Behaviour Research and Therapy 178 (2024) 104547

Contents lists available at ScienceDirect

Behaviour Research and Therapy

journal homepage: www.elsevier.com/locate/brat

Can an intervention designed to reduce repetitive negative thinking alter the response to a psychosocial stressor? A randomized controlled study

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ARTICLE INFO

Keywords:
Repetitive negative thinking
Digital interventions
Stress response
Emotional reactivity

ABSTRACT

Prior research suggests that repetitive negative thinking (RNT) negatively impacts mental health by intensifying and prolonging emotional reactivity to stress. This study investigated whether an intervention designed to reduce RNT alters emotional reactivity.

Young adults with high trait RNT (N = 79) were randomly allocated to an RNT-focused intervention (smartphone app-based, 10 days) or a waiting list before exposure to a standardized stressor.

The pre-registered analysis did not reveal a significant condition * time interaction for negative affect. However, exploratory analyses showed that whilst initial increases in negative affect in response to the stressor did not differ between conditions, participants in the intervention condition reported less negative affect throughout the following recovery phase. Additionally, participants in the intervention condition appraised their ability to cope with the stressor as higher and reported less RNT in the recovery phase. In contrast, the intervention did not affect biological stress responses.

The findings indicate that RNT-focused interventions might have positive effects on mental health by breaking the self-reinforcing cycle of RNT, negative affect and maladaptive appraisals in response to stress. However, as findings are partly based on exploratory analyses, further research is needed to confirm whether reduced subjective stress reactivity mediates the effects of RNT-focused interventions on psychopathological symptoms.

1. Introduction

1.1. Repetitive negative thinking and psychopathology

Repetitive negative thinking (RNT) is a transdiagnostic process that includes rumination about one's own sad mood (Nolen-Hoeksema, 1991), worrying about the future (Borkovec, Robinson, Pruzinsky, & DePree, 1983) or post-event processing after stressful social situations (Rachman, Gruter-Andrew, & Shafran, 2000). A growing body of research suggests that RNT is an important risk and maintaining factor for psychopathology. Patients with mental disorders such as depression, anxiety disorders, posttraumatic stress disorder or eating disorders score higher on measures of RNT than healthy controls (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Arditte, Shaw, & Timpano, 2016; Arditte Hall, Quinn, Vanderlind, & Joormann, 2019; Szabo, Warnecke, Newton, & Valentine, 2017; Watkins & Roberts, 2020). Additionally, a heightened tendency to engage in RNT was found to predict the development of future mental health problems (Funk, Takano, Schumm, & Ehring, 2022; Spinhoven, van Hemert, & Penninx, 2018; Whisman, du Pont, & Butterworth, 2020; Wild et al., 2016). Moreover, experimental studies inducing RNT and comparing it to control conditions indicate that RNT is causally involved in the development and maintenance of psychopathology (Santa Maria, Reichert, Hummel, & Ehring, 2012; Schaich, Watkins, & Ehring, 2013; White & Wild, 2016).

1.1.1. Emotional reactivity as a possible mechanism linking RNT and psychopathology

Psychological theories and empirical findings suggest several mechanisms that could account for the link between RNT and poor mental health (for an overview, see Watkins & Roberts, 2020). One putative mechanism is that RNT may impact emotional reactivity in response to stressful situations or negative experiences, as suggested by

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https://doi.org/10.1016/j.brat.2024.104547
Received 14 September 2023; Received in revised form 7 December 2023; Accepted 21 April 2024
Available online 22 April 2024

response style theory (RST; Nolen-Hoeksema, 1991). RST conceptualizes RNT as a dysfunctional cognitive reaction to negative affect, which maintains depression by intensifying and prolonging negative affect. Paradoxically, a frequent self-reported reason to engage in RNT is to understand and reduce negative emotions (Papageorgiou & Wells, 2003). However, in line with RST, excessive RNT appears to have the contrary effect. Evidence comes from two lines of research: Ecological momentary assessment (EMA) studies investigating the link between RNT and naturally occurring negative affect and laboratory-based studies testing the effects of RNT on induced negative affect.

EMA studies have found reciprocal associations between RNT and negative affect (Blanke, Neubauer, Houben, Erbas, & Brose, 2021; Moberly & Watkins, 2008; Smith et al., 2021), i.e., increased RNT predicted increased negative affect at a subsequent occasion and vice versa. The association between momentary levels of RNT and negative affect was found to be stronger in individuals with heightened depressive symptoms (Moberly & Watkins, 2008; Ruscio et al., 2015), lending further support for RST. Additionally, a strong bi-directional relationship between RNT and negative affect was shown to predict the development of depressive symptoms (Stefanovic, Rosenkranz, Ehring, Watkins, & Takano, 2022).

To assess the effect of RNT on negative affect in the laboratory, laboratory-based studies used standardized stressors such as the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993). During the TSST, participants perform a free speech and a mental arithmetic task while standing in front of an evaluative jury. In these laboratory-based studies, RNT was either induced experimentally (Capobianco, Morris, & Wells, 2018; Watkins, Moberly, & Moulds, 2008) or measured before (Aldao, McLaughlin, Hatzenbuehler, & Sheridan, 2014) or after the stress exposure (Hilt, Aldao, & Fischer, 2015). In line with findings from EMA studies, results suggest that RNT increases stressor-related negative affect. Whilst prior research mostly had a narrow focus on the association between RNT and negative affect, some studies also investigated how RNT is linked to stress-related emotional reactivity in a broader sense. On a cognitive level, RNT was found to be associated with appraising stressors as more threatening (Aldao et al., 2014). Moreover, some studies have investigated the relationship between RNT and stress reactivity on a biological level. It has been proposed that when individuals engage in RNT after stress exposure, the stressor continues to be mentally represented resulting in increased and sustained activation of biological stress systems (Brosschot, Gerin, & Thayer, 2006). In line with that, studies using standardized stress inductions found links between RNT and hypothalamic–pituitary–adrenal (HPA) axis stress responses. Specifically, RNT was shown to be associated with increased HPA axis activation (Gianferante et al., 2014; Hilt et al., 2015), poorer HPA axis recovery (Stamatis, Puccetti, Charpentier, Heller, & Timpano, 2020) and slower HPA axis habituation (Gianferante et al., 2014). In addition, RNT was found to be linked to autonomic stress responses, e.g., slower recovery of heart rate and heart rate variability after stress inductions (Aldao et al., 2014; Rocha-Oliveira & Zibetti, 2022).

