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Can induced rumination modulate attention? An experimental approach using the attention Network Test (ANT)

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ABSTRACT

The efficiency of our daily performance depends on our ability to manage cognitive resources on different levels and to select relevant information for current task demands. One phenomenon that can limit the efficiency of daily performance is intrusive, repetitive negative thoughts also known as rumination. The present online study aimed at examining the influence of induced state rumination on specific networks of attention, namely alerting, orienting and executive control. Overall, 172 participants (f = 128; m = 44; M_{age} = 24.97, range: 18–40 years) were randomly assigned to an experimental and a control condition and then subjected to different goal-related inductions. Before and after the inductions, participants performed the Attention Network Test (ANT) to examine potential effects of rumination on participants' performance and rated their state rumination. Mixed ANOVAs were computed to investigate whether induced goal-related state rumination had an impact on performance in the three attentional networks. In addition, to better evaluate the results, we also applied Bayesian repeated measures ANOVA's. Overall, results showed no effect of rumination on attention regarding performance on the ANT. We discuss the present null effects and provide starting points for future research.

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1. Introduction

Rumination is a common phenomenon that describes a predominantly maladaptive thinking style in which people repeatedly experience negative thoughts that revolve around past events and are difficult to inhibit (Watkins & Roberts, 2020). Rumination is usually studied in the context of mental health and well-being, not least because of its strong relationship to depression (Watkins, 2008; Watkins & Roberts, 2020). However, it is likely that rumination can have a broader effect on subjective experience and adaptive behavior, as rumination involves cognitive processes and therefore consumes central cognitive resources. In other words, rumination probably interferes with other cognitive processes on different levels. For instance, a study by Tanovic et al. (2017) suggested that rumination is associated with reduced performance monitoring, as evidenced by diminished neural and behavioral indicators of error processing. One approach to investigating the effect of rumination on cognition is to induce rumination in an experimental setting and to measure possible changes in task performance. Here, we aim to directly test whether rumination may impair the maintenance of central and limited resources, namely attentional control. For this reason, we combine an attentional paradigm (the Attentional Network Test, ANT; Fan et al., 2002) with an established protocol for inducing state rumination (see below).

One approach to test the causality between rumination and cognitive processes is to conduct experimental studies that manipulate rumination. These experimental manipulations are commonly used in clinical psychological research, but we decided to apply a non-clinical paradigm to avoid limited generalization to everyday life. We therefore used the goal-cueing task developed by Roberts et al. (2013;

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further developed by Michel-Kröhler et al., 2023; for more details see Methods). The goal-cueing task is based on Martin and Tesser's (1996) Goal Progress Theory (GPT), which conceptualizes rumination as recurrent instrumental thinking about unsatisfactory goal progress. GPT stated that rumination is triggered by the perception that progress in pursuing a goal is slower than expected, and that rumination continues until either satisfactory progress is made in reducing the goal discrepancy or the person disengages from the goal (Martin & Tesser, 1996). Accordingly, the goal-cueing task uses a standardized rumination induction paradigm based on the individual's perception of the discrepancy between the current state and the desired outcome. Participants are free to choose the content so that a broader range of thoughts can be addressed, which occur more naturally in everyday situations (e.g. a certain negative event and its influence on the person's feelings in the last week; thoughts about the fact that the comparison to other people in relation to a personal important aspect is not positive). So far, the goal-cueing task has mainly been used to investigate sustained attention (Edwards, 2017; Michel-Kröhler et al., 2023; Michel-Kröhler & Berti, 2023; Roberts et al., 2020) or attentional disengagement (Kornacka et al., 2019). With regard to sustained attention, results were mixed, as condition differences in task performance were found in one study (Roberts et al., 2013), while no differences were obtained in two other studies (Edwards, 2017; Roberts et al., 2020). Interestingly, findings from Roberts et al. (2013) showed that participants in the unresolved goal condition made significantly fewer errors and had longer reaction times compared to the control condition. This could indicate a speed-accuracy trade-off (i.e. slower responses in favor of more accurate reactions). However, processes of attention have different functional aspects – alerting, orienting and executive control, which can be understood as three anatomically distinct, but functionally inter-related sub-systems (Fan et al., 2002; 2005). Posner and Petersen (1990) defined alerting as achieving and maintaining an alert state, orienting as the selection of information from sensory inputs and executive control as resolving conflict among responses. One attention paradigm that is often applied in experimental research is the ANT (Fan et al., 2002), which is a combination of the Posner cueing task (Posner, 1980) and the Eriksen flanker task (Eriksen & Eriksen, 1974). To evaluate the efficacy of these different attentional networks, reaction time (RT) differences between specific cue and flanker conditions are measured (for more details see the Method section). To the best of our knowledge, no study to date has used the goal-cueing task in combination with the ANT to investigate the influence of state rumination on attentional control.

The aim of the present study was to explore whether induced rumination using the goal-cueing task impairs cognitive processes in relation to performance in the attentional networks, which is alerting, orienting, and executive control. To answer this research question, we conducted an online experiment with a mixed study design using a within-subject factor time (pre induction [ANT I] *versus* post induction [ANT II]) and a group-factor condition (experimental *versus* control condition). In more detail, participants in the experimental condition were subjected to the rumination induction using the goal-cueing task (Roberts et al., 2013). In contrast, participants in the control condition were subjected to a control induction, which was not related to personal goals. Before and after the induction, we assessed participants' current state of rumination, mood, and affect (as manipulation check) as well as their performance in the ANT (Fan et al., 2002). Since the ANT can map performance in three different attention networks, it is very well suited for detecting differences between conditions. Our approach was completely exploratory, so we did not formulate specific hypotheses. However, if rumination consumes cognitive resources, we expect impaired task performance by induced state rumination in at least one of the three ANT network measures.

