)	Dual-task recency probes task	Neutral words	?	MDD had significantly greater interference in the condition combining within-task and cross-task interference and rerouting. Interference levels between groups were equivalent for all other conditions. Trait brooding was associated with greater cross-task interference under dual task conditions

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Meiran et al (2011)	Correlational	OCD MDD & controls	Working memory, Stroop & task switching	Neutral	?	Across all groups, trait rumination was associated with poorer working memory updating and less preparation during task switching. No associations with Stroop performance
Owens & Derakshan (2013)	Compared high and low ruminators based on a median split	Dysphoric and non-dysphoric students	Task switching paradigm	Neutral	?	High trait ruminators were less accurate on congruent trials. For high trait ruminators the preparation effect on congruency RTs (incongruent-congruent) was only evident when the relevant task was the predominant one.
Ray et al (2005)	Correlated neural activity with trait rumination	Healthy students	Cognitive reappraisal task	Negative and neutral images	?	No significant behavioural effects. Trait rumination associated with greater increases in amygdala activity when increasing negative affect and greater decreases in prefrontal activity when decreasing negative affect.
Smallwood et al. (2002)	Compared high and low ruminators based on a 3-way split	Study 1: unselected students; Studies 2&3: BDI>12 & BDI<12	Word recall task	Neutral words	?	High trait ruminators better at word recall than low trait ruminators based on a three-way split (studies 1&3)
Stout & Rokke (2010)	Correlational	Healthy s tudents	Change-detection task	Coloured squares	?	Measures of working memory capacity and resistance to distraction interacted to predict individual differences in trait rumination

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Vanderhasselt, Kuhn, & De Raedt (2011)	Correlational; compared high and low trait ruminators based on a median split.	Healthy students	Emotional go/no-go task	Sad and happy faces	?	Depressive brooding was not correlated with no-go trial accuracy for either sad or happy faces, or with the difference between no-go accuracy for happy and sad no-go trials. No correlation between brooding and accuracy rates for low trait brooders, but a significant correlation between brooding and the difference in accuracy for happy and sad no-go trials in the high brooders
Von Hippel, Vasey, Gonda, & Stern (2008)	Correlated trait rumination with the association between depression and interference control (mediation)	Older adults (>65 years) with late (>60 years) and early onset depression	Stroop, paragraph reading and working memory task collapsed into a composite score	Neutral	?	Rumination mediated relationship between executive dysfunction score and depression in individuals with late-onset depression.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
Whitmer & Banich (2007)	Correlational	Expt 1: Students high & low in trait rumination (top & bottom 10% scores on RRS from sample of 776. Expt 2: unselected students	Task-switching paradigm	Neutral	✓	Expt 1:RRS was positively associated with set-switching costs, as was brooding, there was a trend towards an association with reflection. RRS was predictive of inhibition after control for depression and worry. RRS was negatively associated with set inhibition, brooding and reflection were both negatively correlated with set inhibition. Expt 2: RRS predicted set inhibition, as did brooding, but reflection did not. RRS and brooding did not predict switch costs but reflection did.
Whitmer & Banich (2010)	Correlational	Students	Retrieval induced forgetting	Neutral words	?	Rumination was positively correlated with greater recall of unpractised words during the final test phase.
Whitmer & Banich (2012)	Correlational	Unselected students	Reversal learning task	neutral	?	Composite measures of adaptive and maladaptive repetitive thought both associated with slower reversal learning
Zetsche, D'Avanzato et al (2012)	Correlational	MDD & controls	Emotional flanker and working memory selection task	Positive, negative, and neutral	✓	Across both groups, trait rumination, brooding, and reflection were associated with working memory interference scores for negative words, but not with flanker interference.

Authors	Design	Sample	Task	Materials	Construct validity	Main finding
			Longitudinal Studies			
Demeyer, De Lissnyder, Koster, & De Raedt (2012)	Mediation analysis relating interference control and trait rumination to depressive symptoms at one year follow-up	Remitted depressed adults	Internal Shift Task	Neutral and angry faces	✓	Emotional shift scores, trait rumination and depressive symptoms were not related at baseline. Trait rumination mediated the relationship between emotional shift scores and depressives symptoms at follow-up.
De Lissnyder, Koster, Goubert, Onreadt, Vanderhasselt, & De Raedt (2012)	Used multi-level modelling to examine whether emotional shift costs moderated the relationship between self-reported stress and trait rumination at follow-up (6, 7, 8, 9 weeks).	Healthy students	Internal Shift Task	Neutral and angry faces	✓	Baseline emotional switch costs significantly moderated the association between baseline stress and trait brooding at follow-up, such that the association was stronger when individuals showed larger switch costs for emotional material. There was no significant moderating effect of non-emotional switch costs.
Zetsche & Joormann (2011)	Related individual differences in trait rumination to interference control at baseline and 6 month follow-up	Healthy students	Verbal and pictorial negative affective priming and emotional flanker	Positive, negative and neutral nouns and faces	?	Interference on the emotional flanker significantly predicted trait rumination and brooding at baseline, but not at follow-up. Reduced negative affective priming for sad faces at baseline predicted trait rumination at follow-up but not at baseline. The negative priming score for sad words predicted reflection at follow-up.