1.1.2. RNT-focused interventions

The well-established association between RNT and psychopathology as well as the accumulating knowledge about the mechanisms linking RNT to poor mental health make RNT a promising target for psychological interventions. In recent years, several interventions specifically targeting RNT have been developed (Bell et al., 2023), including rumination-focused cognitive–behavioural therapy (RFCBT; Watkins, 2016). RNT-focused interventions such as RFCBT typically combine several elements to reduce RNT as effectively as possible. A core component of RFCBT is addressing RNT as a mental habit. The rationale behind this component is the idea that RNT may initially occur as a goal directed covert behavior in response to goal discrepancies but over time turns into a mental habit, which is automatically triggered by certain contexts such as low mood (Watkins & Roberts, 2020). RFCBT aims to reduce habitual RNT by helping clients form more functional habits. An example would be training to engage in behaviors that are opposite to the negative emotions which typically elicit RNT, such as going for a walk. Another key element of RFCBT is training processing modes that are incompatible with RNT. This concept is based on the processing mode account of RNT, which distinguishes maladaptive RNT from more adaptive forms of thinking about problems or negative experiences (Watkins, 2008; Watkins et al., 2008). The processing mode account proposes that maladaptive RNT involves an abstract thinking style (e.g., "why did something negative happen to me?"), whereas more constructive cognitive engagement with problems is characterized by concrete and experience-oriented processing (e.g., "how am I feeling?", "how did the event unfold?"). RFCBT tries to reduce maladaptive abstract processing by training concrete, solution-focused thinking and facilitating experience-oriented states, drawing on mindfulness and self-compassion exercises.

Several randomized controlled trials (RCTs) provide evidence for the efficacy of RFCBT. The intervention was shown to reduce depressive symptoms and prevent relapse in adults and adolescents with a history of depression (Hvenegaard et al., 2020; Jacobs et al., 2016; Watkins et al., 2011). In addition, a recent trial in patients with Major Depressive and/or Generalized Anxiety Disorder demonstrated that an RNT-focused group intervention with similarities to RFCBT is a promising add-on intervention to other forms of treatment (Rogiers et al., 2022). Furthermore, three trials have tested RFCBT as a preventive intervention for adolescents and young adults at risk for mental disorders and found that the intervention decreased the probability of developing depression or anxiety disorders (Cook, Mostazir, & Watkins, 2019; Edge et al., 2021; Topper, Emmelkamp, Watkins, & Ehring, 2017). Finally, these three RCTs showed that RFCBT is not only efficacious when delivered in a traditional face-to-face setting, but also when administered as an internet- (Cook et al., 2019; Topper et al., 2017) or smartphone app-based intervention (Edge et al., 2021).

While these studies underline the potential of RNT-focused interventions such as RFCBT, relatively little is known about their working mechanisms. Considering evidence on the link between RNT, emotional reactivity and psychopathology, it is conceivable that RNT-focused interventions improve mental health by reducing emotional stress reactivity. Additionally, a number of studies indicate that conceptually overlapping psychological interventions like mindfulness interventions (MIs) alter stress responses (Morton, Helminen, & Felver, 2020). Exploring how RNT-focused interventions affect processes such as emotional stress reactivity could provide information on how to further improve them.

1.2. Aim of the current study

The aim of the current study was to investigate the effect of an RNT-focused intervention on emotional reactivity in response to stress. Specifically, we examined whether the intervention altered the affective, cognitive and endocrinological response to a standardized psychosocial stressor. Participants with a tendency to engage in RNT but no current depression were assigned to either a 10-day RNT-focused intervention via smartphone app or a waiting list control condition before being confronted with the stressor (TSST). In accordance with our preregistration (https://osf.io/bzrsh), we tested two primary hypotheses. We predicted that participants in the intervention condition would report a smaller increase in negative affect in response to the stressor as well as less sustained negative affect in the recovery phase after the stressor. To investigate how the intervention affected emotional reactivity in a broader sense, we tested the following predictions as secondary hypotheses. We hypothesized that participants would differ in their anticipatory stress appraisals in that participants in the intervention condition would appraise the anticipated stressor as less demanding and their own abilities to cope as higher. Moreover, we assumed that participants in the intervention condition would show a smaller HPA

axis activation in response to the stressor as well as less sustained HPA-axis activation in the recovery phase after the stressor.

2. Methods

2.1. Participants

We lacked meaningful effect size estimates as to our knowledge no prior studies had investigated the effects of a similar RFCBT-based intervention on the response to the TSST. We therefore conducted a power analysis based on a medium size effect (Cohen, 1992) of Cohen's $d = 0.65$.[1] The results showed that with 39 participants per condition (78 in total) we would have 80% power to detect medium size or larger differences in the response to the stressor between the intervention and control condition (two-sided comparison, alpha of 0.05).

Participants were recruited via mailing lists, newsletters, other circulars and noticeboards within universities as well as at the campuses of universities in Munich. Inclusion criteria for participation in the study were: (1) Age between 18 and 26, (2) heightened levels of RNT, indexed by sum scores score at or above the 50th percentile (≥34) on the Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991), and (3) ownership of a smartphone. Exclusion criteria were as follows. As the study included a stress induction which can be highly aversive for vulnerable individuals, we (1) excluded individuals with indications for an acute depression, indexed by sum scores >13 (Manea, Gilbody, & McMillan, 2012) on the Patient Health Questionnaire-9 (PHQ-9; Spitzer, Kroenke, Williams, & the Patient Health Questionnaire Primary Care Study Group, 1999). Furthermore, we had several exclusion criteria to minimize confounding effects due to factors that can be associated with HPA axis reactivity (Badrick, Kirschbaum, & Kumari, 2007; Herhaus & Petrowski, 2018; Nijm & Jonasson, 2009): (2) diagnosis of a chronic or acute medical condition, (3) taking prescription medications (exception: oral contraceptives), (4) a body mass index (BMI) < 18 or >30, and (5) consumption of >10 cigarettes or equal amount of nicotine per week. Finally, we had exclusion criteria to preclude confounding effects due to other treatments specified as (6) psychological treatment at the time of study, and (7) participation in an earlier study testing a similar intervention (Funk, Kopf-Beck, et al., 2023). Of the 178 participants who had completed the eligibility screening, 114 participants fulfilled the inclusion criteria and were randomly allocated into either the intervention or control group with 1:1 ratio. Reasons for exclusions can be found in the Supplementary Material.