2. Method

2.1. Procedure

We recruited potential participants via the institutes' student mailing list, university laboratory for behavioral and experimental studies, student contacts, and notices on the bulletin board. The study consisted of two parts: an initial survey and a subsequent experimental session, both conducted by participants online (see Figure 1 A). The survey was conducted using *SoSci Survey* (Leiner, 2019) and comprised biographical and sociodemographic questions as well as different personality-related information (see

Measures & Material). The study protocol was approved by the local Review Board of the Institute for Psychology at the Johannes Gutenberg-University Mainz (2022-JGU-psychEK-012) and was conducted according to the guidelines of the Declaration of Helsinki (World Medical Association, 2013). The instructions for the participants also included information about the inclusion criteria. Moreover, participants were informed about the nature and the procedure of the study and gave consent before completing the questionnaires. After the survey, the participants were assigned to one of two groups (for more details see 'Participant' section) and had the option of continuing directly with the experimental part of the study or completing it at a later date. In both cases, the participants received a link with which they could complete the experimental part of the study online at the desired time. Participation in this study was voluntary and participants received either 12 Euro or course credit as compensation for their participation.

2.2. Participants

Table 1 presents an overview of sample characteristics separated by condition and for the entire sample. According to our requirements for participation in the study, participants were excluded if they (1) had suffered a traumatic event in the past, (2) had a diagnosed mental disorder, (3) were currently undergoing psychotherapeutic treatment, (4) had a diagnosed neurological disorder or a diagnosed attention deficit disorder, (5) were taking sleep medication or psychotropic drugs, or (6) had participated in previous rumination induction studies. This information was obtained as self-report from the participants.

Overall, 193 participants completed the experiment. However, we excluded six participants, because they indicated that they already participated in previous study with rumination induction. Since previous research indicates aging effects on attention control capabilities (e.g. Federico et al., 2021; Jennings et al., 2007), we limit our sample to participants aged between 18 and 40. Thus, another twelve participants were excluded due to their age (> 40 years) and further three participants due to technical problems.

Our final sample consisted of 172 participants, including 145 students (of which 49,66% were psychology students), 20 employees and 7 others (civil servant, self-employed, job seeker, other). Mean age was 24.97 ($SD = 4.01$; age range: 18–40) and the sample included 128 women and 44 men. Of these, 84 participants were assigned to the experimental condition (*i.e.* unresolved problem condition of the goal-cueing task), while the other 88 participants were assigned to the control condition (*i.e.* daily routine condition). Group assignment was randomized with the restriction that gender distribution should not differ substantially in the two conditions (i.e. stratified randomization by gender). To ensure this, we used the 'randomization with urns' feature of SoSci Survey (Leiner, 2019), which automatically assigned participants to one of two conditions based on their gender. Table 1 indicates that the assignment worked well in principle and that the confidence intervals overlap for the relevant variables. To test whether the participants in the two groups had similar characteristics and to exclude potential influencing factors, we examined the groups regarding general rumination, brooding and reflection. Participants did not significantly differ in their general rumination assessed with the Perseverative Thinking Questionnaire (PTQ, Ehring et al., 2011), $p_{wilcox} = 0.71$, $r = 0.03$. In addition, there were no group differences regarding participants' brooding, $p_{wilcox} = 0.60$, $r = 0.04$, or reflection ability, $p_{wilcox} = 0.39$, $r = 0.07$,

Table 1. Mean (M), standard deviations (SD), 95% confidence intervals (95% CI) and Cronbach's alpha (α) of sample characteristics separated by conditions.

			Experimental condition n = 84 (f = 64, m = 20)		Control condition n = 88 (f = 64, m = 24)		Total n = 172 (f = 128, m = 44)	
Sample characteristics	Range	α	*M* (*SD*)	*95%CI*	*M* (*SD*)	*95%CI*	*M* (*SD*)	*95%CI*
Age	18–40		25.08 (4.20)		24.86 (3.84)		24.97 (4.01)	
Personality-related information								
Perseverative thinking (PTQ)	0–60	0.91	27.18 (9.32)	[25.16, 29.20]	26.20 (10.06)	[24.07, 28.34]	26.68 (9.69)	[25.22, 28.14]
Brooding (RSQ)	5–20	0.78	10.94 (3.17)	[10.25, 11.63]	10.64 (3.45)	[9.91, 11.37]	10.78 (3.31)	[10.29, 11.28]
Reflection (RSQ)	5–20	0.65	11.13 (2.53)	[10.52, 11.65]	11.58 (3.33)	[10.95, 12.35]	11.37 (2.99)	[10.92, 11.82]

Note. f = female, m = male.

captured with the Response Styles Questionnaires (RSQ; Huffziger & Kühner, 2012), indicating balanced groups in terms of these characteristics.

2.3. Measures & materials

We used the German versions of the following questionnaires. In Table 1, mean values, standard deviations, 95% confidence intervals (95% CI), and Cronbach's alpha (α) of the respective scales are summarized. Unless otherwise stated, we report the sum score of a scale.

2.3.1. Perseverative thinking

The Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) is a content-independent self-report questionnaire of repetitive negative thoughts. The PTQ consists of 15 items (e.g. 'Thoughts come to my mind without me wanting them to') and is rated on a 5-point scale, ranging from '0' (*never*) to '4' (*almost always*). Here, we report the general PTQ score. Cronbach's alpha for the entire PTQ is $\alpha = 0.95$ for the original study (Ehring et al., 2011).

