Reduced Attention Towards Accomplishments Mediates the Effect of Self-Critical Rumination on Regret

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Abstract

Background: Rumination is associated with counterfactual thinking (CFT) and regret, but underlying mechanisms in this association are uninvestigated. Rumination is characterized by attentional biases and focusing attention towards accomplishments versus lost opportunities influences CFT and regret. The goal of this study was to investigate the association between self-critical rumination and attention towards accomplishments and lost opportunities, and how this may underly the link between rumination and CFT and regret.

Methods: Hundred healthy female participants performed a risk-taking task while a) attention towards accomplishments and lost opportunities, and b) self-reported CFT and regret were measured.

Results: Analyses showed that participants with high (versus low) rumination tendencies focused less on accomplishments, and this mediated the association between rumination and regret.

Conclusions: These findings suggest that reduced attention towards accomplishments may be an underlying mechanism in the link between rumination and regret, and interventions could target this attentional bias for therapeutic benefit.

Keywords: self-critical rumination, counterfactual thinking, regret, attentional deployment, attentional bias

Introduction

In contemporary western societies, we have, more than ever, the possibility to arrange our lives as we desire (e.g., education, career, relationships, hobbies, etc.). However, this freedom for self-determination comes at a cost, as individuals increasingly feel pressure to

achieve personal goals and success (Hidaka, 2012; Schwartz, 2000), and experience distress surrounding personal decision making (Schwartz, 2004). When confronted with progress towards a personal goal that is either blocked (i.e., nonoptimal) or unsatisfactory (i.e., suboptimal), individuals may contemplate their decisions and imagine that different personal decisions in the past would have led to more favorable outcomes (Epstude & Roese, 2011; Roese & Epstude, 2017). These counterfactual cognitions, termed upward self-referent counterfactual thinking (CFT) can coincide with the emotional experience of self-blame regret (Buchanan et al., 2016; Byrne, 2016), and can be elicited via the perception of lost opportunities (i.e., a past opportunity to achieve a favorable outcome, which in the present is no longer obtainable; Beike et al., 2009; van Dijk & Zeelenberg, 2005) and failures in goal pursuit (Epstude & Roese, 2011). These counterfactual cognitions and emotions in response to personal decision making outcomes are thought to serve the adaptive function of improving future decision making (Roese & Epstude, 2017). However, the excessive experience of CFT and regret has been shown to be associated with lower levels of reported life satisfaction and subjective well-being, and with higher levels of depressive symptomatology (Broomhall & Phillips, 2018; Broomhall et al., 2017; Jokisaari, 2004). Importantly, CFT and regret have been shown to be related to rumination (Allaert et al., 2019; Roese et al., 2009; Yu et al., 2017), which is a well-established transdiagnostic factor in a wide array of common psychopathology, such as depressive, anxiety and eating disorders (Rickerby et al., 2022).

While rumination is a multi-faceted construct and many conceptualizations of rumination co-exist, rumination is most defined as a form of repetitive negative self-referential thinking in response to experienced negative affect and distress (Smith & Alloy, 2009). For instance, when individuals who are prone to ruminate are experiencing a negative emotional state, this may prompt them to rehash in their mind negatively appraised personal

qualities (e.g., "*why do I have problems other people don't have?*") or past behavior (e.g., "*why can't I handle things better?*"). Recent network analytic approaches aiming to examine psychological phenomena in terms of a network of interrelated processes (Contreras et al., 2019), have shown that self-critical cognitions represent a central feature underlying rumination (Bernstein et al., 2017, 2019), and these self-critical cognitions may share some conceptual overlap with the negative self-blame attributions involved in regret (Allaert, 2022). While CFT and regret are constructs that can be conceptually distinguished from rumination, they are related to it, and may even represent a symptom of rumination, when experienced repetitively, and maladaptively (Allaert, 2022; Roese & Epstude, 2017). For instance, some items in commonly used questionnaires assessing rumination relate to CFT and regret, suggesting these may indeed be a prevalent experience that people ruminate about (e.g., "Thinking about a recent situation, wishing it had gone better" [Ruminative Response Scale; Roelofs et al., 2006], "I can't stop thinking about how I should have acted differently in certain situations." [Self-Critical Rumination Scale; Smart et al., 2016]). In line with this, research has shown that the tendency to ruminate is positively associated with reported levels of regret while both making decisions and when experiencing goal failure, indicating that individuals who are prone to ruminate, are also more prone to experience CFT and regret (Allaert et al., 2019; Roese et al., 2009; Yu et al., 2017). Furthermore, there is evidence to suggest a bidirectional relationship between ruminative thinking and CFT / regret, implying that rumination can be a trigger for CFT / regret, but that CFT / regret can also be a trigger for rumination (Allaert, 2022; Allaert et al., 2019; Dey et al., 2018; Kamijo & Yukawa, 2018). For instance, a recent study showed a) that the presence of ruminative thinking (regardless of interindividual rumination tendencies) makes individuals more susceptible to experience regret (Allaert et al., 2019; Dey et al., 2018), and b) that regret after goal failure can incite ruminative thinking among individuals prone to ruminate (Allaert et al., 2019).

Taken together, there's a close association between rumination and both CFT and regret, with rumination reflecting a style of thinking (i.e., the process of repetitively focusing on negative self-referential thoughts and emotions), whereas CFT / regret can be one type of negative self-referential thoughts and emotions that are experienced while ruminating (Allaert, 2022; Watkins, 2009). Importantly, research investigating potential mechanisms underlying the association between rumination and both CFT and regret is currently lacking. Given the clinical relevance of counterfactual cognitions and emotions, and the tight link between rumination and maladaptive regret, it is important to investigate mechanisms that potentially underly the association between rumination and regret, as insight into these mechanisms could then be used to improve treatment methodology (De Raedt, 2020; Kopf-Beck & Fietz, 2021; Quoidbach et al., 2015).