2.2. Measures

2.2.1. Screening measures to establish eligibility and assess sample characteristics

Demographic and health status questionnaire. A demographic questionnaire was included to assess relevant demographic information to establish eligibility and/or obtain sample characteristics, i.e., age, gender, highest level of education and current employment or occupation. To establish eligibility, the questionnaire furthermore comprised questions about health-related information as well as about participation in an earlier study testing a similar intervention.

Trait RNT. The German version (Kühner, Huffziger, & Nolen-Hoeksema, 2007) of the Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991) was administered to assess participants' tendency towards RNT. The RRS is a frequently used 22-item scale measuring the extend with which respondents think about their own sad mood. Items such as "When I feel sad or down, I think about a past situation and wish it had gone better" are rated on a 5-point scale ranging from "almost never" to "almost always". The RRS has demonstrated good internal consistency, test–retest reliability, and high construct validity (Just & Alloy, 1997). Cronbach's alpha in the current study was 0.81.

Depressive symptoms. The German version (Löwe, Spitzer, Zipfel, & Herzog, 2002) of the 9-item Patient Health Questionnaire-9 (PHQ-9; Spitzer et al., 1999) was used to assess participants' depressive symptoms. Respondent are asked to rate how much symptoms such as "feeling down, depressed, or hopeless" bothered them in the last two weeks on a 4-point scale ranging from "not at all" to "nearly every day". The PHQ-9 is a commonly used measure of depressive symptoms with good psychometric properties (Spitzer et al., 1999). In the current study, Cronbach's alpha was 0.64.

2.2.2. Measures assessing participants' response to the TSST

Negative affect. The 5-item Negative Affect Subscale (PANAS-NA) of the Positive and Negative Affect Schedule – Short-Form (PANAS-SF; Thompson, 2007) was administered in a German version (Krohne, Egloff, Kohlmann, & Tausch, 1996) to assess participants' level of negative affect before and after the stress induction. Respondents are asked to indicate to what extend adjectives such as "upset" or "afraid" apply to them at the moment of filling out the questionnaire. Items are rated on a 5-point scale ranging from "not at all or a bit" to "extremely". The PANAS-NA is a commonly used measure of negative affect and demonstrated good psychometric properties (Thompson, 2007). Cronbach's alpha for each of the seven times the PANAS-NA was presented in the current study ranged between 0.64 and 0.81.

Cognitive appraisals. The German version of the Primary Appraisal Secondary Appraisal Questionnaire (PASA; Gaab, 2009) was administered directly after participants were introduced to the TSST. The PASA was specifically constructed to assess anticipatory cognitive appraisals at the beginning of the TSST. Based on Lazarus and Folkman (1984), the questionnaire was designed to measures how individuals appraise the demands of the stressful situation (primary appraisal) as well as their own ability to cope (secondary appraisal). Items such as "I do not feel concerned as the situation does not pose a threat for me" are rated on a 6-point scale ranging from "completely wrong" to "completely right". Moreover, the PASA allows to compute a *stress index* by subtracting the secondary appraisal score from the primary appraisal score. In the current study, Cronbach's alpha was 0.83 for the primary appraisal scale and 0.77 for the secondary appraisal scale.

State RNT. A modified 4-item version (PTQ-S; Rosenkranz, Takano, Watkins, & Ehring, 2020) of Perseverative Thinking Questionnaire (PTQ; Ehring et al., 2011) was used to measure state RNT after exposure to the TSST. The PTQ is a questionnaire which measures processes features of RNT such repetitiveness and intrusiveness, irrespective of specific thought content. While the PTQ assesses RNT as a general tendency or trait, the PTQ-S was constructed to measure momentary (state) RNT. Items such as "the same negative thoughts keep going through my mind again and again" are rated on a 7-point scale ranging from "not at all" to "very much". In three ecological momentary assessment studies, the PTQ-S demonstrated good psychometric properties and predicted increased psychopathological symptoms as well as decreased well-being (Funk et al., 2023; Rosenkranz et al., 2020, 2023). In the current study, Cronbach's alpha was 0.86.

HPA axis and autonomic nervous system stress responses. HPA axis activation in response to the TSST was assessed by measuring salivary cortisol. Autonomic nervous system (ANS) activation in response to the TSST was determined by measuring salivary α amylase. To minimize the effect of confounding variables on cortisol responses, participants were instructed to refrain from sport and food 1 h prior to their appointment, participants were not allowed to drink during the laboratory session and all laboratory sessions took place after 2pm. Saliva samples were collected using the Salivette collection system (Sarstedt, Nümbrecht, Germany). The samples were kept at room

[1] We based our power calculations on an effect size of $d = 0.65$, which is middle point of effect sizes, which are classified as medium ($d = 0.50$ to $d = 0.80$, Cohen, J. (1992). A Power Primer. *Psychological Bulletin, 112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155).

temperature until the end of the laboratory session and then stored at −80 °C until later analysis. After data collection ended, samples were preprocessed and analyzed at the laboratory of the Health Psychology Chair of Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany. Prior to analysis, salivettes were thawed and centrifuged at 2000g and 20 °C. Free cortisol concentrations in saliva were measured using commercial chemiluminescence immunoassay (CLIA, IBL-Hamburg, Hamburg, Germany). All samples were assayed in duplicate. Intra-assay coefficient of variability (CV) was 4.68% and inter-assay CV was 3.53%. A amylase concentrations in saliva were measured using an in-house enzymatic kinetic assay, also in duplicate measurements with reagents from Roche Diagnostics (Mannheim, Germany) and DiaSys Diagnostic Systems GmbH (Holzheim, Germany). Intra-assay CV was 3.70% and inter-assay CV was 4.36%.

Control items for assessing the potential confounding variables for the response to the stressor. Control items were presented at the end of the laboratory session and comprised questions about whether participants had taken part in studies using a similar stress induction prior to their participation in the current study, were taking hormonal contraceptives or were working night shifts.