2.3.2. Brooding and reflection

Huffziger and Kühner (2012) validated the 10-item short version of the Response Styles Questionnaire (RSQ; original English version: Treynor et al., 2003) with the facets Reflection and Brooding. It is assumed that brooding describes dysfunctional ruminating about an unattained goal (e.g. 'What am I doing to deserve this?'), while reflection describes a more goal- and solution-oriented self-reflection (e.g. 'I write down what I am thinking and analyze it.'). Each scale comprises five items. Participants rated the items on a 4-point Likert Scale ranging from '1' (*almost never*) to '4' (*almost always*). Cronbach's α for the original study is 0.60 for brooding and 0.73 for reflection (Huffziger & Kühner, 2012).

2.3.3. State rumination

We tested state rumination with three measures: First, we assessed the momentary ruminative self-focus (Moberly & Watkins, 2010) with two items (1. How much did you focus on your feelings? 2. How much did you focus on your problems?), rated on an 11-point scale ranging from '0' (*not at all*) to '10' (*very*). According to Moberly and Watkins (2010), the scores were averaged to a combined index[1]. Second, we used a single item ('To which extent did you ruminate over something?'; see also Koval et al., 2015) to assess general state rumination (hereinafter referred to as general rumination rating), which was also rated on an 11-point scale. Third, we applied a shortened four-item version of the goal-directed rumination questionnaire (Krys et al., 2020) to capture repetitive and intrusive thinking about a particular goal failure or problem (e.g. 'Without me wanting it, thoughts of the problem came to my mind'). Goal-directed rumination is measured on a 5-point scale ranging from '1' (*does not apply at all*) to '5' *(fully applies*) and calculated as an index. McDonald's omega is 0.79 for the original study (Krys et al., 2020). Note we collected goal-directed rumination only two times during the experimental setting.

2.3.4. Mood

We assessed the Multidimensional Mood Questionnaire (MDMQ; Wilhelm & Schoebi, 2007) to measure three basic dimensions of mood – valence, energetic arousal, and calmness. The MDMQ consists of six items and is a bipolar measure that comprises three pairs of adjectives rated on a 7-point scale describing opposite end points of different mood dimensions (e.g. energetic arousal: tired vs. awake, full of energy vs. without energy). Cronbach's α for the original study is 0.80 for energetic arousal, 0.76 for valence and calmness (Wilhelm & Schoebi, 2007).

2.3.5. Affect

We used the International Positive and Negative Affect Schedule Short Form (I-PANAS-SF; Thompson, 2007; English original version by Watson et al., 1988) to measure affective state. The I-PANAS –SF includes 10 items to assess both positive and negative state affectivity (PA and NA), each with 5 items. Participants

were asked to rate the degree to which they feel the emotional state described in each item, on a five-point Likert scale, ranging from '1' (*very slightly or not at all*) to '5' (*extremely*). Cronbach's α for the original study is 0.76 for NA and 0.75 for PA (Thompson, 2007).

2.3.6. Goal-cueing task

We used a modified version of the goal-cueing task (Michel-Kröhler et al., 2023; original version from Roberts et al., 2013), which consists of a three-step procedure. In step 1, participants in the experimental condition are instructed to identify and outline a current, unresolved goal that has repeatedly troubled them in the past week and made them feel sad, negative, or stressed. In step 2, participants were asked to answer 12 questions about the characteristics of their chosen goal. The questions also serve as manipulation check to verify, among other things, that the identified goal is an important goal and that participants were engaged in at the time of the experiment (for more details see Michel-Kröhler & Berti, 2023). In step 3, a 5-min focus period followed during which participants work through a pre-recorded script, delivered over headphones, which guided them to focus thoroughly on the identified unresolved concern. Example instructions are 'Think about what is important about this difficulty in terms of your personal goals', or 'Focus on the aspects of the difficulty that repeatedly come to mind' (Roberts et al., 2013; see also Michel-Kröhler et al., 2023). Depending on the individual processing time of the participants, this part of the study took around 10 minutes in total. Participants in the control condition were given a neutral writing task that did not relate to personal goals and consists of two comparable steps: In step 1, participants were asked to describe what they did from the morning until the time of the experiment instead of identifying a problem of their individual goal achievement process (Konig et al., 2014, Yu-Hsin Liao et al., 2012). After that, in step 2, participants of the control condition answered eight questions related to their daily routine and planning of the next days and weeks (e.g. 'How typical is your described daily routine for a regular weekday?' or 'How much do you already have planned for the next day?'). In contrast to the experimental condition, participants in the control condition did not receive any audio instructions.

To summarize, our experimental design includes two conditions: One group of participants received a rumination induction (i.e. experimental condition), while the other group of participants did not receive any rumination induction (i.e. control condition), but an alternate control procedure. While we do not expect any group differences before the experimental manipulation, we would expect group differences after the experimental induction, in case rumination does influence cognitive performance.

2.3.7. Attention network test

During the ANT (Fan et al., 2002), in every trial a target is presented which is either preceded by a cue (three different cue types) or without a cue (the 'no-cue' condition). The cue can provide only temporal (center cue, double cue) or temporal and spatial (spatial cue) information about the subsequent occurrence of the target. The participants should determine whether the target, a central arrow, points left or right. The arrow can appear above or below the fixation cross and may or may not be accompanied by either congruent or incongruent arrows (flankers). This results in four cue conditions (see Figure 1 B left part) and three target conditions, whereby the target appears in one of two locations (see Figure 1 B right part). Efficiency of the three attentional networks is assessed by measuring how reaction times are affected by alerting cues (alerting), spatial cues (orienting), and flankers (executive control). For instance, central cues provide information about when the next target will appear, while spatial cues provide both information (i.e. when and where the target will appear). These cues activate the alerting and orienting networks, respectively, leading to incremental reduction in reaction time compared to the no cue condition. In contrast, incongruent flankers place greater demands on the executive control network and increase reaction times (Fan et al., 2005). In total, participants went through the ANT twice, once before (ANT I) and once after (ANT II) the condition specific experimental manipulation. Prior to the first run, the task was explained in detail to the participants before they completed 24 practice trials to familiarize themselves with the task. The practice period had a duration of approximately 2 minutes and participants received feedback on speed and accuracy. The experimental ANT runs were performed without feedback. Each of the two runs consisted of three blocks of 96 trials. Each block lasted approximately 5 minutes.