The regulation of attention towards relevant and irrelevant information is of crucial importance in adaptive behavior and mental health (Gross & Thompson, 2007; Werner & Gross, 2010). For instance, when exposed to a negative stimulus, focusing on more neutral (compared to negative) aspects of the stimulus attenuates negative emotional reactivity, and vice versa (Ferri et al., 2013, 2016). This shifting of attention to modulate emotional reactivity is an emotion regulatory process coined attentional deployment (Gross & Thompson, 2007; Wadlinger & Isaacowitz, 2011). It has been shown that rumination is associated with various attentional biases, and these represent important neurocognitive mechanisms underlying the role of rumination in the etiology of depression (De Raedt & Koster, 2010; DeJong et al., 2019; Koster et al., 2011). For instance, using eye-tracking methodology, it has been shown that the tendency to ruminate is associated with a) more attention towards sad faces, b) less attention towards happy faces, and c) a slower ability to disengage attention away from sad faces (Owens & Gibb, 2016; Sanchez-Lopez et al., 2019b; Yaroslavsky et al., 2019). In a similar vein, it has been shown that attention to dysphoric and

threat-related words predicts ruminative thinking in daily life in a sample of clinically depressed individuals (Holas et al., 2019). Furthermore, using a dot-probe paradigm, it has been shown that rumination is associated with an attentional bias towards stimuli depicting themes of loss and failure (Hur et al., 2019). Taken together, these data suggest that rumination is characterized by attentional biases towards distinct types of emotional information (e.g., sadness, happiness, loss and failure, threat), and these biases may amplify negative emotional reactivity, stimulate the development of depressive symptomatology over time and reduce well-being (De Raedt & Koster, 2010; DeJong et al., 2019; Koster et al., 2011; Holas et al., 2019).

Research has shown that attentional processes also play a role in the experience of CFT and regret (Bault et al., 2016; Li et al., 2021; Liu et al., 2020; Liu et al., 2017). By using a sequential risk-taking task in which participants repeatedly make choices towards a goal (e.g., a monetary reward), it is possible to investigate the sensitivity to experience CFT and regret, via the explicit presentation of factual (e.g., acquired gains) and counterfactual (e.g., lost opportunities) feedback information about made choices (Allaert et al., 2019; Brassen et al., 2012). This explicit presentation also allows to assess and manipulate attention towards factual and counterfactual information. It has been shown that focusing attention on counterfactual information is associated with the experience of more regret, whereas focusing attention on factual information represses the experience of regret (Li et al., 2021; Liu et al., 2020; Liu et al., 2017). In light of this data, and the presence of specific attentional biases associated with rumination (e.g., loss and failure; Hur et al., 2019), it can be hypothesized that (H1) individuals with higher tendencies towards rumination will focus their attention more on counterfactual information (e.g., lost opportunities), and less on factual information (e.g., accomplishments). Furthermore, based on a) the interplay between attention and emotional reactivity (Ferri et al., 2013; Liu et al., 2017), and b) the role of attentional biases

in the negative outcomes (e.g., depressive symptomatology) associated with rumination (Owens & Gibb, 2016; Sanchez-Lopez et al., 2019b; Yaroslavsky et al., 2019), it can be hypothesized that attentional biases towards (counter)factual information will underly the association between the tendency to ruminate and the propensity towards counterfactual thinking and regret (H2).

To investigate these hypotheses, an ecologically valid decision-making paradigm was employed in which counterfactual cognitions and emotions naturally arise in varying degree among individuals with different tendencies towards rumination (Allaert et al., 2021a; Allaert et al., 2019). In this paradigm, participants make choices that are linked to the goal of obtaining a monetary reward, while under the impression that their performance is predictive of various relevant life domains, including mental health, academic performance, career success, and interpersonal relationship quality (Allaert et al., 2021a; Allaert et al., 2019). After each set of choices, participants are provided feedback about factual (i.e., acquired gains) and counterfactual (i.e., lost opportunities) outcomes, allowing them to evaluate the relative utility of their choices in progressing towards their goal, and may incite CFT and regret. Via eye-tracking methodology, attention towards this factual versus counterfactual feedback can be measured, whereas self-report assessments can be used to inform about CFT and regret. In view of both recent research highlighting the central role of self-critical cognitions (e.g., I am incompetent) and emotions (e.g., shame, regret) in rumination (Bernstein et al., 2017, 2019; Smart et al., 2016), and the inherent self-referential nature of regret (Connolly & Zeelenberg, 2002), rumination was operationalized as self-critical rumination, as this construct emphasizes specifically on self-critical aspects of rumination (Smart et al., 2016). In addition, because female populations are more prone to ruminate (Johnson & Whisman, 2013), the current study sample consisted exclusively of female participants, with the aim to reduce variability and to increase statistical power.

In summary, the goal of this study was to investigate a) the association between the tendency towards self-critical rumination and attentional deployment towards (counter)factual information, and b) how these rumination-associated attentional biases may influence counterfactual thinking and regret. We expected self-critical rumination to be associated with more attention towards counterfactual information and less towards factual information (H1), and that this attentional bias mediates the association between self-critical rumination and counterfactual thinking and regret (H2).

Methods

Participants

Hundred[1] healthy female Dutch-speaking individuals between 18 and 30 years old (M_{age} = 22, SD_{age} = 2.47) from the general community were recruited via internet posting on social media. The selection criteria to participate were: (a) right handed, (b) no personal or family history of epilepsy, (c) no eye, heart, respiratory or neurological disorders/problems, (d) no current psychiatric or neurological disorders, (e) no current use of psychiatric drugs, (f) no current substance abuse, (g) no close relatives who committed suicide, and (h) no unstable medical condition or chronic pain conditions. Prior to the laboratory session, participants were asked via email not to smoke or ingest caffeine and/or alcohol 2 hours prior to the experiment, in order to prevent potential confounding effects. Whether participants adhered to this request was not asked explicitly. The study was conducted with the approval of Ghent University's Medical Ethical Committee, and participants' informed consent was obtained

[1] The sample size was determined based on simulations to test the hypothesized indirect mediation effect of self-critical rumination on CFT/regret via attentional deployment. In these simulations, the sample size was increased stepwise in increments of 10, starting from 10, until a power of .80 was achieved with alpha set to .05. The effect size for the first step of the mediation model, testing the effect of self-critical rumination on attentional deployment was estimated based on past research on rumination and attentional biases (Owens & Gibb, 2016; Sanchez-Lopez et al., 2019b; Yaroslavsky et al., 2019). The effect size for the second step in the mediation model, testing the effect of attentional deployment towards CFT/regret, was based on past research on attentional deployment and regret (Li et al., 2021; Liu et al., 2020; Liu et al., 2017).

according to the Declaration of Helsinki. The experiment was performed in accordance with relevant guidelines and regulations. Participants received € 40 for participating.