2.3. RNT-focused intervention

The RNT-focused intervention was based on RFCBT and employed core principles of RFCBT, namely psychoeducation on RNT, addressing RNT as a mental habit and training processing modes that are incompatible with RNT, such as concrete thinking, self-compassion, and mindfulness. The intervention was administered via smartphone app in an automated manner using the services of the software developer m-Path (m-Path, 2021). It followed a structured 10-day plan with new exercises to complete in the app every day (duration: 10–15 min per day). On the first two days, participants received psychoeducation on how RNT can affect mental health by becoming a habit and learned simple strategies designed to break habitual RNT. One such strategy was engaging in actions that are opposite to negative emotions which typically trigger RNT. Day 3–8 consisted of psychoeducation about the benefits of concrete and experience-oriented processing modes over abstract and self-critical RNT. Importantly, this phase included several exercises to train more helpful processing styles. On the last two days, participants were instructed to reflect about which of the strategies they found most helpful to reduce RNT and could complete more exercises to further train the strategy they subjectively benefitted the most from. To make the intervention as engaging as possible, the intervention app combined video, audio files, explanatory texts, multiple choice and open question formats. For example, benefits of concrete thinking over abstract RNT were explained in a short video, followed by an audio-guided exercise, where participants compared the effects abstract versus concrete thinking about a negative scenario had on them. For more details on the intervention contents and structure see Supplementary Material. To increase adherence, participants received a push notification on their smartphone at 10am each day notifying them that the exercises for this day were now available and that they had 48 hours to complete them. Furthermore, participants were sent three automatic emails over the course of the intervention reminding them how important it is that they complete the exercises consistently and asking them if they needed help or had questions.

2.4. Stress induction

To investigate the effects of the intervention on participants' emotional stress reactivity, participants were confronted with the TSST (Kirschbaum et al., 1993), a standardized psychosocial stressor commonly used in laboratory settings. During the TSST, participants have to perform tasks while standing in front of an evaluative jury (two persons) and a video camera (duration: 15 min). Consistent with the standard protocol, the experimenter brought the participant into the room were the TSST would take place and told them that they would have to take part in a job interview for their dream job. When the experimenter left the room, the TSST started with a 5-min anticipatory phase, in which participants could take notes for the upcoming task (3 min) and were told to fill out the PASA (2 min). Following that, participants had to perform their speech about what made them a suitable candidate for their desired job without looking at their notes (5 min). Finally, participants had to complete a mental arithmetic task (5 min), still while standing in front of the jury.

2.5. Procedure

For an overview of the study timeline see Fig. 1. All procedures were approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences at Ludwig-Maximilians-Universität München, Germany, and preregistered on the open sciences framework (OSF) platform (https://osf.io/bzrsh). Data collection started on October 7, 2022, and ended on March 21, 2023.

2.5.1. Part A (online, day 0–10)

Obtaining informed consent, eligibility screening, appointment selection, randomization and post-randomization instructions took part via the survey platform *Research Electronic Data Capture* (REDCap; Harris et al., 2009) in an automated manner. The app-based RNT-focused intervention was administered via an online platform for mobile assessments and interventions, m-Path (m-Path, 2021). After having provided informed consent, participants filled out questionnaires to establish eligibility and obtain sample characteristics, namely a demographic and health status questionnaire, the PHQ-9 and the RRS. Eligible participants were guided to select an appointment for their laboratory session. After having selected an appointment, participants were randomized into either the RNT-focused intervention condition or the waiting list control condition. Randomization was conducted based

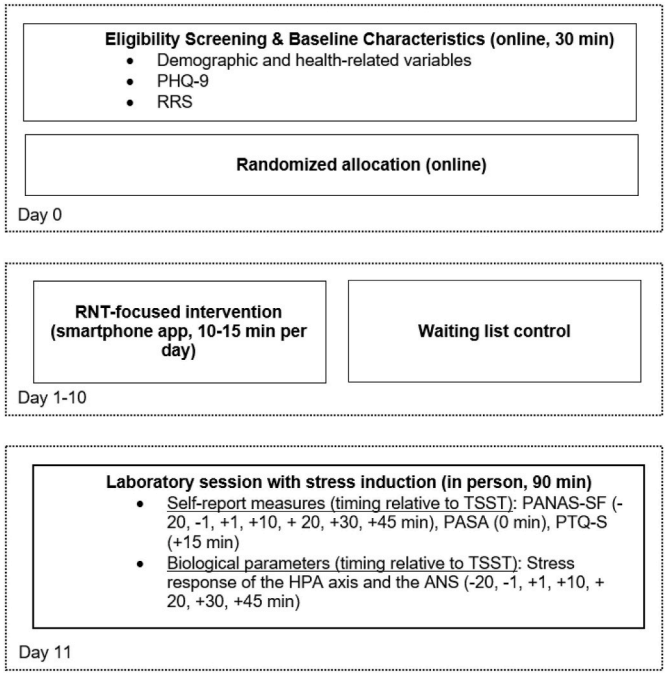

Fig. 1. Overview of the study procedure. PHQ-9 = Patient Health Questionnaire-9, RRS = Ruminative Response Scale, min = minutes, RNT = repetitive negative thinking, TSST = Trier Social Stress Test, PANAS-SF = Positive and Negative Affect Schedule – Short Form, PASA = Primary Appraisal Secondary Appraisal Questionnaire, PTQ-S = adapted version of the Perseverative Thinking Questionnaires for measuring state RNT, HPA axis = hypothalamic–pituitary–adrenal axis, ANS = autonomic nervous system.

on a pre-generated randomization table applying block randomization and stratification by gender as some of the study's outcomes were expected be unequally distributed across genders (Kivlighan, Granger, & Booth, 2005; Thomsen, Mehlsen, Viidik, Sommerlund, & Zachariae, 2005; Uhart, Chong, Oswald, Lin, & Wand, 2006). Following randomization, participants in the waiting list control condition were given the information that the next step of their study participation would be the laboratory session. Participants in the RNT-focused intervention condition received instructions on how to install the intervention app 11 days prior to their booked laboratory appointment. The 10-day RNT focused intervention took part in the 10 days before the laboratory session (for details see section RNT-focused intervention and Supplementary Material).

2.5.2. Part B (laboratory session, day 11)

When participants arrived at the laboratory, the experimenter reminded them that as described in the consent form, they would have to answer questionnaires and take part in a psychosocial stress test during the laboratory session. In the period before the TSST, participants filled out the PANAS-SF twice and gave two saliva samples (−20 and −1 min relative to the start of the TSST). The experimenter then took the participants to the room where the TSST would take place (for details on the TSST see section stress induction). After the TSST, participants were taken back to the other room, where they filled out the PANAS-SF five more times and gave five more saliva samples (+1, +10, +20, +30 and + 45 min relative to completing the TSST). Moreover, participants were instructed to fill out the PTQ-S 15 min after completing the TSST. In the periods between giving the samples and filling out the questionnaires, participants were not given any filler tasks or instructions, however, they were allowed to use their smartphones or read if they wanted to. After completing the study, participants either received monetary compensation (20 €) or partial course credit as compensation.