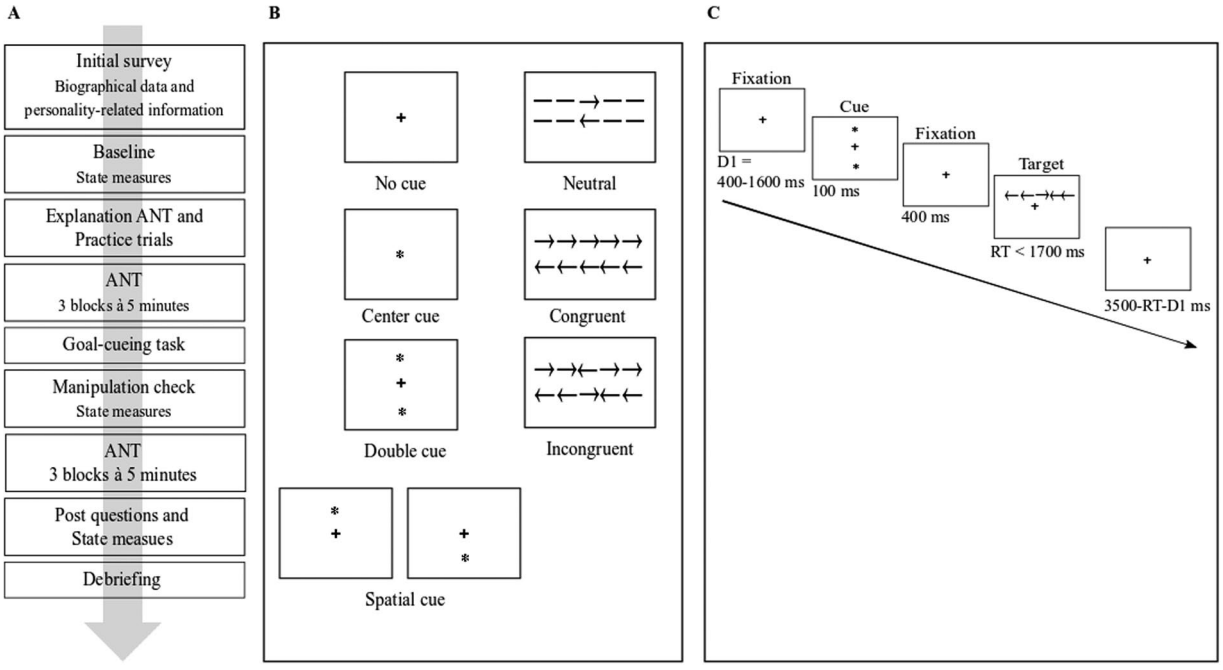

Figure 1. (A) Overview of the procedure, starting with an initial survey, in which biographical data and personality-related information were collected via an online survey. The participants then automatically received the link for the experimental part, which started with a baseline survey that captured participants' current feelings of stress, state of rumination, affect, and mood, followed by a detailed explanation of the Attentional Network Test (ANT, Fan et al., 2002), and a two-minute practice phase. After that, participants performed the first round of the ANT (ANT I; three blocks à 5 minutes), and then completed the goal-cueing task. State rumination, mood, and affect, which are the manipulation check for the goal-cueing task, were queried again. Afterwards, the second round of the ANT (ANT II) was completed to the same extent. At the end, the state measures were assessed again, and the follow-up survey was conducted. Participants were then debriefed, fully informed about the study, and provided renewed written informed consent. (B) The left part displays the four cue conditions of the ANT; the right part presents the three flanker conditions and (C) presents one trial (4000 ms) of the ANT as an example.

Independent of reaction time, one trial had a duration of 4000 ms (see Figure 1 C). Between the blocks, participants were instructed to take a short break with a self-determined length (limited to a maximum of 3 minutes). In contrast to the practice trials, participants received no feedback during the three blocks. Participants were instructed to respond as fast and accurately as possible.

2.3.8. Computation of attentional network parameters

In addition to evaluating the absolute reaction times of the respective cue and flanker conditions as well as their interaction, difference scores are typically calculated to determine the efficacy of each attentional network. For this purpose, for each of the attentional networks, the value obtained under the critical stimulus condition is subtracted from the baseline value. Thus, the difference scores for the alerting network were obtained by subtracting the mean RT for the double cue trials from the mean RT for no cue trials. The difference scores for the orienting network were obtained by subtracting the mean RT for spatial cue trials from the mean RT for center cue trials. Finally, the difference scores for the executive control network were computed by subtracting the mean RT for incongruent trials from the mean reaction time for congruent trials. According to Fan and Posner (2004) results related to the three networks can be interpreted as follows: larger difference scores in the alerting network indicate either difficulty in maintaining alertness without a cue, or, in contrast, more efficient use of warning cues or even increased effort. Larger difference scores in the orienting network indicate difficulty in disengaging from the center cue, where no target appears, or an increased effort that allows more efficient use of the peripheral cue, i.e. a stronger allocation of attention to the cued location. In contrast, larger scores in the conflicting network indicate a less efficient conflicting network, meaning that there are greater difficulties in resolving the conflict.