Materials

Sequential Risk-Taking Task

An adaptation of the Devil's task, a sequential binary choice risk-taking paradigm was used (Allaert et al., 2019; Liu et al., 2017; Slovic, 1966). Prior to performing this task, participants were presented an introductory text telling them they would perform a choice task that has been found to be predictive for various life domains, such as academic success, interpersonal skills, coping behavior, and psychopathology, and that they could obtain a monetary bonus if they performed well enough. This information was merely presented as a cover story, to stimulate a self-relevant decision-making context (Allaert et al., 2021a; Allaert et al., 2019). Participants were told to try to accumulate as many points as possible in order to obtain the monetary reward. At the start of each trial, 10 closed boxes were presented, from which 9 contained 10 points, whereas one contained a 'devil'. The task consisted of 100 trials, and the devil's location for each trial was pseudo-randomly determined based on the constraint that the devil should have been equally present in all boxes by the end of the task. Participants could open one box at a time, in a left to right fashion. If a box was opened that contained the 'devil', all trial points were lost. To consolidate trial points, participants could choose when to stop opening boxes. At the end of every trial (by either stopping or unpacking the devil), the location of the devil is revealed, and participants can evaluate their choice outcome based on feedback about the factual (i.e., acquired gains) and counterfactual (i.e., lost opportunities) outcomes, for a period of 6 seconds. These trial-based outcomes can be classified into three distinct types: (a) non-optimal, referring to lost opportunities with no factual gains, indicative of no goal progress, (b) suboptimal, referring to factual gains and lost

opportunities, indicative of some goal progress, and (c) optimal, referring to factual gains with no lost opportunities, indicative of optimal goal progress. The frequency of each type of outcome varied between players, as the outcome is contingent on the decision making of the player. On average, 42.45 % of the trials were nonoptimal, 47.26 % suboptimal, and 10.29 % optimal. The unbalanced nature of such a design is not problematic for the statistical analyses as the employed linear mixed effects models (see further) can handle unbalanced data (Cnaan et al., 1997). After the trial-based outcome evaluation, a screen is displayed for 6 seconds through which participants can evaluate their progress, based on the total acquired gains and lost opportunities so far, using a visual score bar. To measure attention towards acquired gains and lost opportunities, an additional eye-tracking feature was added in this paradigm. Specifically, trials resulting in a suboptimal outcome feature the presence of both acquired gains and lost opportunities, and during these trials, attentional deployment towards these was measured (Figure 1A). When participants gazed towards the opened boxes showing the acquired gains, a green frame appeared around these, and presented the amount of acquired gains in the center of the screen. In contrast, when a gaze was captured on the closed boxes visualizing the lost opportunities, a red frame appeared around these, and presented the number of lost opportunities in the center of the screen. During the progress evaluation after every trial, both acquired gains and lost opportunities so far were visually presented, and similarly, when participants gazed towards the green area of the score bar, the amount of acquired gains so far were explicitly presented (Figure 1B). In contrast, when tended to the red area of the score bar, the lost opportunities so far were presented. The implementation of associations between colors and outcome meanings (green – acquired gains, red – missed chances) was inspired by past research (Li et al., 2021; Liu et al., 2020; Liu et al., 2017) and done to stimulate task engagement, according to principles of gamification for experimental paradigms (Mullins & Sabherwal, 2020). Attentional deployment towards acquired gains was

computed as the sum of the total attention focused on a) the score visualization (based on the opened boxes or score bar) and b) the text display showing the gained number of points. Following the same principle, attentional deployment towards lost opportunities was computed based on the sum of total attention focused on a) the score visualization (based on the closed boxes or score bar) and b) the text display showing the number of points missed. Separate attentional indices were computed during the outcome evaluation (only for suboptimal outcome trials) and progress evaluation (for all trials). Every 4 trials, a short break period was present, during which participants self-reported the experience of counterfactual thinking and regret during the last 4 trials (see further). These self-report measures were only present every 4 trials to prevent fatigue among participants and to retain a natural flow in the task. After completion of the task, participants were informed they did not perform well enough to obtain the monetary reward, and participants then self-reported counterfactual thinking and regret about all the choices made in the task. The paradigm was presented on a 24-inch widescreen display and was made using E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA).

Self-Report Assessments

Counterfactual Thinking and Regret. During the sequential risk-taking task, participants' level of experienced counterfactual thinking and regret were assessed every 4 trials. Two questions were displayed "To what extent do you think about what other choices would have led to in the last four trials?" and "To what extent do you regret the made choices in the last four trials?". Participants responded using a visual analog scale (VAS), ranging from 0 = not at all, to 100 = a lot. Similarly, after completion of the task, when participants were informed they did not perform well enough to achieve the monetary bonus (goal failure), counterfactual thinking ("To what extent do you think about what other choices would have led to in the task?") and regret ("To what extent do you regret the made choices in the task?") was

assessed using a VAS. Given that mediation analyses require the outcome variable (CFT and regret) to be measured after the mediator (attentional deployment) variable (Gelfand et al., 2009), only the assessment of CFT and regret at the end of the task, related to goal failure, will be employed for the current research question.

Self-Critical Rumination. The habitual tendency to engage in self-critical rumination (e.g., "I often worry about all the mistakes I have made", "Sometimes it is hard for me to shut off critical thoughts about myself") was assessed using the Self-Critical Rumination Scale (SCRS; Smart et al., 2016). The scale consists of ten items, rated on a 4-point (1 = not at all, 2 = a little, 3 = moderately, 4 = very much) Likert scale. Participants were asked to indicate how well each item described them. The scale displayed excellent internal consistency (Cronbach's $\alpha = 0.91$).