2.6. Statistical analysis

For transparency, R Code for the analyses as well as the data set and corresponding codebook can be found on OSF https://osf.io/bzrsh/resources.

2.6.1. Analysis of primary hypotheses

We used a linear mixed-effects model to test our primary hypotheses. In the model, we tested the effects of condition, time as well as condition * time interaction on self-reported negative affect (PANAS-NA score). In case of a significant interaction, we planned to follow up with simple slope tests to test whether consistent with our hypotheses (1) participants in the intervention condition reported a smaller increase in negative affect in response to the TSST and (2) reported less sustained negative affect in the recovery phase after the TSST relative to participants in the control condition. The model included a random intercept for participants and was estimated using restricted maximum likelihood estimation.

2.6.2. Analysis of secondary hypotheses

To test our secondary hypotheses regarding group differences in anticipatory stress appraisals, we conducted independent sample *t* tests. Specifically, we tested whether participants in the intervention condition appraised the demands of the situation as less challenging (lower PASA primary appraisal score) and their own coping competencies as higher (higher PASA secondary appraisal score). Furthermore, we tested whether participants in the intervention condition had a lower stress index (resulting from larger differences between the secondary and primary appraisal score).

We analyzed our secondary hypotheses regarding group differences in HPA axis response to the stress induction as follows. We calculated the maximum increase in cortisol for each participant according to the following procedure. The baseline cortisol level (−1 min pre-stressor) was subtracted from the peak cortisol value (either measured at +10, +20 or +30 min post-stressor) for each participant. We then tested whether, in line with our hypothesis, participants in the intervention condition showed a smaller HPA axis activation in response to the stressor (lower maximal increase scores) than participants in the control condition using an independent sample *t*-test. To investigate our predictions regarding HPA-axis activation at recovery we tested group differences in cortisol values + 45 min post-stressor using a one-way analysis of covariance (ANCOVA) controlling for baseline cortisol values (−1 min relative to stressor).

2.6.3. Exploratory analysis

We explored whether participants in the intervention condition showed lower levels of state RNT (PTQ-S score) 15 min after the end of the stress induction. Additionally, we explored whether participants in the intervention condition showed decreased ANS stress responses by analyzing differences in maximal α amylase increase between conditions (for details see Supplementary Material).

For analyses described above, we included all participants who completed the lab session. We additionally reran all analyses excluding participants in the intervention condition who completed less than 9 days of the 10-day program ($n = 9$) to explore whether results would change depending on the intervention dose.[2] All analyses were conducted in R (R Development Core Team, 2022) using the following packages: 'dplyr' (Wickham, François, Henry, Müller, & Wickham, 2023) and 'reshape2' (Wickham, 2020) for data wrangling, 'psych' (Revelle & Revelle, 2023) and 'QuantPsyc' (Fletcher & Fletcher, 2022) for data screening and calculating descriptive statistics, 'ggplot2' (Wickham, Chang, & Wickham, 2023) and 'ggpubr' (Kassambara, 2023a) for visualizing data, 'rstatix' (Kassambara, 2023b) for basic statistical tests, 'lme4' (Bates et al., 2023) and 'lmerTest' (Kuznetsova, Brockhoff, & Christensen, 2020) for computing linear mixed-effects models, 'emmeans' (Lenth, Singmann, Love, Buerkner, & Herve, 2019) and 'effsize' for calculating effect sizes for linear mixed-effects model (Torchiano & Torchiano, 2020) and 'sjPlot' (Lüdecke, 2023) for making results tables.

3. Results

3.1. Baseline and control variable differences between conditions

Table 1 shows baseline demographic variables and scores on baseline questionnaires as well as control variables that were assessed after the TSST by condition. Independent sample *t* tests and chi-squared tests, respectively, showed that conditions did not differ significantly on any of these variables.

3.2. Adherence in the RNT-focused intervention condition

Participants in the intervention condition on average used the app on 9.24 ($SD = 1.22$) of the 10 intervention days. Of 41 participants in the intervention condition, 32 (78.05%) fulfilled our pre-defined full-dose criterion and completed all tasks in the app on at least 9 of the 10 intervention days.

3.3. Effect of the RNT-focused intervention on subjective stress reactivity

3.3.1. Effect of the RNT-focused intervention on negative affect in response to the TSST (primary hypotheses)

Fig. 2 depicts mean negative affect (sum score on the PANAS-NA) for

[2] We preregistered to additionally run a minimum-dose sensitivity analysis excluding all non-starters in the intervention condition who did not use the intervention app at all but came to the laboratory session. However, there were no non-starters in the intervention condition, and we thus dropped this analysis.

Table 1
Sample characteristics and means (with standard deviations) by condition.

Variable		Condition	
		RNT-focused intervention (n = 41)	Waiting list control (n = 38)
Gender, n (%)	female	34 (82.93%)	31 (81.58%)
	male	6 (14.63%)	7 (18.42%)
	non-binary	1 (2.44%)	0 (0%)
Age, M (SD)		21.41 (2.48)	21.71 (2.51)
Education, n (%)	A levels	27 (65.85%)	26 (68.42%)
	bachelor's degree	12 (29.27%)	11 (28.95%)
	master's degree	2 (4.89%)	0 (0%)
	apprenticeship	0 (0%)	2.63%
Occupation, n (%)	student in university	39 (95.12%)	37 (97.37%)
	employee	1 (2.44%)	0 (0%)
	voluntary service	0 (0%)	1 (2.63%)
	gap year	1 (2.44%)	0 (0%)
PHQ-9, M (SD)		7.83 (3.19)	7.58 (3.28)
RRS, M (SD)		45.27 (8.41)	47.53 (8.85)
Night shifts, n (%)*		4 (9.76%) yes	1 (2.63%) yes
Exposure TSST, n (%)*		7 (17.07%) yes	4 (10.52%) yes
Hormonal c., n (%)*		8 (19.51%) yes	7 (18.42%) yes

Note. Age = age in years, education = highest educational degree; occupation = current occupation; PHQ-9 = sum score on the Patient Health Questionnaire-9, RRS = sum score on the Ruminative Response Scale, * = assessed after lab session, night shifts = has worked night shifts in the last two weeks, exposure TSST = took part in a study using the Trier Social Stress Test prior to participation in the current study, hormonal c. = currently taking hormonal contraceptives.