2.3.9. Follow-up survey

Following ANT II, participants in the experimental condition indicated (1) how difficult it was to stop thinking about the unresolved goal, (2) to what extent their focus was mainly on negative aspects, or (3) on bad feelings, (4) to what extent thinking about the problem made it seem worse and (5) made them feel worse (cf. Mosewich et al., 2013). Participants rated all questions on a 5-point scale ranging from '1' (*not at all*) to '5' (*very*). In addition, participants from both conditions answered four further questions related to either their unresolved goal or their daily routine (e.g. 'During the completion of the study, how often did thoughts related to your unresolved problem/daily routine occur?'). Items were adapted from Curci et al. (2013), rated on a 5-point scale ranging from '1' (*not at all*) to '5' (*very often*) and the averaged ratings depict the score for rumination. Cronbach's α is 0.92 for the original study (Curci et al., 2013). In addition, we asked participants from the control condition whether they thought of a problem when conducting the experiment.

2.4. Evaluation of the quality of the online experiment

Finally, to rule out possible influencing factors, and to evaluate the quality of performance in the online experiment, we asked participants at the end of the experiment (1) how concentrated they were, (2) how seriously they tried to implement the instructions on how to perform the experiment, and (3) how well they managed to do this. Participants answered these three questions on a 5-point scale ranging from '1' (*not at all*) to '5' (*very*). In addition, the participants indicated the location where they conducted the experiment and how quiet it was at that location. The latter was measured on an 11-point scale ranging from '0' (*not at all quiet*) to '10' (*very quiet*).

Participants rated the quality of their performance, indicating that their concentration was 3.69 ($SD = 0.86$), that they made an average effort of 4.42 ($SD = 0.77$) to follow the instructions seriously, and that they succeeded with 4.10 ($SD = 0.83$). One-hundred-sixty-one participants reported completing the study at home, another five participants at the library, one participant at the university, and five participants at other locations (e.g. workplace). On average, participants reported that their environment was very quiet during implementation ($M = 8.36$, $SD = 1.68$). Furthermore, participants in the two conditions did not differ significantly on these three quality measures (all p_{wilcox}'s > 0.05, all r's < 0.05).

2.5. Data analyses

Collection of experimental data was carried out with Inquisit 5 (Millisecond Software, Seattle, WA). Data preparation and statistical analyses were performed with the software R Studio (Version 2025.05.1+513, R Core Team, 2025) with the exception of the Bayesian analysis, which were calculated in JASP (Version 0.95.4, 2025).

2.5.1. Manipulation check

The aim of the manipulation check was to verify a successful induction of state rumination in the experimental condition (hereinafter we refer to it as manipulation check). Therefore, we applied single mixed analyses of variance (ANOVAs) with the ezANOVA-function ('ez'-package; Lawrence, 2016) to test for group differences during the experimental setting in different state measures. Dependent variables were two measures of state rumination (ruminative self-focus and general rumination rating), the three dimensions of mood as well as positive and negative affect. As independent factors, we used time (before the goal-cueing task [t_1], after the goal-cueing task [t_2], at the end of the experiment [t_3]) and condition (experimental version control condition). Beforehand, we checked the requirements for the application and conducted a Shapiro-Wilk Test for testing the assumption of normality ($p > 0.05$) and a Levene's Test for testing the homogeneity of variance ($p > 0.05$). We used Mauchly's Test ($p < 0.05$) to test violations of sphericity and applied a Greenhouse-Geisser correction for ANOVAs if necessary. As effect sizes we used partial eta squared (ηp^2) with the following criteria for small, medium, and large effect: 0.01, 0.06, and > 0.14 (Fritz et al., 2012). Furthermore, since the participants in the two conditions answered different questions either in relation to an unresolved problem (i.e. experimental condition) or in relation to the daily routine (i.e. control condition), we reported mean values and standard deviations of participants'

characterization of problems or their daily routine. The same applied to the evaluation of the identified problem after the experimental setting.

2.5.2. Main analyses

The RT for each cue and flanker condition was separately computed for each participant. Only trials with correct responses were included. Before averaging, reaction time distributions across all conditions for each subject were calculated. Reaction times exceeding the mean ±2 SD were deemed outliers and excluded (Berger & Kiefer, 2021). In detail, the RT outliers were determined intra-individual in reference to all ANT conditions. Out of 99.072 trials in the complete data set, we excluded 3.850 outlier trials (3.89%). More specifically, the average number of outlier trials was 22.38 ($SD = 6.08$) with a range of 1 to 36, with all participants having at least one outlier trial. In addition, to assess the accuracy of the responses, we determined the respective error rate of the participants and expressed it as a percentage of all trials. Please note, incorrect or no responses were counted as errors, regardless of RT.

To compare the ANT performance across participants in different conditions, we chose two approaches: First, we performed three single mixed ANOVAs with the difference RT-scores for each of the attentional networks with time (ANT I, ANT II) and condition (experimental vs. control condition) as independent factors. Because we had some missing information in the data, we excluded data from four participants for the analyses ($N = 168$) and we applied Holm's correction for p-values to consider familywise errors. In addition, to provide further information to readers interested in detailed results regarding the ANT (which were beyond the scope of this article and therefore reported in the Supplement, see Table S4), we examined the RT for correct trials for the absolute reactions as well as accuracy in terms of error rates and applied two mixed ANOVAs with cue (no cue, double cue, center cue, spatial cue), flanker (congruent, incongruent, no flanker), time (ANT I, ANT II), and condition (experimental vs. control condition) as factors. This allows potential group differences to be considered at the level of absolute reaction times and accuracy (for detailed statistical analyses and descriptive statistics see Supplement).

Second, to better evaluate the results, we also applied Bayesian repeated measures ANOVA's with the above-mentioned factors for each of the attention networks. Default priors were used for standardized effect-size parameters (Cauchy r = 0.707; Rouder et al., 2012). Prior model probabilities were set to be equal. For each effect, we report BF_{10}, which is defined as the ratio of the marginal likelihood of the model that includes the effect to the marginal likelihood of the null model. Furthermore, we report Bayes Factors comparing specific effects to the best model. Additionally, we report in- and exclusion Bayes factors (BF_{incl}/BF_{excl}). These were computed by averaging over all models. Inclusion Bayes Factors must be interpreted with caution, as per default, JASP excludes models, which include interaction effects but lack the corresponding main effects (van den Bergh et al., 2020). We interpret evidence based on Jeffreys (1961) scheme, as reported in Schönbrodt and Wagenmakers (2018).