Eye-Tracking

During the sequential risk-taking task, gaze behavior was recorded at a sample rate of 300 Hz with the Tobii Pro Spectrum (Tobii AB, Stockholm, Sweden), and this functionality was programmed with the E-Prime Extensions for Tobii Pro 3.2 (Psychology Software Tools, Pittsburgh, PA). A standard 9-point calibration sequence was used to calibrate participants' eye tracking. Fixations were defined to be at least 100 ms of duration and the total fixation time towards lost opportunities and acquired gains was computed with Tobii Pro Lab 1.142 (Tobii AB, Stockholm, Sweden).

Procedure

Before the lab session, on an online webpage participants read a description of the study, including the exclusion criteria and part of the cover story. Here, the participants were told the study included an online questionnaire and a lab session with a computer task. On the

webpage, they completed the SCRS and afterwards made an appointment for the lab session. All participants were tested individually in the faculty laboratory. At the start of the lab session, participants were seated in front of a computer screen, were connected to the physiological recording equipment, and were instructed to remain calmly seated for a period of 10 minutes, in order to habituate to the lab environment. Participants were then introduced to the choice task and performed it. At the end of the lab session, participants were compensated with € 40. They were debriefed about the cover story and the nature of the regret-inducing paradigm was explained. The procedure lasted roughly 50 minutes[2].

Data Analytic Plan

All data were analyzed in R 4.0.2 (R Core Team, 2013) using linear mixed models (LMMs) fitted via the '*lmer*' function of the '*lme4*' R package (Bates et al., 2014), or linear models (LMs) fitted via the '*lm'* R function. The statistical significance level was set to $p < .05$ and *p*-values for the fixed effects of LMMs were estimated with the 'lmerTest' R package, using the Satterthwaite approximations to degrees of freedom (Kuznetsova et al., 2017). Continuous predictors that interact with categorical variables were standardized prior to model fitting. The analysis-of-variance tables were computed via the 'anova' R function, with the sum of squares estimated using the type III approach (Fox et al., 2012). Follow-up tests were carried out via pairwise comparisons of the estimated marginal means (EMMs) computed via the '*emmeans*' function of the '*emmeans'* R package (Lenth, 2018). For the decomposition of interaction effects where self-critical rumination was implied, the EMMs were computed at low (M – 1 SD [low]) and high (M + 1 SD [high]) levels of self-critical rumination. This procedure preserves the continuous measurement structure of the rumination

[2] After this procedure, an additional task (relational responding task; De Houwer et al., 2015) was performed, in which implicit attitudes towards actual and ideal self-esteem were measured (Remue et al., 2014). The results of this section of the experiment fall outside of the scope of the current manuscript and are reported elsewhere. In addition, skin conductance and heart rate was measured throughout the protocol, but these indices were not used to inform about the current research question.

variable while mitigating loss of statistical power that is present in common procedures in which continuous variables are categorized into groups (Dawson & Weiss, 2012). Where applicable, *p*-values from follow-up tests were corrected for multiple comparisons using the false discovery rate correction (Benjamini, 2010; Benjamini & Hochberg, 1995). Mediation effects were estimated via the '*mediation'* R package (Tingley et al., 2014), using 1000 non-parametric bootstraps, and a mediation effect was considered statistically significant if zero is not included in the 95% confidence interval (Hayes, 2013).

To investigate the influence of self-critical rumination on attentional deployment towards (counter)factual information during *outcome* and *progress evaluation*, 2 LMMs were fitted with *total fixation time* (i.e., total time fixating on an area of interest ([AOI])) as dependent variable. For *outcome evaluation*, the LMM featured *self-critical rumination* and *AOI* (lost opportunities, acquired gains) as fixed effects, and *subject* as random intercept. For *progress evaluation*, the LMM featured *self-critical rumination*, *AOI* (lost opportunities, acquired gains) *and choice outcome* (non-optimal, suboptimal, optimal) as fixed effects, and *subject* as random intercept. Important to note, the analysis of attentional deployment towards lost opportunities and acquired gains during *outcome evaluation* was only based on trials which feature both lost opportunities and acquired gains (i.e., suboptimal outcome trials), whereas the analysis during *progress evaluation* was based on all trials.

To investigate the mediating effect of attentional biases in the association of trait self-critical rumination with both regret and CFT, 2 mediation models were fitted with self-reported CFT and regret after goal failure as outcome variables, respectively. Based on the results of the previous LMM analyses of attentional deployment, the observed attentional bias associated with rumination (see results; i.e., fixation time to acquired gains) was entered as a mediator in these models. To integrate the findings on attentional deployment during both the outcome and progress phase in the mediation analyses, the average fixation time to acquired

gains across all trials and evaluation phases (outcome, progress) was computed for every subject. Each mediation model consisted of 2 LMs, with the 1st LM testing the effect of the predictor (i.e., self-critical rumination) on the mediator (i.e., average fixation time to acquired gains), and the 2nd LM testing the effect of the mediator (i.e., average fixation time to acquired gains) on the outcome (self-reported regret after goal failure, CFT after goal failure). The 1st LM of each mediation model featured *self-critical rumination* as predictor, and *average fixation time to acquired gains* as dependent variable. The 2nd LM featured *average fixation time to acquired gains* and *self-critical rumination* as predictors, and either self-reported regret or CFT after goal failure as dependent variable.

Results

During the debriefing at the end of the experiment, 24 participants raised doubts about the cover story, which suggests the validity of the experimental paradigm may be compromised for these people (i.e., 24% of the sample). Therefore, analyses were performed excluding the data of these participants. Analyses in which these data are included are reported in the supplementary materials. Overall, the conclusions derived from these analyses are in line with the results reported in the main manuscript, with the exception of the mediation effects. Specifically, the mediation effect with regret as outcome was marginally significant (p = .07) and the mediation effect with CFT as outcome was non-significant (p = .2).

