Emotional cueing modulates attention and Stroop interference in high ruminators

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Abstract

Rumination involves the repetitive dwelling on negative thoughts, emotions and memories, is a risk factor for depression, and may be produced by deficits in emotional and attentional control processes. We assessed the impacts of rumination on attentional control for emotional stimuli using both the standard and emotional Stroop tasks in high and low ruminators. High ruminators had slower reaction times for both tasks. A rumination induction negatively impacted performance on the emotional Stroop task for high ruminators, who tended to have slower response times for positive rather than negative words. We modified a computational model of the Stroop task to include an emotion processing pathway, and used this model to propose mechanistic hypotheses to explain the Stroop data we collected. Model parameter adjustments produced simulated results that qualitatively aligned with the Stroop data. Based on our model's connection weights, we propose that moderate attentional biases for negative stimuli coupled with the need for emotional regulation may explain why high ruminators perform poorly for positively valenced stimuli but not for negatively valenced stimuli. Our modelling predicts that greater negative attentional biases in depression along with baseline emotional regulation needs may shift the balance between attention and emotion pathways, leading to the slower reaction times for negative stimuli observed in clinical populations.

Keywords: rumination; cognitive model; Stroop task; attention; emotion

Introduction

Rumination is a symptom and risk factor shared by many mood and anxiety disorders (Watkins, 2008; Spasojević & Alloy, 2001), and involves the repetitive dwelling on negative thoughts, emotions, and past or future events (Whitmer & Gotlib, 2013). The *impaired disengagement hypothesis* posits that rumination may arise due to the inability to disengage one's attention from internal self-referent information (E. H. Koster, De Lissnyder, Derakshan, & De Raedt, 2011). Rumination may also be a depressive *response style* or an *emotional regulation* strategy, where an individual may focus on their mood to adjust their response to a stressor (Nolen-Hoeksema & Morrow, 1991; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Therefore, a combination of attentional and emotional processes may lead to rumination. What the relative balance is between attentional control and emotion in individuals who tend to ruminate is unknown. The aims of this study are twofold: 1) to assess the impacts of rumination on attentional control for emotional stimuli, and 2) to propose a mechanistic hypothesis characterising the balance between emotion and attention in rumination.

Methods

Attentional control was assessed using standard and emotional Stroop interference tasks (Stroop, 1935; Riemann & McNally, 1995; Waters, Sayette, Franken, & Schwartz, 2005; Williams, Mathews, & MacLeod, 1996). For both tasks, participants identified the ink colour of words and their reaction time is measured. In the standard Stroop task, ink colour may be congruent or incongruent with the word presented (e.g., the word "red" may be presented in red ink for congruent conditions, and blue ink for incongruent). The emotional Stroop task uses words with negative, positive and neutral emotional valence (e.g., "hostile", "sincere", and "chair", respectively).

We first collected Stroop data, and subsequently built a computational model to present mechanistic hypotheses to explain those data.

Experimental Design

85 participants (32 females) between 18 to 71 years of age without a current or previous mental health diagnosis completed 1) questionnaires quantifying rumination, 2) a rumination induction, and 3) both the standard and emotional Stroop tasks in a counterbalanced order. The Ruminative Response Scale (RRS) was used to assign participants to high and low rumination groups via median split (Nolen-Hoeksema & Morrow, 1991). To induce rumination, participants were asked to think about a recent difficulty in their lives for 2 minutes.

Statistical Analysis The predicted impacts of rumination, trial condition (congruence and emotional valence), counterbalancing, age and sex on mean reaction time for the standard and emotional Stroop tasks were characterised using linear mixed effects models, with a Bonferroni-corrected statistical significance threshold of α=0.025.

Computational Model of Stroop Tasks

We adapted the Stroop GRAIN model to allow for the simulation of both the standard and emotional Stroop tasks (J. D. Cohen, Dunbar, & McClelland, 1990; J. Cohen & Huston, 1994). This model uses a parallel distributed processing framework, where different stimulus qualities (word identity vs. ink colour) are each processed by their separate, parallel pathways. We included an additional pathway for emotional processing (Figure 2A). Automaticity of processing is dependent on the pathway strength, which increases with training. Attentional selection is driven by the task demand layer. A balance between automaticity and task demand characterises attentional control.

Pathway strengths were scaled between the emotional stimuli nodes and 1) the response layer, and 2) the emotional processing node in the task demand layer, to produce simulated data that aligned with our Stroop data. For comparison, we developed a depression model by increasing the weight of the connection from the negative stimuli node to the response layer, and increased the drive from the emotional stimuli layer to the emotional processing node, representing 1) an attentional processing bias for negative material (Williams et al., 1996; E. H. W. Koster, De Raedt, Goeleven, Franck, & Crombez, 2005), and 2) greater need for emotional processing due to dysphoric mood (Joormann & Gotlib, 2010).

Results

Experimental Results High ruminators had slower reaction times than low ruminators, for both standard and emotional Stroop tasks, regardless of counterbalancing condition (Figure 1) (standard Stroop: β = 2391.01, CI=307.59–4474.43, p=0.025; emotional Stroop: β = 2409.31, CI=474.63–4343.99, p=0.015). Immediately following rumination induction, high ruminators performed more poorly on the emotional Stroop task than if they performed the standard Stroop task first (Figure 1B) (counterbalancing x rumination; β = -1606.51, CI= -2857.80 – -355.23, p=0.012). High ruminators tended to have somewhat slower response times for positive rather than negative words (Figure 1), although the effect of emotional valence was not significant.