2.5.3. Follow-up survey

Regarding participants' rumination after the experimental setting, we have created a composite score of rumination according to Curci et al. (2013) and analyzed mean differences between conditions with independent t-tests. Beforehand, we checked the requirements for normal distribution and homogeneity of variances. In case of non-parametric distribution, we reported the significance of Wilcoxon signed-rank test as robust alternative for independent t-tests (p_{wilcox}) and the respective effect size r (Field et al., 2012). The same applies to the group comparisons in the sample description and in the evaluation of the quality of the online experiment.

3. Results

3.1. Manipulation check

The detailed results of the manipulation check can be found in the Supplement: Table S1 summarizes the participants' ratings of goal characteristics and goal evaluation; Table S2 summarizes mean values and standard deviations of the neutral task evaluation for the control condition; Results of detailed statistical analyses and detailed descriptive statistics for the respective variables of the manipulation check

are also in the Supplement (see Table S3). In the following we only report the analyses with regard to rumination and provide a short summary of the remaining analyses.

3.1.1. State rumination

Results of the 2 x 3 ANOVA showed significant main effects for condition on participants' state rumination as measured by the ruminative self-focus index, $F(1,170) = 13.32$, $p < 0.001$, $\eta p^2 = 0.07$, and the general rumination rating, $F(1,170) = 12.4$, $p < 0.001$, $\eta p^2 = .07$. The main effect of time as well as the condition x time interaction were also significant for both ruminations measures [ruminative self-focus index: time: $F(2,340) = 27.09$, $p < 0.001$, $\eta p^2 = 0.14$; interaction: $F(2,340) = 29.64$, $p < 0.001$, $\eta p^2 = 0.15$; general rumination rating: time: $F(2,340) = 39.25$, $p < 0.001$, $\eta p^2 = 0.19$; interaction: $F(2,340) = 34.82$, $p < 0.001$, $\eta p^2 = 0.17$]. Post-hoc test revealed that there were no significant differences between the conditions before the goal cueing-task (t_1; both p's ≥ 0.40). In addition, participants of the experimental condition showed significant higher levels of state rumination on both state rumination measures after the goal-cueing task (t_2) compared to the control condition (both $p_{bonf} < 0.001$), thus confirming the successful induction of state rumination. Furthermore, there were also significant differences at the end of the experiment (t_3; ruminative self-focus: $p_{bonf} = 0.02$; general rumination rating: $p_{bonf} = 0.02$), indicating higher state rumination for the experimental condition compared to the control condition (see also Table 2).

Table 2. Mean values (M) and standard deviations (SD) of relevant experimental state variables separated by condition and time.

	Experimental condition			Control condition		
	t_1 *M* (*SD*)	t_2 *M* (*SD*)	t_3 *M* (*SD*)	t_1 *M* (*SD*)	t_2 *M* (*SD*)	t_3 *M* (*SD*)
State Rumination						
Ruminative self-focus	4.23 (1.41)	5.52 (1.10)	4.21 (1.51)	4.37 (1.21)	3.99 (1.57)	3.70 (1.56)
General rumination rating	2.99 (1.67)	4.99 (1.35)	3.61 (1.65)	3.19 (1.55)	3.22 (1.71)	3.05 (1.64)
Goal-directed rumination	–	3.47 (0.85)	3.08 (0.95)	–	2.98 (1.07)	2.86 (1.06)

Note. t_1 = before the goal-cueing task, t_2 = after the goal-cueing task, t_3 = at the end of the experiment.

With regard to the time, a significant decrease of the rumination values from t_2 to t_3 can be observed (both $p_{bonf} < 0.001$), indicating a subsequent recovery during the attentional task. However, regarding the general rumination rating values at t_3 stayed higher than at baseline. In contrast, the values in the control condition remained stable (general rumination rating) or significantly decreased (ruminative self-focus: t_1 to t_2 ($p_{bonf} = 0.04$); t_1 to t_3 ($p_{bonf} < 0.001$). Table 3 shows means and standard deviations of the respective state variables separated by condition and time point.

3.1.2. Goal-directed rumination

With regard to participants' goal directed rumination, results revealed significant main effects for condition, $F(1,170) = 6.20$, $p = 0.01$, $\eta p^2 = 0.04$, time, $F(1,170) = 28.39$, $p < 0.001$, $\eta p^2 = 0.14$, and for the condition x time interaction, $F(1,170) = 7.35$, $p < 0.001$, $\eta p^2 = .04$. Subsequent post-hoc analyses showed a significant difference in goal directed rumination between both conditions after the goal-cueing task (t_2: $p_{bonf} < 0.001$), indicating higher values in the experimental condition. In addition, the level of goal-directed rumination significantly decreased from t_2 to t_3 in the experimental condition ($p_{bonf} < 0.001$) and did not significantly change in the control condition ($p_{bonf} = 0.06$). At the end of the experiment (t_3), there was no significant difference between both conditions ($p_{bonf} = 0.14$).