Effects of Self-critical Rumination on Attentional Deployment Towards Acquired Gains and Lost Opportunities

The LMM for *outcome evaluation* showed a significant main effect of *AOI*, $F(1, 6196.2) = 23.35$, $p < .001$, in the presence of a significant higher-order *AOI* × *self-critical rumination* interaction effect (see figure 2), $F(1, 6220.3) = 4.74$, $p = 03$. Follow-up pairwise

comparisons of the EMMs at low (*M* – 1 *SD*) and high (*M* +1 *SD*) levels of self-critical rumination showed that both participants with low, *b* = 161.2, SE = 34, *t* = 4.73 , *p* < .001, and high rumination tendencies, *b* = 60.9, SE = 30.9, *t* = 1.97, *p* = .04, spent more time fixating on the acquired gains, compared to lost opportunities. However, a comparison of the attentional bias towards acquired gains (versus lost opportunities) for individuals with high (versus low) levels of self-critical rumination showed that the attentional bias towards acquired gains (versus lost opportunities) was less strongly present among individuals with high (compared to low) ruminative tendencies, *b* = -100, SE = 46, *t* = 2.18, *p* = .03. Furthermore, a marginally significant effect was present, showing a trend for participants with high (versus low) rumination tendencies to spend less attention on the acquired gains, *b* = -88.6, SE = 50.5, *t* = 1.76, *p* = .08.

The LMM for *progress evaluation* showed a significant main effect of *AOI*, *F*(1, 11944.7) = 132.09, *p* < .001, and *choice outcome*, *F*(2, 11900) = 12.05 , *p* < .001, in the presence of both an *AOI* × *self-critical rumination* interaction (see figure 2), *F*(1, 11945.2) = 44.94, *p* < .001, and an *AOI* × *choice outcome* interaction, *F*(2, 11889.1) = 5.87, *p* = .003. Consistent with the results of the analysis of *outcome evaluation*, follow-up pairwise comparisons probing the *AOI* × *self-critical rumination* interaction showed that both participants with low (*M* – 1 *SD*), *b* = 356.8, SE = 29.3, *t* = 12.17, *p* < .001, and high (*M* + 1 *SD*) rumination tendencies, *b* = 95.4, SE = 26, *t* = 3.68, *p* < .001, spent more time fixating on acquired gains (compared to lost opportunities), but this was again less strongly the case among rumination-prone participants, *b* = -261, SE = 39, *t* = 6.70 , *p* < .001. Furthermore, participants prone to use rumination spent less time fixating on acquired gains compared to participants with low tendencies towards rumination, *b* = -224.3, SE = 76.5, *t* = 2.93, *p* = .004. For the *AOI* × *choice outcome* interaction, follow-up pairwise comparisons showed that

participants (regardless of rumination level) spent more time fixating on acquired gains after non-optimal, compared to suboptimal outcomes, b = 135.79, SE = 21.1, t = 6.45, p < .001

Mediating Effect of Attentional Deployment on Counterfactual Thinking and Regret

Consistent with the earlier LMM analyses, the mediation models showed that higher levels of trait self-critical rumination were associated with less attention towards acquired gains, b = -12.7, β = -.24, SE = 6.03, t = 2.10, p = .04. Furthermore, less attention towards acquired gains was associated with a higher level of self-reported regret after goal failure, b = -.02, β = -.27, SE = .01, t = 2.36, p = .02 (Figure 3A), whereas only a marginally association was observed between attention towards acquired gains and self-reported counterfactual thinking after goal failure (Figure 3B), b = -.01, β = -.19, SE = .01, t = 1.74, p = .09. Overall, the mediation model with regret as outcome showed a significant indirect effect of self-critical rumination on regret via reduced attention towards acquired gains, b = .24, 95% CI [.02, .58], p = .02, whereas the direct effect of self-critical rumination on regret was non-significant, b = .56, 95% CI [-.28, 1.45], p = .22. The total effect on regret (encompassing the direct and indirect effect) was significant, b = .80, 95% CI [.03, 1.62], p = .04. The mediation model with CFT as outcome showed a marginally significant indirect effect of self-critical rumination on CFT via reduced attention towards acquired gains, b = .15, 95% CI [-.01, .45], p = .08, whereas the direct, b = 1.01, 95% CI [.25, 1.75], p = .01, and total effect was significant, b = 1.17, 95% CI [.45, 1.87], p < .001.

Discussion

The goal of the present study was to investigate a) the association between the habitual use of self-critical rumination and potential attentional biases to (counter)factual information, and b) the underlying role of these biases in the association between the

tendency towards self-critical rumination and the propensity towards counterfactual thinking and regret.

Analyses showed that, in general (during both outcome evaluation and progress evaluation), participants tended to look more towards factual information regarding their outcome and goal progress (i.e., accomplishments), compared to counterfactual information (i.e., lost opportunities). This general attentional bias towards accomplishments was stronger after the encounter of a non-optimal (compared to suboptimal or optimal) outcome. Yet, analyses showed that the general attentional bias towards acquired gains (versus lost opportunities) was less strongly present among individuals with high (compared to low) self-critical rumination tendencies. Taken together, these findings are in line with cognitive and attentional biases commonly observed in the general population (e.g., positivity bias, optimism bias, and reward-associated bias; Kress & Aue, 2017). Specifically, a majority of the population naturally focuses more on positive (compared to negative) information, and displays attentional biases towards reward-related information (Mezulis et al., 2004). These biases contribute to the maintenance of a positive outlook on the current circumstances, preserve physical and mental health, boost motivation, and play a protective role in response to encountered adversities, such as nonoptimal outcomes in this case (Campbell & Sedikides, 1999; Taylor & Armor, 1996; Taylor et al., 2000). Furthermore, besides the inherent hedonistic nature of rewarding stimuli (Berridge & Kringelbach, 2008), biases towards reward-related information are thought to be derived from an evolutionary benefit, as individuals who preferably focus on rewarding stimuli in their daily environment are more likely to perceive opportunities to maximize future gains, thereby contributing to survival fitness (Kress & Aue, 2017). Moreover, it has been shown that these general self-serving cognitive and attentional biases are attenuated among populations which are predisposed towards psychopathology (Jopling et al., 2020; Mezulis et al., 2004), which is in line with the

current finding that this general attentional bias was less present among individuals with high ruminative tendencies.