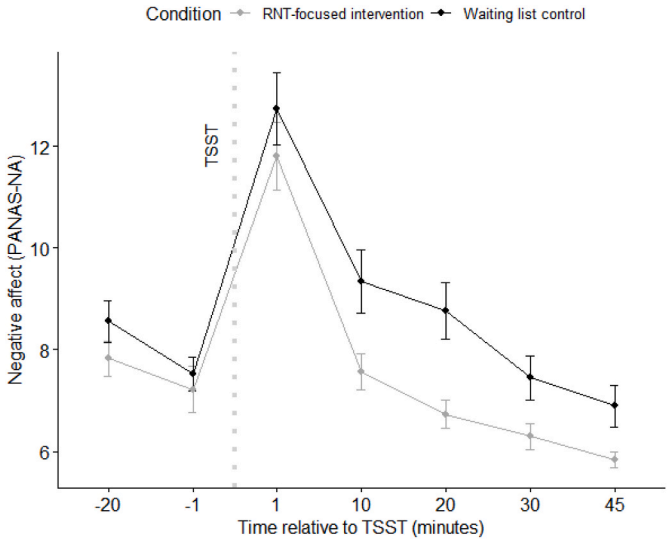

Fig. 2. Mean negative affect with standard error bars by time (relative to the stressor) and condition. PANAS-NA = Sum score on the Negative Affect Subscale of the Positive and Negative Affect Schedule – Short-Form, TSST = Trier Social Stress Test.

each time point (−20,-1,+1,+10,+20,+30,+45 min relative to TSST) by condition (RNT-focused intervention vs. waiting list control condition). As preregistered, we statistically tested the effects of condition, time as well as condition * time interaction on negative affect in a linear mixed-effects model[3] with random intercept for participants, for details see Table 2. The fixed effects of time and condition on negative affect were significant. Contrary to our preregistered assumption, there was no significant interactive effect of condition * time on negative affect. Next to our preregistered analysis, we ran additional analyses to explore potential group differences specific to initial affective response and affective recovery. The reason for this deviation from the preregistration was an issue with translating our predictions into adequate statistical models in the preregistration. Instead of a monotonically increasing or decreasing trend, the affective response to the TSST resembled an asymmetric inverted u-shape (see Fig. 2). Due to this non-linear effect of time, the preregistered linear model was not well suited to detect a condition * time interaction. However, the main effect of condition appeared to be largely driven by group differences in negative affect in the interval from 10 to 45 min post-TSST (see Fig. 2). To further investigate this, we split the data into an initial response (−20,-1,+1 min relative to TSST) and a recovery phase (+10,+20,+30,+45 min relative to TSST) and exploratively reran the analysis separately for these two phases. For the initial response phase, the model showed a significant effect of time, but no significant effect of condition or condition * time interaction on negative affect (see Table 2). For the recovery phase, the model yielded significant effects of time and condition, but not of condition * time interaction on negative affect (see Table 2). As a measure of effect size, we calculated Cohen's ds for the effect condition by time point based on estimated marginal means of the models, which suggested negligible effects of condition in the initial response phase (d = 0.14 - 0.19) and small to moderate effects of condition in the recovery phase (d = .32 -.56). Thus, even though effects were mostly small, participants in the intervention condition showed significantly lower levels of negative affect throughout the recovery phase relative to participants in the control condition.

3.3.2. *Effect of the RNT-focused intervention on anticipatory stress appraisals (secondary hypotheses)*

The sample for this analysis comprised n = 74 participants as three participants in the control and two participants in the intervention condition had missing data on the PASA. Participants in the intervention condition (M = 17.35, SD = 3.11) did not differ significantly from participants in the control condition (M = 17.93, SD = 3.22) in how they appraised the demands of the stressful situation (primary appraisal score). However, participants in the intervention condition appraised their abilities to cope with the situation (secondary appraisal score) as significantly higher (M = 16.90, SD = 2.47) than participants in the control condition (M = 15.41, SD = 3.28), t (62.74) = 2.18, p = 0.03, d = −0.52. Overall, participants in the intervention condition did not show a significantly lower *stress index* (M = 0.45, SD = 4.70) than participants in the control condition (M = 2.51, SD = 4.39), t (71.88) = −1.96, p = 0.06, d = 0.46.

3.3.3. *Effect of the RNT-focused intervention on state RNT after the TSST*

Participants in the intervention condition had a significantly lower score on the PTQ-S (M = 13.95, SD = 5.76) than participants in the control condition (M = 16.66, SD = 5.527), t (76.90) = −2.13, p = 0.04, d = 0.49.

[3] Sum scores on the PANAS-NA were log-transformed for analysis as the distribution was skewed at every time point throughout the laboratory session (for descriptive statistics of negative affect throughout the laboratory session see Supplementary Material, Part B).

Table 2
Linear mixed-effects models predicting negative affect.

Predictors	PANAS-NA (all time points)				PANAS-NA (initial response)				PANAS-NA (recovery)			
	B [95% *CI*]	SE	β	p	*B* [95% *CI*]	SE	β	p	*B* [95% *CI*]	SE	β	p
Time	−0.01 (−0.01 to −0.00)	0.00	−0.33	**<0.001**	0.01 (0.00–0.02)	0.00	0.22	**0.007**	−0.01 (−0.01 to −0.00)	0.00	−0.26	**<0.001**
Condition	0.11 (0.01–0.22)	0.05	0.16	**0.035**	0.07 (−0.05 – 0.19)	0.06	0.10	0.243	0.22 (0.08–0.36)	0.07	0.34	**0.002**
Condition *Time	0.00 (−0.00 – 0.00)	0.00	0.05	0.241	−0.00 (−0.01 – 0.01)	0.00	−0.10	0.906	−0.00 (−0.00 – 0.00)	0.00	−0.10	0.181
Random Effects												
σ^2	0.07				0.12				0.03			
τ_{00}	0.04				0.02				0.06			
ICC	0.36				0.13				0.69			
N, participants	79				79				79			
N, Observations	553				237				316			
Marginal/ Conditional R^2	0.119/0.435				0.057/0.177				0.157/0.739			

Note. *B*[*CI*] = regression coefficient [with 95% confidence interval], *SE* = standard error of *B*, β = standardized regression coefficient, *p* = *p*-value, PANAS-NA = Negative Affect Subscale of the Positive and Negative Affect Schedule, PANAS-NA (all time points) = log-transformed sum score on the PANAS-NA (−20,-1,+1,+10,+20,+30,+45 min relative to stressor), PANAS-NA (initial response) = log-transformed sum score on the PANAS-NA (−20,-1,+1 min relative to stressor), PANAS-NA (recovery phase) = log-transformed sum score on the PANAS-NA (+10,+20,+30,+45 min relative to stressor), time = continuous variable, coded as the temporal distance relative to the stressor (range: −20 to +45 min), σ^2 = within-participant variability, τ_{00} = between participants variability, *ICC* = intraclass (i.e., intraparticipant) correlation, marginal/conditional R^2 = Proportion of variance explained by fixed/by fixed and random effects.