Simulations Our depression model demonstrates slower reaction times for negative and positively valenced words (Figure 2B). Since our high ruminating participants are healthy, we hypothesised that they may have less of a negative attentional processing bias than depressed individuals; thus, a moderate strength between the negative emotional stimuli node and response layer was chosen, with no up-scaling of the emotional processing pathway strength, producing moderately slower reaction times for negative and positive stimuli (Figure 2C). To simulate the acute effects of rumination induction, we increased the strength of the emotional processing pathway in our high rumination model, which caused slower reaction times for positive and neutral stimuli, but no changes for negative stimuli (Figure 2D), qualitatively aligning with our emotional Stroop data (Figure 1B).

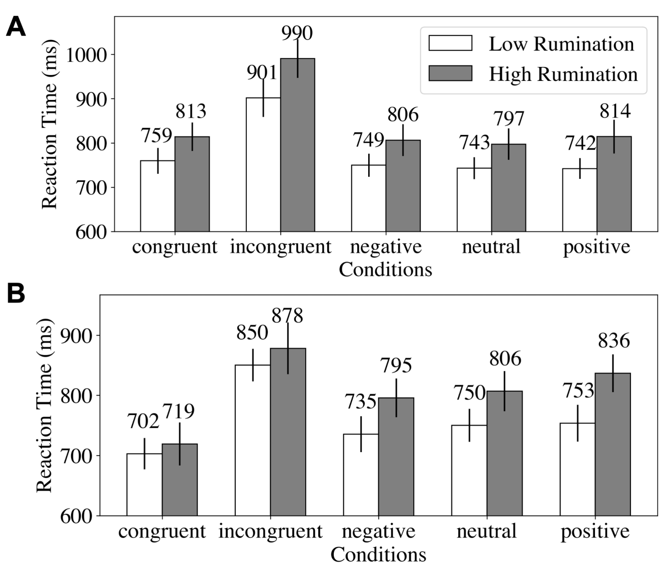

Figure 1: Standard and emotional Stroop performance for high and low ruminators, for both counterbalancing conditions. Mean reaction times are shown for the A) Standard Stroop first, and B) Emotional stroop first. Error bars show standard error of the mean.

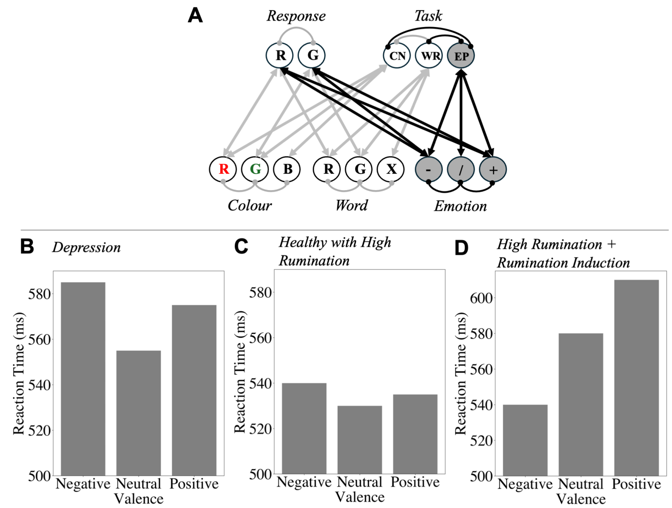

Figure 2: Computational modelling of the standard and emotional Stroop tasks. A) Model schematic. Grey circles with black arrows indicate our additions to the original GRAIN model to simulate the emotional Stroop task. “R, G, B, X” = red, green, black and blank; “-, / , +” = negative, neutral and positive emotional valence; “CN, WR, EP” = colour naming, word reading and emotional processing. Bi-directional excitatory connections are indicated by arrow heads, and within-layer connections are all inhibitory. Model predictions are shown for the emotional Stroop task for B) individuals with depression, C) healthy high ruminating individuals, D) healthy high ruminators after rumination induction.

Discussion

By combining experiment with computational modelling, we propose that healthy high-ruminating individuals may not experience impaired emotional processing at baseline, but present with a slight attentional bias for processing negative stimuli, representing their risk for depression. Rumination induction will place higher demands on the emotional processing pathway; here, the slight bias for negative material becomes an advantage, preventing performance deficits for negative material (Figures 1B, 2D). We propose that depression progression can be represented in our model as the gradual increase in the attentional bias for negative material and baseline emotional drive, which would shift the balance between negative word processing automaticity and emotional drive, producing Stroop performance deficits for negative words.

Our model can be extended to include a learning algorithm that takes amygdalar drive and dopaminergic signalling into account (Stolicyn, Steele, & Seriès, 2017). Models can then be fitted trial-by-trial to individual participant's data, and statistical analysis can then assess whether parameter values predict rumination scores, similar to what has been done for reinforcement learning algorithms for anhedonia in depression (Huys, Pizzagalli, Bogdan, & Dayan, 2013). These subsequent studies can more precisely identify attentional and emotional processing mechanisms in rumination.

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