Importantly, analyses showed that participants with high (compared to low) tendencies towards self-critical rumination focused their attention less towards factual information depicting their accomplishments. This was especially the case during the evaluation of goal progress, whereas this finding was marginally significant during the evaluation of choice outcome. In contrast, self-critical rumination was not associated with attention towards counterfactual information depicting lost opportunities. Taken together, these findings partially support the first hypothesis (H1) and suggest that the tendency to self-critical rumination is associated with an attenuated bias towards factual (versus counterfactual) information, with less attention being deployed towards factual accomplishments. These findings extend past research showing specific attentional biases associated with rumination, such as reduced attention towards positive stimuli (Owens & Gibb, 2016), and an innovative aspect of this current finding is that attentional processes were investigated in an ecologically valid setting (i.e., a self-relevant decision-making context). The absence of an effect of self-critical rumination on attentional deployment towards lost opportunities is not in line with past research showing an association between rumination and increased attention towards negative stimuli (Owens & Gibb, 2016). This absence could be due to the specific context (self-relevant decision-making with feedback about choice outcomes) used in the present study. This could invoke strong general attentional biases towards reward-related information, which are not present in past research employing tasks of passive viewing of emotional stimuli, not related to reward (Owens & Gibb, 2016).

In a next step, it was investigated whether this reduced attention towards accomplishments mediated the effect of self-critical rumination on counterfactual thinking and regret after goal failure (H2). Empirical support for this mediation was obtained with the

analysis of self-reported regret, whereas the mediation effect was only marginally significant for self-reported counterfactual thinking. Specifically, the tendency towards self-critical rumination was negatively associated with attentional deployment towards accomplishments, which in turn was associated with higher levels of regret after goal failure. The current results thus suggest that reduced attentional deployment towards accomplishments may be a mechanism underlying the predisposition to experience regret after goal failure among individuals prone to self-critical rumination. While this has never been investigated before, this current finding is in line with research showing that attentional processes, in general, represent an underlying neurocognitive mechanism in the negative consequences of rumination, such as depressive symptomatology (Koster et al., 2011; Sanchez-Lopez et al., 2019a; Sanchez-Lopez et al., 2019b; Yaroslavsky et al., 2019). A large body of research highlights the importance of attentional deployment as an emotion regulatory process which, depending on the attentional focus, can have a positive or negative influence on mood and emotion regulation (Liu et al., 2020; Sanchez-Lopez et al., 2019a; Wadlinger & Isaacowitz, 2011). Furthermore, there are interindividual differences in the habitual use of adaptive and maladaptive emotion regulation processes (Gross & John, 2003; Ray et al., 2005), and the current study shows how the tendency to ruminate is associated with the use of more maladaptive emotion regulation processes in the context of self-relevant decision making (less attentional deployment towards accomplishments).

The findings of the current study are clinically relevant as attentional biases are an important neurocognitive mechanism underlying the role of rumination in the etiology of depression (De Raedt & Koster, 2010; DeJong et al., 2019; Koster et al., 2011; Yaroslavsky et al., 2019). Moreover, there is evidence suggesting that the experience of counterfactual thinking and self-blame regret may even partially mediate the association between rumination and depressive symptomatology (Yu et al., 2017). Therefore, insights into mechanisms

underlying the rumination-associated predisposition towards counterfactual cognitions and emotions are crucial for the development and adaptation of interventions. These interventions could target attentional biases and potentially offset the negative consequences of excessively experiencing counterfactual thinking and regret. For instance, training individuals to focus more on their accomplishments attenuates the experience of counterfactual thinking and regret (Liu et al., 2020; Liu et al., 2017). Furthermore, focusing more on what actually happened (i.e., factual information), may help to more quickly come to terms with the current circumstances, and possibly promote self-acceptance and self-compassion, which are protective mechanisms against maladaptive self-blame regret (Cheng & Lin, 2016; Zhang & Chen, 2016). In addition, non-invasive brain stimulation (e.g., transcranial direct current stimulation; tDCS) targeting the neural circuitry involved in selective attention (i.e., frontoparietal cognitive control network) has shown adaptive effects on attentional processes and attenuates emotional reactivity to emotional stimuli (Allaert et al., 2021b; Mondino et al., 2015; Smits et al., 2020). Furthermore, prefrontal tDCS has been shown to attenuate counterfactual thinking and regret, specifically among individuals prone to self-critical rumination (Allaert et al., 2021a). Of interest, based on previous research (Berryhill & Martin, 2018; Sanchez-Lopez et al., 2020), a multimodal intervention, in which attentional training is combined with prefrontal tDCS may show even stronger therapeutic benefits. In future studies, the hypothesized adaptive effects of prefrontal tDCS on attentional deployment towards accomplishments and the influence on counterfactual thinking and regret can be investigated, and whether a concurrent attentional training amplifies these. Taken together, the current results increase our understanding of the underlying role of attentional biases in the relationship between rumination and regret, and highlight how these attentional mechanisms could be targeted in clinical interventions.