3.4. Effect of the RNT-focused intervention on biological stress reactivity

3.4.1. Effect of the RNT-focused intervention on HPA axis stress response (secondary hypotheses)

The sample for analyzing maximal increase in cortisol comprised n = 71 participants and the sample for analyzing cortisol recovery comprised n = 70 participants (for details on missingness in cortisol data, exclusions based on outliers and transformations see Supplementary Material). Contrary to our expectations, participants in the intervention condition did not show a significantly lower maximal increase score (M = 3.68 nmol/l, SD = 5.29 nmol/l)[4] relative to participants in the control condition (M = 3.44 nmol/l, SD = 4.62 nmol/l), t (68.27) = −0.37, p = 00.71, d = 0.09. In contrast to our predictions, a one-way ANCOVA controlling for baseline cortisol values (−1 min pre-TSST) also did not show a significant effect of condition on cortisol level at the cortisol recovery time point (+45 min post-TSST), F (1,67) = 0.410, p = 00.41, η_p^2 = 0.01. For a graphical depiction of the HPA axis stress response by condition see Supplementary Material. Asides from the lacking intervention effect, there was also no significant correlation between state RNT after the stressor and maximal increases in cortisol, or cortisol recovery (controlling for baseline) in the whole sample or single conditions (see Supplementary Material).

3.4.2. Effect of the RNT-focused intervention on ANS stress response

The sample for analyzing changes in α amylase concentrations in response to the TSST comprised n = 74 participants (for details on missingness in α amylase data, transformations and analyses see Supplementary Material). Maximal increase in α amylase (peak minus baseline) did not differ significantly between conditions, t (66.24) = −1.75, p = 00.08, d = 0.43, (intervention condition: M = 72.44 U/ml, SD = 58.48 U/ml, control condition: M = 73.16 U/ml, SD = 56.90 U/ml).[5] There was also no significant correlation between maximal increase in α amylase and post-stressor RNT in the whole sample or single conditions (for details see Supplementary Material).

3.5. Full-dose sensitivity analysis

The results of the sensitivity analysis comparing participants in the control condition to only participants in the intervention condition who completed at least 9 days of the 10-day program (n = 32) were largely consistent with the analysis based on the whole sample. There was only one deviation. Unlike in the full sample analysis, there was no significant main effect of condition on negative affect in the mixed-effects model including all laboratory session time points. R code for the full-dose sensitivity analysis can be found on OSF https://osf.io/bzrsh/resources.

4. Discussion

This study investigated the effect of an app-based RNT-focused intervention on the emotional response to a standardized stress induction. Contrary to our expectations, no significant interactive effect of condition and time on negative affect in response to the TSST emerged. However, participants in the intervention condition reported significantly less negative affect throughout the laboratory session. Exploratory analyses indicated that this main effect of condition was driven by group differences in negative affect during the recovery phase after stress exposure; whilst the intervention did not reduce initial increases in negative affect in response to the TSST, participants in intervention condition reported significantly lower negative affect in the phase 10–45 min post-stressor. As effects of condition on negative affect were mostly small, even in the recovery phase, results regarding negative affect should be interpreted with caution. In addition to small effects on negative affect, the intervention had medium size effects on anticipatory cognitive appraisal of coping abilities and RNT following the stress exposure. Therefore, in sum, the results suggest that the intervention altered subjective stress responses. In contrast, we did not find any effects of the intervention on biological stress markers, cortisol and α amylase stress response did not differ significantly between conditions.

4.1. Intervention effects on the subjective stress response

The findings regarding the effect of the RNT focused intervention on the *initial* subjective stress response are only partially in line with prior empirical findings. Studies using standardized stress inductions consistently found that RNT was linked to higher initial increases in negative affect in response to stressors (Aldao et al., 2014; Hilt et al., 2015; Watkins et al., 2008). One of these studies additionally analyzed

[4] *M* and *SD* of the raw scores are reported in nanomoles per liter (nmol/l) here, the *t*-test was conducted on log-transformed values.

[5] *M* and *SD* of the raw scores are reported in Units per milliliter (U/ml) here, the *t*-test was conducted on log-transformed values.

associations between RNT and cognitive appraisals as part of the initial subjective stress response and found that RNT also correlated with appraising the stressor as more threatening (Aldao et al., 2014). Therefore, we expected an effect of the RNT-focused intervention on anticipatory stress appraisals as well as initial increases in negative affect in response to the TSST in the current study. While we found that participants in the intervention condition appraised their own coping competencies more positively, initial increases in negative affect from before to directly after the stress exposure were unaffected by the intervention. However, it is conceivable that the RNT-focused intervention tested in the current study is less capable of altering an early affective response to stress, but rather has effects on the duration of the affective response.

The finding that participants in the intervention condition reported less negative affect in the recovery phase after the TSST fits well with theoretical concepts of RNT. According to RST, it is not decisive for the development of long-term emotional problems how much negative affect individuals initially experience following a stressor, but rather how they respond to their own negative affect (Nolen-Hoeksema, 1991). Specifically, RST assumes that reacting to negative affect with RNT prolongs negative affect. The finding that negative affect initially increased similarly in both conditions, but decreased faster in the intervention condition suggests that the intervention could break the self-reinforcing cycle of RNT and negative affect. This notion is further supported by the finding that participants in the intervention condition reported lower levels of RNT in the recovery phase after the stressor.