3.1.3. Summary

Regarding the goal characteristics, trouble at the time of the experiment and at its worst as well as goal importance received the highest ratings, which is comparable to what has been reported in previous studies (Michel-Kröhler et al., 2023; Michel-Kröhler & Berti, 2023, 2025; Roberts et al., 2013). In addition, results of the mixed ANOVAs indicated a successful induction of rumination, which is expressed by significant interaction effects (time x condition) on all three state rumination measures. Values of the experimental condition were significantly higher after the goal-cueing task compared to the values of the

control condition. With respect to the mood measures, there were significant time effects on all three dimensions, showing a decrease over time in both conditions (with exception of calmness values in the control condition, which stayed relatively stable across the experiment). In addition, participants showed significantly higher valence and calmness ratings in control condition compared to experimental condition after the goal-cueing task. While positive affect showed a significant time effect indicating a decrease over time, negative affect showed an additional significant interaction. Participants in the experimental condition reported significantly higher negative affect after the goal-cueing task and at the end of the experiment than in the control condition. Finally, regarding the goal evaluation, focus on negative aspects and a worse feeling at the end of the experiment received the highest ratings.

3.2. Main results

Table 3 summarizes the difference scores (means and standard deviations) for each of the attentional networks. We conducted three mixed ANOVAs with time (ANT I, ANT II) as a within-subjects factor and condition (experimental vs. control condition) as a between-subjects factor to examine differences in each of the attentional networks.

For the alerting network, the ANOVA revealed a significant main effect of time, $F(1,166) = 12.81$, $p_{holm} < 0.001$, $\eta p^2 = 0.07$, indicating an increase in RT differences from the first to the second ANT. There were no effects for condition, $F(1,166) < 1$ or the condition x time interaction, $F(1,166) = 1.83$, $p_{holm} = 0.18$, $\eta p^2 = .01$. For the orienting network, there were neither significant main effects nor a significant interaction, all F's $(1,166) < 1$. Furthermore, the executive control network showed a significant main effect of time, $F(1,166) = 31.39$, $p_{holm} < 0.001$, $\eta p^2 = 0.16$, indicating a decrease in RT differences from the first to the second ANT. In addition, there was neither a main effect of condition nor an interaction effect between time and condition, all F's $(1,166) < 1$.

Table 3. Means (M), standard deviations (SD) and 95% confidence intervals of reaction time differences (in ms) for each attentional network separated by time and condition.

	Experimental condition				Control condition			
	ANT I		ANT II		ANT I		ANT II	
Attentional networks	*M* (SD)	95% CI	*M* (SD)	95% CI	*M* (SD)	95% CI	*M* (SD)	95% CI
Alerting network	36.80 (20.39)	[32.37, 41.22]	41.06 (24.46)	[35.75, 46.37]	35.46 (26.97)	[29.61, 41.31]	44.92 (24.61)	[39.58, 50.26]
Orienting network	17.43 (15.57)	[14.05, 20.81]	16.82 (25.15)	[11.36, 22.28]	18.87 (14.07)	[15.82, 21.93]	17.89 (19.10)	[13.74, 22.04]
Executive control network	69.02 (23.18)	[63.99, 74.05]	61.23 (25.68)	[55.66, 66.80]	68.74 (24.82)	[63.36, 74.13]	61.88 (19.13)	[57.73, 66.04]

Note. ANT = Attention Network Test.

To further advance our understanding of the findings from the classical ANOVA, Bayesian repeated measures ANOVA's were conducted (see Table 4 and for more details on effect analysis see Supplement Table S5). For the alerting network, the main effects model with the factor time received the most support against the null model ($BF_{10} = 44.10$). Adding the main effect condition decreased the degree of this support by the factor 4.99. The level of support for the full model, including both the main effects and the time by condition interaction, declined even more in comparison with the model only including the main effect of time ($BF_{01} = 12.85$). Using a weighted average of all tested models, we find moderate evidence in the data for excluding the main effect condition ($BF_{excl} = 5.42$) and the time by condition interaction ($BF_{excl} = 3.95$). In case of the orienting network the null model received most support from the data. The inclusion of any effects reduced this support substantially. The evidence for the null model was moderate when contrasting it to models including the main effects ($BF_{01} > 4.82$) and strong when contrasting it to the full model including the time by condition interaction ($BF_{01} = 204.45$). Like for the alerting network, for the executive control network the model including the main effect of time received most support against the null model ($BF_{10} = 1.28e+5$). The inclusion of the main effect condition ($BF_{01} = 3.56$) and the time by condition interaction ($BF_{01} = 18.83$) reduced this support. Again, we find moderate evidence in the data for excluding the time by condition interaction when using a weighted average of all tested models ($BF_{excl} = 6.03$).

Table 4. Results of Bayesian repeated measures ANOVA's.

	Alerting					Orienting					Conflict				
	P(M)	P(M|data)	BF_M	BF_{10}	Error %	P(M)	P(M|data)	BF_M	BF_{10}	Error %	P(M)	P(M|data)	BF_M	BF_{10}	Error %
Null model	0.20	0.017	0.071	1.00		0.20	0.73	10.57	1.00		0.20	5.83e-6	2.33e-5	1.00	
Time	0.20	0.77	13.09	44.10	1.38	0.20	0.10	0.44	0.14	1.65	0.20	0.75	11.96	1.28e+5	0.83
Condition	0.20	3.00e-3	0.01	0.20	0.86	0.20	0.15	0.71	0.21	0.98	0.20	0.21	1.07	0.25	3.10
Time + Condition	0.20	0.15	0.73	8.85	1.36	0.20	0.02	0.09	0.03	2.46	0.20	0.04	0.17	3.61e+4	3.55
Time + Condition + Time * Condition	0.20	0.06	0.25	3.43	1.98	0.20	4.00e-3	0.01	0.01	3.31	0.20	1.48e-6	5.92e-6	6.82e+3	4.36

Note. All models include subject, and random slopes for all repeated measures factors.

In summary, these analyses are in line with the findings of the null hypothesis significance tests. The data supports the notion that there are no interaction effects.