Whereas the current study featured several strengths, such as the inclusion of an ecologically valid paradigm that allows to directly measure attentional processes and autonomic reactivity related to counterfactual thinking and regret, some important limitations must be mentioned. Since the aim of this study was to investigate processes related to rumination in a healthy, non-depressed population, it was important to have sufficient variability in rumination levels. Therefore, only female participants were included in the sample, as female populations display larger levels of rumination (Johnson & Whisman, 2013). However, this limits the generalizability of current results, and further research is needed to determine whether these conclusions hold for all gender identities. In addition, since the experimental paradigm involves personal decisions that can be rewarding or aversive and activates brain regions related to reward and punishment sensitivity (Studer et al., 2013), the absence of measurements relating to interindividual differences in reward-sensitivity and punishment sensitivity is an important limitation. In this way, it could not be directly investigated whether the obtained results would hold when statistically controlling for these interindividual differences. Future research should verify if this is the case, and investigate the potential role of reward sensitivity and loss aversion in the link between rumination and regret, since findings from a previous study have suggested that sensitivity to punishment may actually be a mechanism by which rumination can lead to maladaptive outcomes (Whitmer et al., 2012). Another important point of discussion is the absence of the hypothesized rumination-associated attentional bias towards lost opportunities. As discussed earlier, a generally strong attentional bias towards acquired gains was observed, which was diminished among habitual ruminators. Important to note however, acquired gains were always presented in the left visual field, whereas lost opportunities were always presented in the right visual field. Past research has shown the presence of general attentional biases towards the left visual field in information processing, (Lambert & Voot, 1993; Śmigasiewicz

et al., 2014; Voyer et al., 2012). This left visual field bias could have hindered the ability to detect the hypothesized rumination-linked attentional bias towards lost opportunities. It is recommended for future research investigating attentional deployment to present the stimuli rather in a top-down manner, instead of left–right. Another important limitation includes the potential confounding role of color (green and red) on the presented frames associated with acquired gains and lost opportunities, respectively. Given that the color green was always associated with acquired gains, and red with lost opportunities, it is possible that the color (green versus red) drove the observed effects on attentional processes, rather than the specific meaning of each information panel (acquired gains or lost opportunities). The rationale for associating specific colors with acquired gains and lost opportunities was twofold. First, the color scheme was based on past research employing the same task and where it was consistently shown that training attention to focus on acquired gains (rather than lost opportunities) attenuates the experience of regret, and vice versa (Li et al., 2021; Liu et al., 2020; Liu et al., 2017). Second, research on gamification (i.e., the addition of game elements such as points, levels, a narrative, etc.) of experimental paradigms shows that motivational user engagement and emotional reactivity can be increased by emphasizing on aspects that are inherently associated with negative or positive emotions (Mullins & Sabherwal, 2020; Nabi et al., 2020), such as associating acquired gains with the color green and lost opportunities with the color red. Given that it was crucial to create a paradigm in which participants are sufficiently emotionally engaged, based on gamification principles (Mullins & Sabherwal, 2020), we have chosen to implement this color scheme, at the cost of the potential confounding effect of color on the observed effects. Another limitation is that no detailed demographic (ethnicity, cultural background, socioeconomic status) information of the participants was assessed. Finally, in contrast to earlier work (Allaert et al., 2019), results from the mediation analysis showed a significant direct effect of rumination on CFT, but only

a marginally significant direct effect of rumination on regret. During the debriefing, several participants mentioned not experiencing regret as they thought the task was merely a gambling task, and thereby lacks in the sense of personal responsibility, which is a prerequisite for the experience of regret (Li et al., 2018; Zeelenberg et al., 1998). In this way, the task may be less effective to induce regret, and in future research it should be considered how this issue could potentially be mitigated.

In conclusion, this study investigated the role of attentional deployment towards (counter)factual information in mediating the association between the tendency to self-critical rumination and the propensity to counterfactual thinking and regret. The results suggest that reduced attentional deployment towards accomplishments (i.e., factual information) is an underlying mechanism in the rumination-associated predisposition to maladaptively experience regret.

Declarations

Consent to Participate

Informed consent was obtained from all individual participants included in the study.

Ethical Approval

The study was conducted with the approval of Ghent University's Medical Ethical Committee, and was in line with the Declaration of Helsinki.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

The experiment was designed by J. A. with guidance from M-A. V., R. D. R., and A. S-L. The data was collected by H. S. Statistical analyses were performed by J. A. The original manuscript was written by J.A. with support and feedback from H. S., M-A. V., R. D. R., and A.S-L.

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Data Availability

The data and analysis scripts are available online (https://osf.io/9yqub/).