Taken together, these findings provide preliminary evidence that reducing subjective emotional stress reactivity could be a working mechanism of RNT focused interventions. RNT-focused interventions might reduce psychopathology by fostering more optimistic anticipatory appraisals of and decreasing RNT and sustained negative affect after stressful situations. However, this needs to be confirmed in studies assessing whether these mechanisms actually mediate the effects of RNT-focused interventions on psychopathological symptoms. Moreover, the reduced subjective stress reactivity in the intervention condition supports the potential of delivering RNT-focused interventions via scalable digital formats such as smartphone apps. The results add to RCTs that found internet- and app-based RNT-focused interventions reduce RNT and psychopathological symptoms when compared to waiting list controls (Cook et al., 2019; Edge et al., 2021; Topper et al., 2017) and have comparable effects to in-person RNT-focused interventions (Topper et al., 2017).

4.2. No intervention effects on the biological stress response

Unlike subjective stress responses, biological stress markers obtained in the current study were not altered by the intervention. The null effect on the biological level might be due to the fact that the relationship between RNT and biological stress markers such as HPA-axis reactivity is complex and less well established than the association between RNT and subjective emotional reactivity. It has been theorized that RNT contributes to negative health consequences of stress by prolonging cardiovascular, immunological and endocrinological stress responses (Brosschot et al., 2006). While prior empirical findings have linked RNT to biological markers like increased HPA axis stress reactivity (Gianferante et al., 2014; Hilt et al., 2015), these associations appear to depend on a variety of factors. Whether or not studies find associations between RNT and HPA axis reactivity was for example found to be influenced by the measure used to assess RNT, the study set up (Zoccola & Dickerson, 2012) and sample characteristics such as the sex of the participants (Shull et al., 2016). The fact that the association between state RNT and biological stress reactivity was not evident in the control group of the current study (see Supplementary Material) could explain the lacking intervention effects on biological outcomes. Moreover, it is conceivable that psychological interventions in general have more immediate effects on subjective experience, whilst it takes longer for biological effects to develop. That is, even though we did not find effects on biological outcomes in the current study, with a longer intervention duration and more training, the RNT-focused intervention tested in the current study could have the potential to eventually change biological stress responses. More research is needed to understand how exactly RNT is linked to biological stress reactivity and whether this association can be altered by RNT-focused interventions.

4.3. Comparison to prior research testing how psychological interventions affect stress reactivity

The results of the current study partially stand in contrast to prior studies testing the effects of conceptually overlapping psychological interventions such as MIs on stress reactivity. MIs usually address RNT less systematically than the RNT-focused intervention tested in the current study. Yet, by fostering being present in the current moment (Creswell, 2017) MIs facilitate a state which is incompatible with RNT and therefore arguably could even be classified as RNT-focused interventions. A review found that out of 13 included studies, 10 studies reported effects of MIs on subjective emotional reactivity in response to standardized stressors and six studies showed effects of MIs on markers of biological stress reactivity (Morton et al., 2020). Note that subjective reactivity was usually operationalized as initial increases in negative affect in response to the stressor. However, due to methodological differences, it is difficult to determine whether MIs and the RNT-focused intervention tested in the current study differ altering initial affective stress reactivity vs. recovery. The studies investigating MIs tested in-person administered and not app-based interventions, used different measures for negative affect and did not measure negative affect during an extended recovery phase after stress exposure. To gain a better understanding of specific working mechanisms of different interventions, it seems promising to directly compare their effects on stress reactivity while keeping as many other factors as possible constant.

4.4. Limitations

The current study has some limitations. Firstly, the finding that participants reported lower levels of negative affect throughout the recovery phase was result of an exploratory analysis. Future studies using the same analytic approach are needed to confirm this result. Secondly, the study was only powered to detect medium size or larger effects. Power was even lower for analyses of effects on HPA axis and ANS reactivity as saliva samples of some participants could not be analyzed. Thus, it is possible that the study failed to statistically detect small intervention effects especially on the biological measures and replication in larger samples is needed. Thirdly, the waiting list control design makes it difficult to disentangle specific effects of the RNT-focused intervention from common intervention effects. It is possible that not the specific RNT-focused techniques, but common factors (Wampold, 2015) or placebo effect (Rosenthal & Frank, 1956) largely account for the results. Future studies should consider testing effects of RNT-focused interventions on stress reactivity against active control conditions. Fourthly, the current study did not assess change in trait RNT from pre-to post-intervention. Whilst we could show that the intervention decreased state RNT post-stressor relative to the control condition, we could not test whether the intervention also had long lasting effects on trait RNT. Moreover, the study did not include a measure for depressive symptoms post-intervention. Therefore, final conclusions about whether changes in trait RNT alter subjective stress reactivity and whether this in turn mediates the decreasing effect of RNT-focused interventions on psychopathology cannot be drawn. Fifthly, the current study did not include a measure of anxiety. As social evaluative stressors such as the TSST typically elicit anxiety, future studies should control for levels of (social) anxiety at baseline and investigate specific intervention effects on anxiety in response to the stressor. Finally, the sample was non-clinical, largely female and mostly consistent of university students.

Results need to be replicated in samples of individuals with diagnoses of mental disorders and more diverse demographics to draw generalizable conclusions about whether RNT-focused interventions change stress responses.

4.5. Conclusion

Despite its limitations, the current study indicates that reducing emotional stress reactivity could be a working mechanism of RNT focused interventions. The results suggest that RNT-focused interventions can break the dysfunctional self-perpetuating circle of RNT and negative affect in response to stress. Findings also indicate that these interventions affect emotional reactivity on a cognitive level by fostering more adaptive appraisals. More research is needed to find out whether RNT-focused interventions also alter biological stress responses. Moreover, future studies need to confirm whether reduced (subjective) stress reactivity actually acts as a working mechanism in that it mediates the effects of RNT-focused interventions on psychopathological symptoms.

Ethics statement

Ethical approval for the study was granted by the Ethics Committee of the Faculty of Psychology and Educational Sciences at Ludwig-Maximilians-Universität München, Germany. All participants gave written informed consent before participating in the study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Julia Funk: Conceptualization, Formal analysis, Methodology, Writing – original draft. **Keisuke Takano:** Formal analysis, Writing – review & editing. **Marina Babl:** Investigation. **Rebecca Goldstein:** Investigation. **Regina Oberwestersberger:** Investigation. **Johannes Kopf-Beck:** Conceptualization, Writing – review & editing. **Nicolas Rohleder:** Methodology, Writing – review & editing. **Thomas Ehring:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The link to the data set, codebook and analytic code are included in the manuscript. These resources are uploaded on OSF (https://osf.io/bzrsh/resources).

Acknowledgements

Julia Funk was supported by a PhD scholarship of the Studienstiftung des deutschen Volkes.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2024.104547.

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