3.3. Sensitivity analyses

To investigate whether rumination affects the attentional networks, it is necessary to interpret the two-way interaction time x condition in the case of difference RT-scores. Since we have null results, this is only acceptable if the power is sufficiently high. The G*Power sensitivity analysis (Faul et al., 2009) revealed that with a sample size of $N = 168$ and a significance level of $\alpha = 0.05$, the design was sensitive to detect effects of $\eta p^2 \geq 0.015$, $\eta p^2 \geq 0.025$, and $\eta p^2 \geq 0.035$ for 80%, 95%, and 99% power for difference RT-scores in the alerting network ($\rho = 0.34$). For the difference RT-scores of the orienting network ($\rho = 0.25$), the design was sensitive to detect effects of $\eta p^2 \geq 0.017$, $\eta p^2 \geq 0.029$, and $\eta p^2 \geq 0.040$ for 80%, 95%, and 99% power and for the difference RT-scores of the executive control network ($\rho = 0.41$), the minimum detectable effect sizes were $\eta p^2 \geq 0.014$, $\eta p^2 \geq 0.023$, and $\eta p^2 \geq 0.032$ for 80%, 95%, and 99% power, respectively.

3.4. Follvow-up survey

Following Curci et al. (2013), we calculated a composite score for rumination to test for the occurrence of thoughts related to the unsolved problem (experimental condition) or daily routine (control condition) and their potential influence on performance on the ANT. Results of a *t*-test showed, that there were significant differences between conditions; $p_{wilcox} = 0.001$; $r = 0.25$ (experimental condition: $M = 2.72$, $SD = 0.88$; control condition: $M = 2.28$, $SD = 0.90$). Finally, 43 participants (48.86%) of the control condition reported thinking about a current problem during the experiment.

4. Discussion

In a nutshell, the results showed no overall effect of rumination on attention regarding performance in the three different ANT networks. Instead, an effect on state rumination and negative affect was observed in the experimental condition. Overall, the findings contrast with a previous study that showed an effect on attention (Roberts et al., 2013). However, results from other studies in this context were mixed (Edwards, 2017; Roberts et al., 2020). Since the relationship between rumination and attention is generally very well motivated (Watkins & Roberts, 2020; Whitmer & Gotlib, 2013), we took up the idea from these previous studies and applied it in an experimental setting with the ANT. Based on our data, we can now conclude that, with a sample size of 168, no effects of rumination induction on attention in the ANT networks are to be expected for this specific experimental setting.

Previous studies have shown that individuals who tend to ruminate in negative moods may suffer from impaired attentional performance (cf. Whitmer & Gotlib, 2013). Although our study found a significant effect for negative affect in the experimental condition after rumination induction, this effect did not translate into the efficiency of the ANT networks. This suggests that the ANT is not ideal for this type of research question, as it does not allow for the addition of effects compared to a Sustained Attention Response Task (Robertson et al., 1997). In other words, rumination may not manifest itself at the basic

mechanistic level of ANT networks, but rather at a higher functional level. This is consistent with the observation that accuracy in the ANT is often very good, which limits the interpretation of the RT data (see Macleod et al., 2010): with high accuracy, the variability in reaction time data is often lacking to reveal finer differences between groups. In our study, too, participants are at ceiling from the outset, which limits interpretation. Another possible explanation for our null results could be that due to our exclusion criteria we excluded a large proportion of individuals (e.g. dysphoric ruminators) who would typically respond with reduced performance on such tasks (see for example: Lyubomirsky & Tkach, 2003; Watkins & Roberts, 2020). This is underlined by Whitmer and Gotlib (2013), who stated that

> rumination inductions seem to have little effect on nondysphoric participants (see Nolen-Hoeksema et al., 2008), […] possibly because nondysphoric individuals can spontaneously and quickly recovery from a rumination induction by redirecting their attention to new thoughts. (p.4)

Last, nearly 50% of the participants from the control condition also reported thinking about a current problem while conducting the study, which may have biased the results. However, the information may need to be put into perspective, as we have no information about when and how long or how intensively they thought about a current problem during the experiment.

4.1. Limitations and future directions

One limitation of this study is that a large part of the sample consists of (psychology) students. On the one hand, during college, reflecting on successes and failures in achieving important personal goals is a commonplace process (Jones et al., 2013). Especially psychology students represent a target group that has experience with self-regulation or at least a good knowledge of it. Therefore, it cannot be excluded that theoretical and practical knowledge about self-regulation influences the effects of the goal-cueing task. On the other hand, students may also depict a higher working memory capacity (see Engle, 2002), which may especially increase executive control and prevent stronger effects of rumination on this attentional network. Therefore, future studies should investigate whether the pattern of results can be replicated considering the capacity of working memory, thus providing more insight into the relationship or difference between different cognitive and attentional mechanisms. Another limitation of our experiment is that it was conducted as an online experiment, which makes it much more difficult to control conditions and potential confounding variables compared to conducting experiments in the laboratory (Hussy et al., 2013), especially when considering the duration of the experiment (approximately 60–70 min). However, we asked participants to provide an honest assessment of their performance quality, and the results indicated that the implementation and environment were appropriate for participation in the experiment. Finally, existing comparative studies between laboratory and online experiments showed that the results agree surprisingly well (Musch & Klauer, 2002; Reips & Lengler, 2005). Finally, a major limitation of our study is that participants in the control condition did not receive audio instructions like the experimental condition and thus the conditions were not 100% identical in structure and procedure. Therefore, future studies should pay attention to the parallelization of conditions so that potential effects can truly be attributed to rumination and not to unequal conditions.

Note

1. The items of the ruminative self-focus index correlate moderately on average across all measurement points (r = .55). The associations at the individual measurement points are: t_1: r = .37, t_2: r = .57, and t_3: r = .66.

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The authors report there are no competing interests to declare.

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Data availability statement

The data that support the findings of this study are openly available in OSF at: https://osf.io/t8suw.

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