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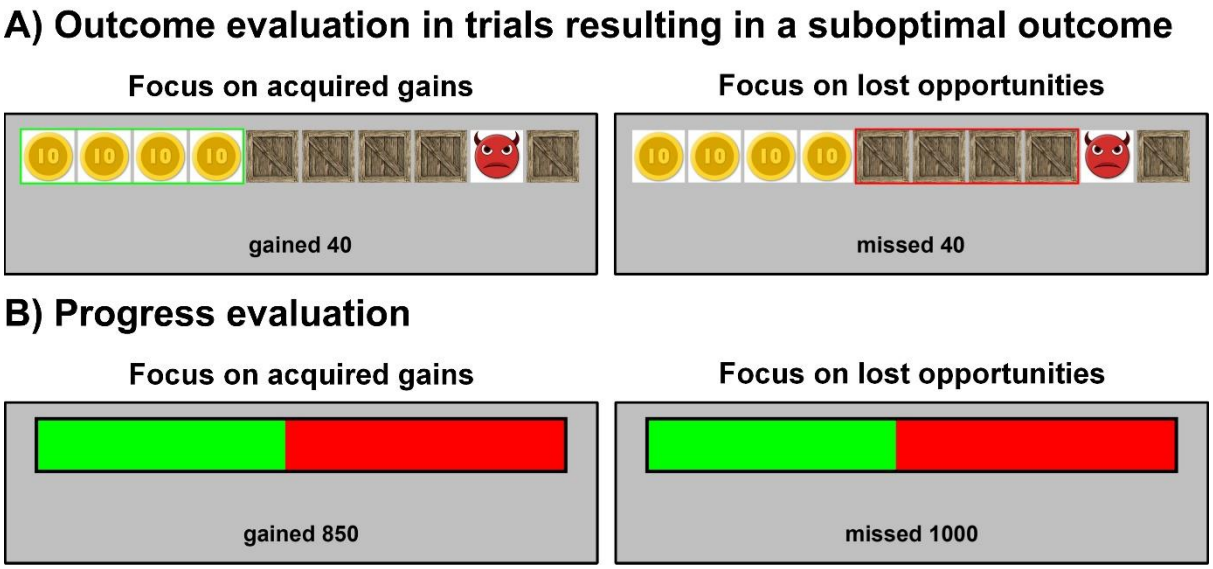
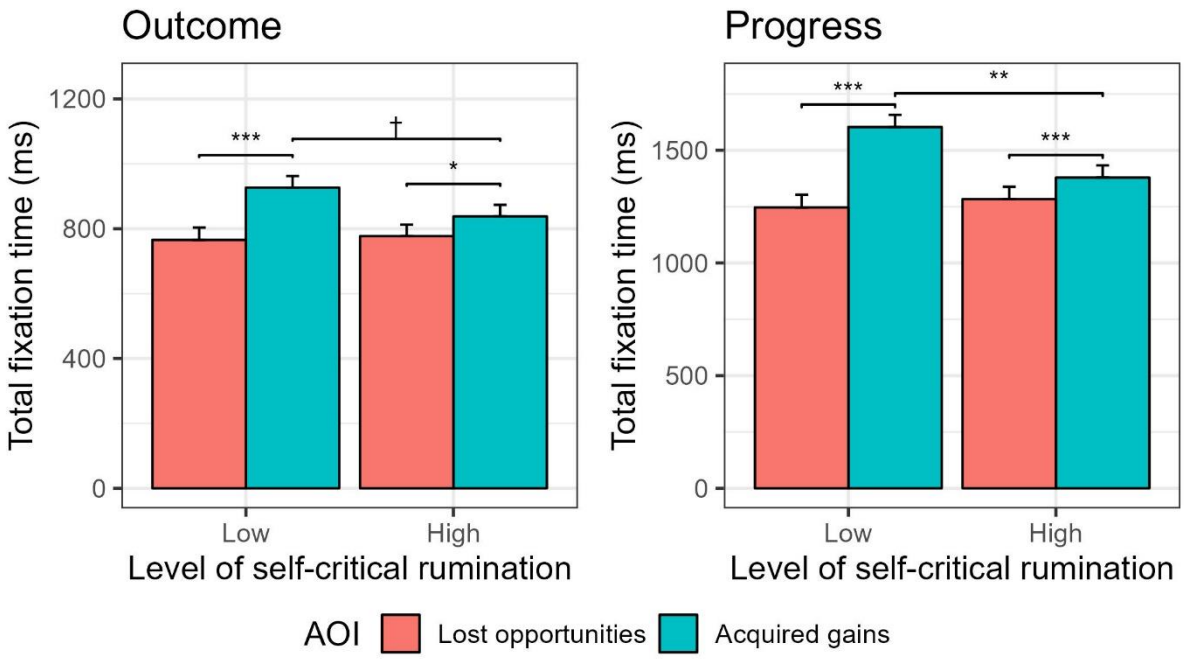
Figure 1. Outcome and progress evaluation



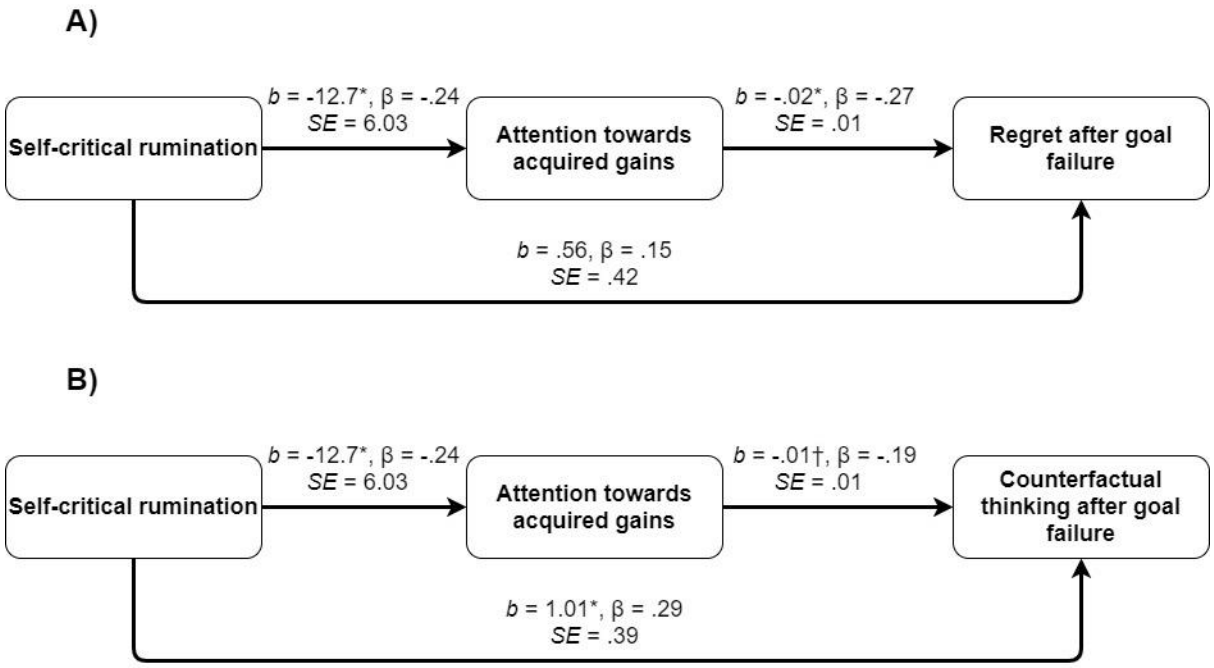
Notes. The green frame (A) or surface area (B) represents the number of acquired gains whereas the red frame (A) or surface area (B) represents the number of lost opportunities.

Figure 2: Effect of self-critical rumination on attentional deployment towards lost opportunities and acquired gains during outcome and progress evaluation



Notes. Error bars represent the standard error. * $p < .05$; ** $p < .01$; *** $p < .001$; † $p < .1$

Figure 3: Mediation models with regret (A) and counterfactual thinking (B) after goal failure as outcome variable



Notes. b = unstandardized coefficient; β = standardized coefficient; *SE* = standard error; *p < .05; † $p < .1$